

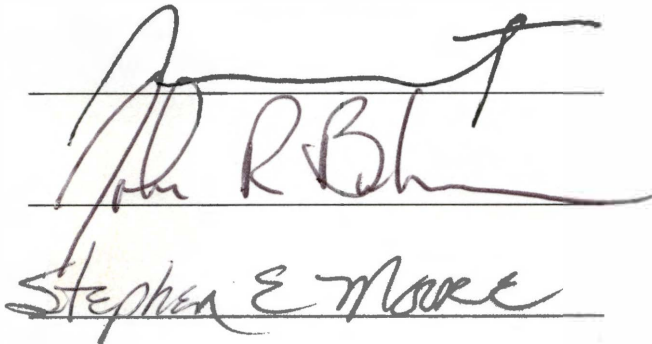
To the Graduate Council:

I am submitting herewith a thesis written by Kevin Hedrick entitled "Best Management Practice Performance and Water Quality Monitoring Before, During and After Road and Tunnel Reconstruction in the Great Smoky Mountains National Park." I have examined the final paper copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Environmental Engineering.

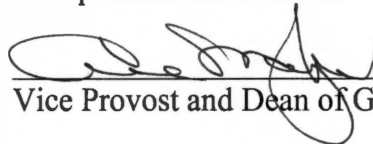


Dr. R. Bruce Robinson, Major Professor

We have read this thesis  
and recommend its acceptance



Accepted for the Council:



Vice Provost and Dean of Graduate Studies

Thesis  
2002  
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**Best Management Practice Performance and Water Quality Monitoring Before, During  
and After Road and Tunnel Reconstruction in the Great Smoky Mountains National Park**

**A Thesis  
Presented for the  
Master of Science  
Degree  
The University of Tennessee, Knoxville**

**Kevin Paul Hedrick  
December 2002**

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## EXECUTIVE SUMMARY

The University of Tennessee (UT) Civil and Environmental Engineering Department monitored the impact of road and tunnel reconstruction on adjacent streams in the Great Smoky Mountains National Park (GSMNP) for the National Park Service and Best Management Practice (BMP) performance. The potential stream impacts of concern were sediment and acid generating geology. Sediment can adversely affect aquatic life and ecosystems by mechanical abrasion, by obstructive silting, by reducing the penetration of light, by providing a surface for the growth of microorganisms, by absorbing or adsorbing chemicals, and by inhibiting normal temperature fluctuations (Swerdon and Kountz, 1973). Anakeesta exposure can upset aquatic life through depression of stream water pH and increased concentrations of toxic mineral elements. BMPs were monitored because little information was available on the performance of these structures and efficiency results help in evaluating each structure's usefulness.

Monitoring took place on a reconstruction project 1.13 km (0.70 mi) in length on US 441 and included two tunnels through Chimney Tops Mountain and Morton Mountain. Reconstruction tasks included repairing the tunneling (deepening the tunnels, installing rock bolts, placing concrete tunnel sidewalls), roadway excavation, grading, drainage, new road base and paving, constructing guard walls, and other work. This report summarizes the pre-, during and post-construction monitoring from May 2001 through September 2002.

During pre- and post-construction periods, grab samples from Walker Camp Prong and the West Prong of the Little Pigeon River (WPLPR) were collected every two weeks at each of four stations: upstream and downstream of the two tunnel

reconstruction sites. A passive sampling device was also located at each of the four stations, taking samples at various stage heights during high flows. During construction more frequent sampling occurred at these stations and around BMPs. The BMPs monitored were rock check dams, inlet protection for existing storm drains and disposal areas encapsulating spoil material. The rock check dams and inlet protection were installed to reduce suspended solids totals (by ponding water and allowing heavier particles to settle out). The check dams also reduced erosion by lowering the water's velocity and dissipating energy.

The tunnel reconstruction had no statistically identifiable impact on stream water quality. This conclusion is based on the following:

- Statistical results did not indicate that construction altered pH or suspended solids concentrations. At a 95% confidence level ( $p=0.05$ ) a statistically significant difference was not detected in the pH of runoff samples entering and leaving the construction area at the Chimney Tops site ( $p=0.375$ ) or Morton Mountain ( $p=0.109$ ). A statistically significant difference was also not detected in the suspended sediment concentrations entering and leaving the construction sites at Chimney Tops ( $p=0.375$ ) and Morton Mountain ( $p=0.742$ ).
- Median suspended solids concentrations for the stream sampling locations were lower during construction than in the pre- and post-construction periods. The low suspended solids totals during construction (during winter) are likely because the ground was frozen during much of this period.
- Stream pH was lower during the construction period than the pre- and post-construction periods. Paired differences (downstream value less the upstream

value for each collection date) were examined to see if these pH trends were a result of seasonal variation. Other streams within the same watershed did show pH differences consistent with the variation observed at the Morton sites (indicating seasonality).

- For each tunnel the water quality parameters that varied between the upstream and downstream sampling during the construction periods were the same ones that varied prior to construction.
- The area of disturbance was small compared to the watershed. Approximate calculations showed that little impact should be expected because the storm runoff volume from the construction site was very small in comparison to the stream flow from the watershed.

BMP performance varied. Success or failure was tied to proper/improper location, design, construction and maintenance. Specific conclusions include:

- Many BMPs were installed according to the plans but were not constructed in locations where they would receive runoff from construction activities.
- Multiple BMPs were added and/or altered after construction began as unforeseen or newly developed runoff conditions were discovered.
- The efficiency of check dams was dependent upon their ability to pond water and the pond volume available for ponding and storage. The rock check dam at the Old Trace Road Disposal site provided area for storage and offered good settleable solids trapping efficiency for runoff events with high suspended solids concentrations (90% and 65% for influents of 23,567 and 42,527 mg/L

respectively). The rock check dams installed at the Chimneys site provided very little ponding and therefore negligible trapping efficiency. A statistically significant difference was not detected in the suspended solids concentrations before and after Chimney Tops rock check dams ( $p=0.813$ ) and inlet protection at Morton Mountain ( $p=0.195$ ). Despite these findings field observance did reveal trapped sediment behind rock check dams indicating that some material was retained by the structures.

- A statistically significant difference was not detected in the pH above and below the rock check dams and inlet protection at Chimney Tops ( $p=0.813$ ) and Morton Mountain ( $p=0.250$ ).
- Silt fences were not observed ponding water at any location
- The disposal practices used for the excavated materials were effective in neutralizing any acidic leachate. The pH of leachate from the disposal mound at Old Trace Road ranged from 6.9 to 7.7. Gnatty Branch disposal mound leachate pH measured 7.2 or greater.

Information in addition to construction impact or BMP performance was gained from this project:

- Storm runoff lowered stream pH values. The effect was more pronounced at the Morton locations. Median pH at the uppermost stream sampling station decreased by 1.1, 0.7 and 0.9 units for the three monitoring periods respectively when comparing baseflow samples with the highest stage passive collection bottle.

Likewise, the Morton sites experienced greater changes during storm events than the Chimney's sites for other water quality parameters.

- Higher flows also resulted in higher suspended solids concentrations. Median concentrations were at least three-fold greater for the highest stage passive collection bottles than for the lowest stage (for all but one out of twelve cases).
- Regular inspection and maintenance is required for BMPs to function properly.
- Excavated material was tracked onto the haul road and contaminated runoff during rain events. Much of this material could have been recovered if a street sweeping truck had been used.

## TABLE OF CONTENTS

|                                                                          | <u>Page</u> |
|--------------------------------------------------------------------------|-------------|
| CHAPTER I. Introduction                                                  | 1           |
| Background                                                               | 1           |
| Description of the Construction Project                                  | 1           |
| Description of the Study Area                                            | 2           |
| Purpose and Scope                                                        | 6           |
| CHAPTER II. Review of the Literature                                     | 8           |
| Potential Environmental Impacts of Construction                          | 8           |
| Variation in pH Due to Natural and Anthropogenic Stresses                | 10          |
| BMP Performance                                                          | 12          |
| Assessing Construction Impacts and Discussion of Water Quality Standards | 15          |
| CHAPTER III. Field Studies and Analysis                                  | 18          |
| Site Descriptions                                                        | 18          |
| Stream Station Sampling Locations                                        | 18          |
| Construction and Disposal Sampling Sites                                 | 18          |
| BMPs                                                                     | 20          |
| Rock Check Dams                                                          | 20          |
| Inlet Protection                                                         | 29          |
| Disposal Sites                                                           | 29          |
| Seeding                                                                  | 29          |
| Sampling Methodology                                                     | 31          |
| Grab Samples                                                             | 31          |
| Passive Samples                                                          | 31          |
| Sample Custody and Preservation                                          | 34          |
| Laboratory Equipment and Methods of Analysis                             | 35          |
| De-ionized Water                                                         | 35          |
| Analytical Balance                                                       | 35          |
| Major Ions                                                               | 35          |
| Conductivity                                                             | 36          |
| pH and Acid Neutralizing Capacity (ANC)                                  | 36          |
| Suspended Solids                                                         | 36          |
| Oil and Grease                                                           | 37          |
| Trace Metals                                                             | 37          |
| Statistical Tests                                                        | 37          |
| QA/QC                                                                    | 38          |
| CHAPTER IV. Results and Discussion                                       | 39          |
| Construction Impact Potential                                            | 39          |
| Streams                                                                  | 40          |
| Paired Differences                                                       | 49          |

|                                                 |    |
|-------------------------------------------------|----|
| Construction Sites and BMPs                     | 67 |
| Disposal Site Leachate                          | 74 |
| CHAPTER V. Conclusions                          | 76 |
| CHAPTER VI. Recommendations for Future Research | 79 |
| LITERATURE CITED                                | 80 |
| APPENDIX                                        | 84 |
| VITA                                            | 87 |

## LIST OF TABLES

| <b><u>Table</u></b>                                                                                                                                                           | <b><u>Page</u></b> |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|
| 1-1. BMPs constructed to prevent erosion and sediment transport and acid generation                                                                                           | 3                  |
| 1-2. Construction tasks impacting erosion and sediment production potential                                                                                                   | 3                  |
| 1-3. Watershed areas contributing to sampling station stream flow                                                                                                             | 5                  |
| 4-1. pH, conductivity and ANC at each sampling site by construction period                                                                                                    | 41                 |
| 4-2. Statistical differences between upstream and downstream baseflow grab sample chemistry                                                                                   | 48                 |
| 4-3. Statistical differences between time periods for baseflow grab samples at the same sampling location                                                                     | 50                 |
| 4-4. Statistical differences between baseflow grab and storm passive sample chemistry                                                                                         | 55                 |
| 4-5. Total suspended solids summary chart by site                                                                                                                             | 60                 |
| 4-6. Statistical differences in storm suspended solids concentrations at the same location for different time periods and comparison between upstream and downstream stations | 65                 |
| 4-7. Trace metal concentrations by site                                                                                                                                       | 66                 |
| 4-8. Statistical results for construction sites and BMP pH and suspended solids                                                                                               | 69                 |
| A1-1. Reproducibility for duplicate / replicate suspended solids analysis                                                                                                     | 85                 |
| A1-2. Sample Calculations                                                                                                                                                     | 86                 |

## LIST OF FIGURES

| <u>Figure</u>                                                              | <u>Page</u> |
|----------------------------------------------------------------------------|-------------|
| 1-1. Sampling stations and area landmarks                                  | 4           |
| 1-2. Watershed areas contributing to stream sampling locations             | 5           |
| 2-1. TSS concentration of samples above and below rock berm                | 14          |
| 3-1. Photograph showing four collection stages of a typical stream sampler | 19          |
| 3-2. Sketch of Chimney Tops check dams                                     | 22          |
| 3-3. Photograph of elevated Chimney Tops check dams                        | 23          |
| 3-4. Photograph of Chimney Tops dams                                       | 24          |
| 3-5. Photograph of Chimney Tops check dam with trapped sediment            | 25          |
| 3-6. Sketch of Old Trace Road                                              | 26          |
| 3-7. Entrance road to Old Trace Road                                       | 27          |
| 3-8. Old Trace Road rock check dam                                         | 28          |
| 3-9. Type D curb inlet protection                                          | 30          |
| 4-1. Baseflow grab sample pH at primary sites                              | 42          |
| 4-2. Conductivity of Morton Mountain Tunnel grab samples vs. date          | 43          |
| 4-3. Conductivity of Chimney Tops Tunnel grab samples vs. date             | 44          |
| 4-4. ANC of Morton Mountain Tunnel grab samples vs. date                   | 45          |
| 4-5. ANC of Chimney Tops Tunnel grab samples vs. date                      | 46          |
| 4-6. Upstream Morton Mountain Tunnel grab and passive pH vs. date          | 51          |
| 4-7. Downstream Morton Mountain Tunnel grab and passive pH vs. date        | 52          |
| 4-8. Upstream Chimney Tops Tunnel grab and passive pH vs. date             | 53          |
| 4-9. Downstream Chimney Tops Tunnel grab and passive pH vs. date           | 54          |

|       |                                                                                                                                   |    |
|-------|-----------------------------------------------------------------------------------------------------------------------------------|----|
| 4-10. | Precipitation data from Newfound Gap and Park Headquarters                                                                        | 56 |
| 4-11. | The pH differences (DS pH – US pH) in baseflow between upstream<br>and downstream stations by event (examines paired differences) | 58 |
| 4-12. | Before construction median total suspended solids by passive<br>collection bottle location and stage (3-D)                        | 62 |
| 4-13. | During construction median total suspended solids by passive<br>collection bottle location and stage (3-D)                        | 63 |
| 4-14. | After construction median total suspended solids by passive<br>collection bottle location and stage (3-D)                         | 64 |
| 4-15. | Difference in pH for construction sites (below minus above),<br>Chimney Tops rock check dams and Morton inlet protection          | 68 |
| 4-16. | Bar chart of suspended solids at Chimney Tops rock check dams                                                                     | 71 |
| 4-17. | Bar chart of suspended solids at Morton Mountain inlet protection                                                                 | 72 |
| 4-18. | Bar chart of suspended solids at Old Trace Road check dam                                                                         | 73 |

## **CHAPTER I. INTRODUCTION**

### ***Background***

The University of Tennessee (UT) Civil and Environmental Engineering Department monitored Best Management Practice (BMP) performance and the impact of road and tunnel reconstruction on adjacent streams, Walker Camp Prong and the West Prong of the Little Pigeon River (WPLPR), in the Great Smoky Mountains National Park (GSMNP) for the National Park Service. The potential stream impacts of concern were sediment and acid generating geology (Anakeesta). Sediment can adversely affect aquatic life and ecosystems by mechanical abrasion, by obstructive silting, by reducing the penetration of light, by providing a surface for the growth of microorganisms, by absorbing or adsorbing chemicals, and by inhibiting normal temperature fluctuations (Swerdon and Kountz, 1973). Anakeesta exposure can upset aquatic life through depression of stream water pH and increased concentrations of toxic mineral elements. Anakeesta exposure on a road construction project in 1963 resulted in lasting adverse environmental impacts: reduced pH, increased heavy metal concentrations, and almost total annihilation of microinvertebrates and fish in more than 7 km of stream (Kucken et al., 1994).

### ***Description of the Construction Project***

The Project consisted of reconstruction along U.S. 441 and included rehabilitation of tunnels through Chimney Tops Mountain and Morton Mountain. The total project was 1.13 km in length. Reconstruction tasks included repair of tunneling, installing rock bolts, placement of concrete tunnel sidewalls, roadway excavation, grading, drainage,

new road base and paving, stone masonry, guard walls, and other work. The tunnel floors were excavated to provide additional overhead clearance, and the road on each side of each tunnel was reconstructed to provide smooth transitions between new tunnel and existing road grades. Heavy excavation took place during the month of December 2001, and the majority (approximately 95%) of the earthwork was completed by January 2002. The length of the disturbed area at the Chimney Tops and Morton Mountain Tunnels was approximately 570 m and 560 m respectively. BMPs constructed to prevent erosion and sediment transport and acid generation are shown in Table 1-1. Construction tasks impacting erosion potential are listed in Table 1-2 below.

### ***Description of the Study Area***

All work was located within the GSMNP. Figure 1-1 shows the tunnel sites, spoil disposal sites and sampling stations. There were four primary sampling stations : upstream and downstream of the Chimney Tops (USC and DSC) and Morton Mountain (USM and DSM) Tunnels. Monitoring took place along Walker Camp Prong and the West Prong of the Little Pigeon River (WPLPR), the adjacent streams potentially impacted by construction. Figure 1-2 and Table 1-3 show the watershed areas contributing to the stream sampling locations. Construction spoil was disposed of at two sites: Morton spoil was hauled to Old Trace Road near Newfound Gap, and Chimney spoil was taken to an abandoned dump east of Spur Road.

Table 1-1. BMPs constructed to prevent erosion and sediment transport and acid generation

| BMP                                                               | Date                                   |
|-------------------------------------------------------------------|----------------------------------------|
| Installed silt fence along outer roadway slope                    | 11/15/01-11/20/01; removed 12/20/01+/- |
| Installed silt fence on disposal sites                            | 10/26/01-12/12/01; still in place      |
| Prepared disposal sites and placed fabric and limestone on bottom | 10/24/01-12/12/01                      |
| Cover material on Newfound Gap Disposal site                      | 5/6/02-5/8/02                          |
| Cover material on Spur Disposal site                              | 5/9/02-5/13/02                         |
| Seeded disposal sites                                             | 05/16/2002                             |
| Seeded roadway slopes and shoulders                               | 05/17/2002                             |
| Check dams installed on roadway                                   | 12/7/01; removed by 12/20/01           |
| Inlet protection installed                                        | Oct. and Nov. 2001                     |
| Riprap at pipe culvert outlets installed                          | 12/19/01+/-                            |

Table 1-2. Construction tasks impacting erosion and sediment production potential

| Task                                                                   | Date              |
|------------------------------------------------------------------------|-------------------|
| Pavement removal and excavation performed in tunnels and on approaches | 11/26/01-12/20/02 |
| Base course placed                                                     | 12/14/01-12/19/01 |
| Paving; first layer                                                    | 12/19/2001        |
| Paving; second layer                                                   | 05/15/2002        |

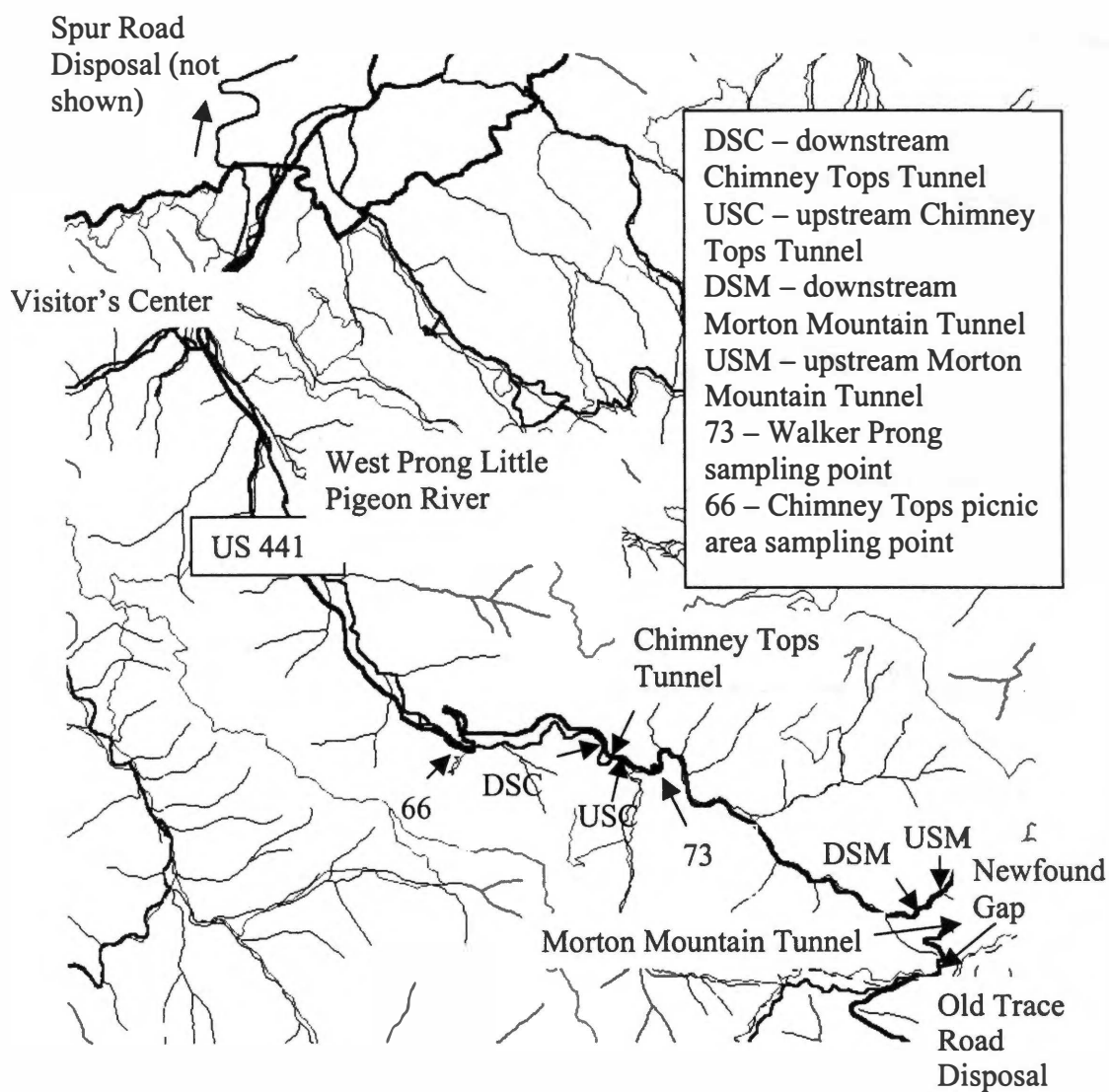


Figure 1-1. Sampling stations and area landmarks

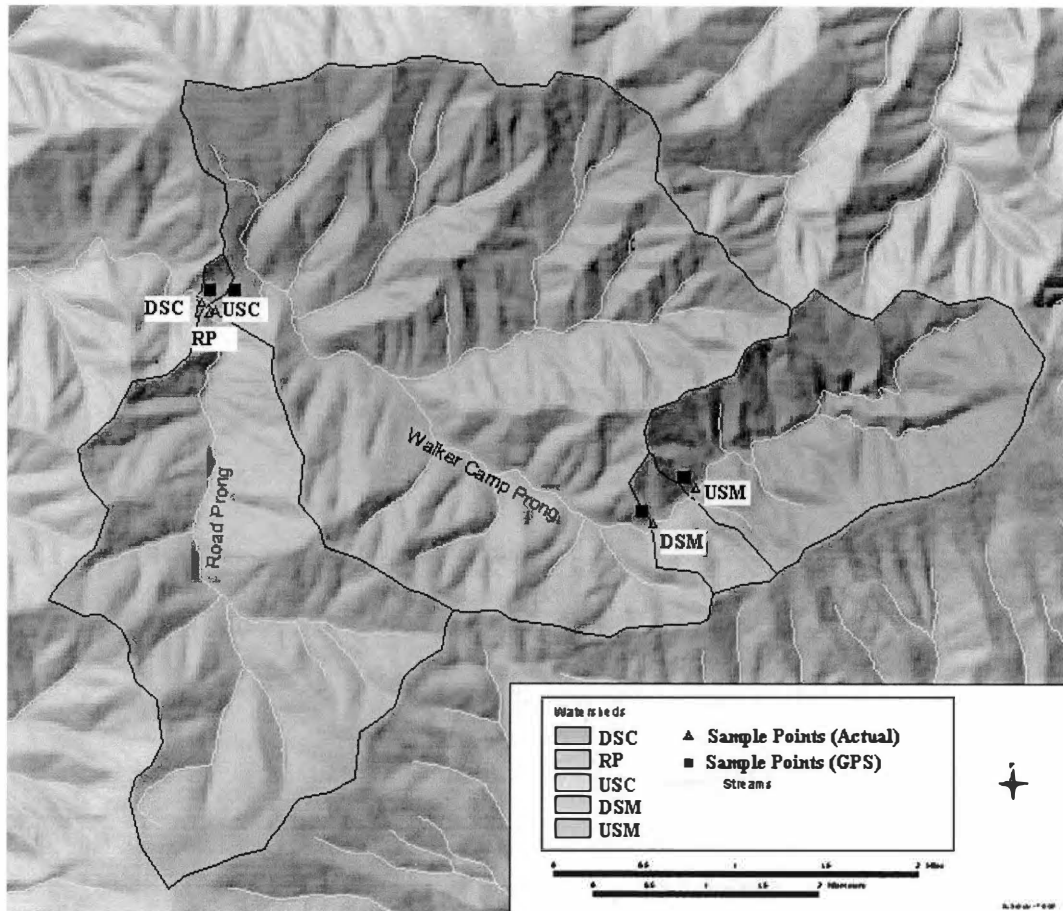


Figure 1-2. Watershed areas contributing to stream sampling locations

Table 1-3. Watershed areas contributing to sampling station stream flow

| Watershed Areas |         |                                  |
|-----------------|---------|----------------------------------|
| ID              | Acres   | Contributing Stream(s)           |
| DSC             | 23.7    | Walker Camp Prong and Road Prong |
| RP              | 2,211.5 | Road Prong                       |
| USC             | 4,385.3 | Walker Camp Prong                |
| DSM             | 165.3   | Walker Camp Prong                |
| USM             | 1,292.5 | Walker Camp Prong                |

## ***Purpose and Scope***

The objectives of the research were:

- Assess the impact of tunnel reconstruction on water quality of adjacent streams
  1. monitor the receiving streams upstream and downstream of each tunnel reconstruction site
    - a. collect periodic stream grab samples at each of the four stations
    - b. collect grab storm samples at each of the four stations
    - c. collect passive storm samples at each of the four stations
    - d. analyze samples for pH, ANC, conductivity, major ions, suspended solids at each of the four stations
  2. analyze the sampling results to determine any statistically significant changes in water quality that may have been caused by the reconstruction
- Evaluate the effectiveness of the best management practices used by the contractor at the construction and disposal sites
  1. collect grab storm samples above and below check dams
  2. collect grab storm samples before and after inlet protection
  3. collect leachate samples from the two disposal sites
  4. analyze samples taken from check dams, inlets and disposal sites for pH, ANC, conductivity, major ions, suspended solids
  5. quantitatively and statistically assess (at the 95% confidence interval) construction impacts on water quality and effectiveness of BMP

- Notify GSMNP officials as environmental concerns arise (Note: Researchers were not contracted or expected to serve as construction inspectors)

The number of samples collected per visit and the frequency of the visits varied with the construction. Pre-construction samples were collected bi-weekly beginning May 2001. During the peak reconstruction period (December 2001 through February 2002) intensive sampling was conducted: 2 or more visits per week depending on rainfall. Samples were collected weekly for the remainder of the construction period (March 2002 through May 2002). Post-construction samples were collected bi-weekly (May 2002 through September 2002).

## CHAPTER II. REVIEW OF THE LITERATURE

### *Potential Environmental Impacts of Construction*

Erosion and sediment yield are common processes associated with road construction. The Highway Research Board (1973) reported earthwork, ditch construction, haul road usage and culvert installation as construction tasks with high erosion risk (Barrett, 1995). In a study referenced by Burton and Pitt (2002), construction site runoff in the Village of Germantown (Washington County, WI) reported high sediment yields as a result of the stripping of vegetation and tracking of mud onto streets by construction vehicles. According to Reed (1978), the five Pennsylvania streams monitored in his study experienced a two to four-fold increase in suspended-sediment discharges during construction on adjacent roadways but quickly returned to pre-construction levels. Storm-runoff suspended solids concentrations in the stream averaged 149 mg/L, up from the 49 mg/L pre-construction and post-construction averages.

Sediment can adversely affect macroinvertebrates. Fossoti et al. (2001) reported a 500-fold increase in downstream suspended sediment concentrations due to road construction in Bolivia. A slight increase in phosphates and bicarbonates was observed immediately downstream of the release points. Other chemical parameters including chlorides, sulfates, nitrates, calcium, magnesium, sodium and potassium were not dramatically impacted by the sediment release. The sediment resulted in a decrease in macroinvertebrate density (200-fold decrease in abundance) and diversity (6-fold decrease in number of taxa). Diversity reductions were most notable where suspended solids concentrations exceeded 100 mg/L. Suspended solids were found to have no

positive effects on any microinvertebrate populations, and several other studies are cited as proof of the adverse impacts of sediment on invertebrates. Fossati also reports that a Canadian highway construction project described by Barton (1977) resulted in a 300-fold increase in suspended solids, but there was only limited variation in observed water chemistry, and that variation could be attributed to elevation change. The conclusion was that "observed impacts on invertebrate fauna are probably related to the direct and indirect effects of [suspended solids], and not to other water changes in the chemical properties of the water (Barton, 1977)."

Swerdon (1973) stated that, "Suspended sediment can injure aquatic life by mechanical abrasion, by obstructive silting, by reducing the penetration of light, by providing a surface for the growth of microorganisms, by absorbing or adsorbing chemicals, and by inhibiting normal temperature fluctuations." Swerdon reports McKee and Wolf findings that fish have the ability to withstand high suspended solids concentrations for short periods. In laboratory tests sixteen North American fish were able to survive concentrations of 100,000 mg/L for one week. Rainbow trout were able to endure 30 mg/L with no effect, 90 mg/L with some effect, and 270 mg/L before harmful effects were observed. The Great Smoky Mountain streams generally have a sufficiently steep gradient to prevent harmful sedimentation in the channel, but elevated suspended solids concentrations are common (Sweeka and Hartman, 2001). Despite trout tolerance and stream characteristics that prevent buildup, an increase in turbidity decreases a brook trout's reactive distance (Sweeka, 2001). This could decrease trout foraging success and growth rates.

Surprisingly, some streams may receive less of some types of pollution during periods of road reconstruction than levels observed during normal, non-construction periods. Roadways are collection areas for pollution. With fewer vehicles operating during construction periods, pollution levels may decline. In a 1998-2000 California Highway study, runoff constituent concentrations including total cadmium, dissolved copper, total copper, dissolved lead, total lead, dissolved nickel, dissolved silver, total silver, dissolved zinc, total zinc, nitrate (as N), nitrite (as N), ammonia, TKN, chemical oxygen demand, oil and grease, fecal coliform, chlorpyrifos, and diazinon were observed to be higher during normal operation than during periods of construction (Kayhanian, 2001). Conversely, total chromium, total nickel, total phosphorus, total suspended solids and turbidity increased during construction periods. The study also found that metals concentrations correlated with particle concentrations, indicating that an increase in total suspended solids would increase metals concentrations.

#### ***Variation in pH due to natural and anthropogenic stresses***

There was concern by GSMNP officials that the construction could expose Anakeesta rock formations which have the potential to generate acidic runoff. A section of Beech Flats Creek, located in the North Carolina section of the Park experienced such contamination in 1963 (Kucken, 1994). The exposure has resulted in lasting adverse environmental impacts: reduced pH, increased heavy metal concentrations, and almost total annihilation of microinvertebrates and fish in more than 7 km of stream. Walker Prong is an example of a GSMNP stream that flows along exposed Anakeesta rocks. As a result samples have shown decreased pH values and elevated concentrations of elements, most notably Al, Mn, and Zn. Huckabee explains the potential danger: "The

leaching of pyritiferous phyllite of the Anakeesta formation appears to be detrimental to fish and salamander populations through the depression of stream water pH and increased concentrations of mineral elements (Huckabee, 1975).” This problem is most common at high elevations since leachates become dilute as they move downstream and flow increases (Herrmann, 1976). This increase in pH at lower elevation causes Al to precipitate in the form of aluminum hydroxide. This precipitate may redissolve as pH varies with runoff volume and season. Despite the potential, Anakeesta does not invariably lead to problems. Leaching experiments have shown that leaching properties of Anakeesta can vary greatly between tested specimens. The conclusion is that not all Anakeesta responds in the same way (Maas 1976).

Anakeesta exposure is not the only source for stream pH reduction. Atmospheric deposition is another cause of pH decline. Season may also play a role in pH trends. "The quantitative distinction of the natural and anthropogenic components of episodic pH decline is important but problematic" (Bishop, 2000). Runoff from snowmelt "is highly susceptible to acid deposition due to the preferential elution of  $\text{SO}_4^{2-}$  and  $\text{NO}_3^-$  from the snowpack at the onset of melt" (Bishop, 2000). This is significant because "[t]he Great Smoky Mountains receive high total atmospheric deposition of sulfur and nitrogen and contain large areas of shallow, poorly buffered soils" (Flum, 1995). In a study by Hruska on boreal streams, snowmelt coincided with a drop in stream pH of as much as 1.8 pH units (2001). A dilution of base cation and strong acid anion concentrations was also measured.

Despite this potential for a seasonal difference, in a study of GSMNP streams by Maas (1976), pH was not observed to vary greatly with season; with the exception that

summertime values were significantly higher. However, the study is over 25 years old and may not reflect current conditions due to atmospheric or other changes. Weekly sample pH variations, in the Maas study, on upper sections of Walker Prong were as much as 1.7 pH units. Also manganese and zinc concentrations were observed to increase significantly during summer months.

Silsbee and Larson report their highest pH values in the fall and lowest pH values coming during winter (McCann, 2000). Results at Noland Divide, a high elevation stream monitoring site in the GSMNP, were consistent with these findings. Lowered pH and increased conductivity generally accompany periods of higher rainfall, and the inverse can be expected in drier periods.

### ***BMP Performance***

Proper planning, design, installation, regular inspection and maintenance are critical to BMP performance (Harbor, 1999). Despite well-designed and properly installed erosion prevention measures, some soil erosion is inevitable. However, BMPs can greatly reduce erosion and sediment transport. Resources are wasted and pollution occurs when plans specifying BMPs that promise to provide adequate pollution prevention do not function properly in the field. Regular inspection and maintenance of BMPs is necessary to detect and/or prevent problems. Design adjustments or revisions are often necessary when field conditions are different from assumed design conditions or when field conditions change.

Installation of rock check dams is a commonly used BMP in construction site ditches and swales. Despite its common usage, the solids removal efficiency of check dams has been questioned (Webber and Wilson, 1976). Heavier or larger sediment

particles deposited behind dams indicates some trapping efficiency. However, periods of high flow could actually result in higher concentrations downstream as a result of resuspension of trapped particles. Dams in Webber's study generally provided a "small reduction in turbidity and/or suspended solids in the water flowing past them (Webber, 1976)." Retention time played the greatest role in determining removal efficiencies. Factors effecting retention time included size of ponding area, velocity in approach channel, and amount of runoff.

In a study by Reed (1978) samples were taken above the pool created by the check dams and then at the outflow. The median reduction in turbidity was about 5 percent. Using calculations based on the sediment yield and the amount of sediment trapped behind the dams, the trap efficiency was also found to also be 5 percent. Check dams in other areas of Pennsylvania were reported to provide similar trap efficiencies.

A rock berm tested by Barrett in the field showed inconsistent results, but generally produced a negligible reduction in suspended solids (Barrett et al., 1995). Figure 2-1 shows the concentrations above and below the berm. Flume tests on rock berms showed only slight reductions in suspended solids concentrations. Short detention times and large pore size were thought to limit their effectiveness.

Though the sediment removal efficiency of rock check dams is important, efficiency numbers alone do not necessarily reflect overall effectiveness for erosion and sediment control. According to Barrett's review of literature, Haan et al. (1994) make the point that erosion and sediment control should be evaluated based upon the performance of the overall system rather than on the performance of individual components (Barrett, 1995). The example cited is a sediment pond. By controlling erosion, site runoff would

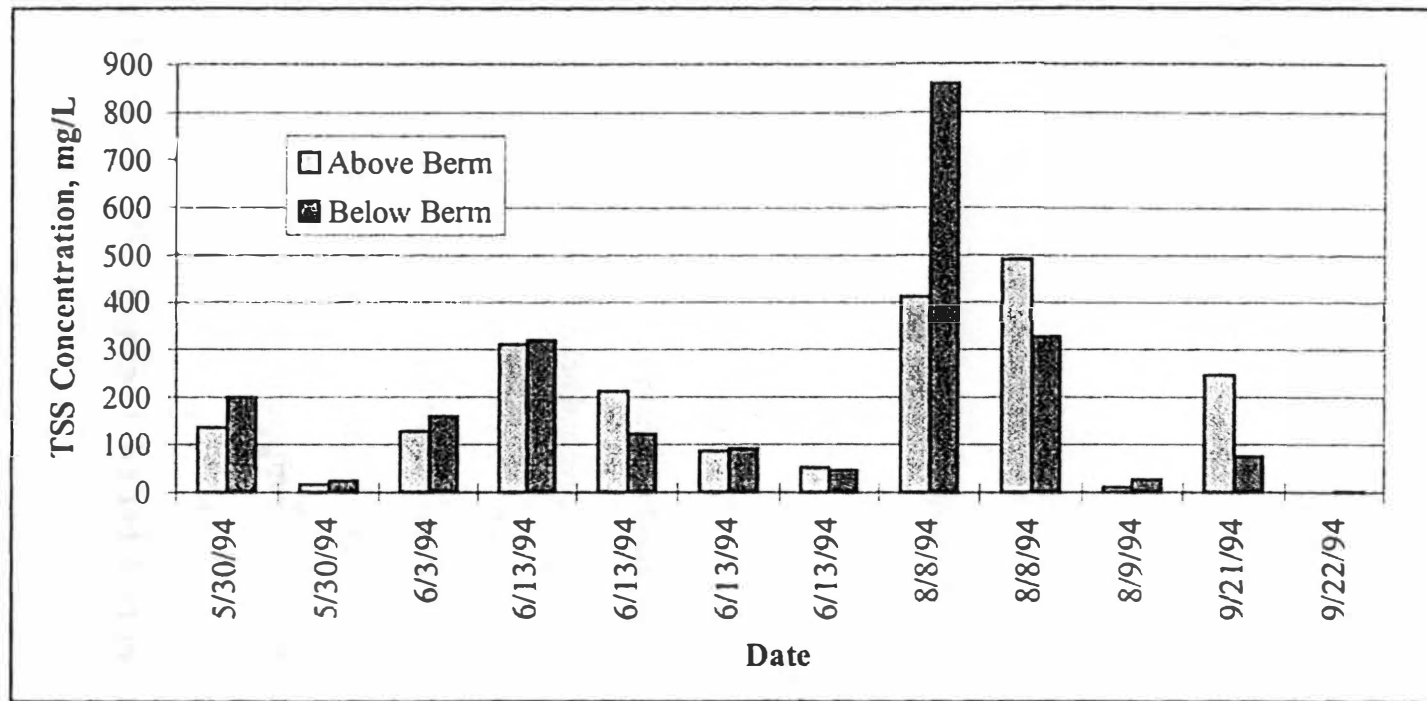


Figure 2-1. TSS concentration of samples above and below rock berm (Barrett, 1995)

contain less sediment, but the suspended particles would likely be very fine. Trap efficiency of sediment ponds and check dams are usually higher for larger particles than for fine particles. The pond's efficiency in trapping these fine particles would be less than the efficiency for runoff containing large particles despite an overall reduction in sediment actually leaving the site.

### ***Assessing Construction Impacts and Discussion of Water Quality Standards***

Due to cost and personnel constraints it is not always feasible to have samples collected by hand during every rain event of interest. Therefore, passive samplers are often left in a stream to collect samples. However, less information is obtainable for passive samples than samples collected by hand (exact time the bottle filled, visual observation of the stream at time of collection, etc.). Therefore, passive samplers are best used for gathering supplemental data that could not be collected by hand.

Assuming that samples taken accurately reflect the water quality of the stream, for a single storm event or a series of storm events, other uncertainties arise. Individual pollutants (including metals, suspended solids, acid, hydrocarbons, etc.) found in stormwater have been researched, and information is available on their effects (Burton, 2002). However, effects from the variable concentrations and intermittent exposure to pollutants in stormwater are less certain. An investigation of water quality alone is generally inadequate for drawing conclusions about the biological impacts associated with runoff. Toxicity studies on a number of benthic and aquatic organisms are a direct way to measure impacts, but these tests are expensive.

A quantitative assessment of the pollutants leaving a construction site can be made by measuring total suspended solids, suspended solids concentrations, settleable

solids or turbidity. However, general water quality standards might not reflect the pollution level that should be considered acceptable for a specific project (EPA, 2002). The EPA considered numerical guidelines for construction site runoff constituents, but decided against them for several reasons. The stochastic nature of rainfall and runoff would account for a variation in runoff concentrations: High intensity rain storms would erode more soil particles than a low intensity event at the same site. Variation in site-specific soil conditions would cause sites with the same BMPs to yield different suspended solids concentrations for a similar rain event: A site that is covered primarily with clay (or other fine particle soils) would have higher suspended solids concentrations than a sandy site. Practical constraints in monitoring also made such limits inconsistent and unenforceable. Other drawbacks were the additional cost that such guidelines could generate for developers and a concern that chemical binding agents would likely be widely utilized to meet standards. Although chemical treatment may be appropriate in some cases, long-term impacts of widespread use of binders are uncertain.

Although no enforceable national standards are in place, EPA offers a compilation of its national recommended water quality criteria for 157 pollutants, developed pursuant to the Clean Water Act (EPA, 1998; EPA, 2002). These limits are not legally binding, but rather provide States with guidance in setting their own criteria. Most limits are expressed by a combination of values that address different toxicity concerns: “The Criteria Maximum Concentration (CMC) is an estimate of the highest concentration of a material in surface water to which an aquatic community can be exposed briefly without resulting in an unacceptable effect. The Criterion Continuous Concentration (CCC) is an estimate of the highest concentration of a material in surface

water to which an aquatic community can be exposed indefinitely without resulting in an unacceptable effect”(EPA, 1998).

The Tennessee Water Quality Control Board provides criteria for streams based on their use. Values for maximum trace metal concentrations for streams supporting fish and aquatic life are presented later in this report alongside trace metal concentrations detected in this study. The portion of the WPLPR located in the GSMNP is designated as one of the Outstanding National Resource Waters (ONRWs) and has the most stringent criteria. As an ONRW, no new discharges that degrade water quality are allowed.

## CHAPTER III. FIELD STUDIES AND ANALYSIS

### *Site Descriptions*

#### Stream Station Sampling Locations

Sampling stations were selected by a team of hydrologists, engineers and National Park Service personnel above and below each tunnel using 1: 24000 scale USGS quadrangle topographic maps. Researchers selected the upstream sampling stations to be free from the respective construction influence and downstream stations to receive all potential runoff from each of the disturbed areas. Note that the upstream Chimney Tops Tunnel station was located on Walker Prong. Walker Prong combines with Road Prong to form the WPLPR. The downstream station was located on WPLPR. A typical sampler is shown in Figure 3-1.

All construction runoff from Morton discharged into Walker Prong via several small, steep and difficult to access streams that drain into Walker Prong (Figure 1-2). Therefore, easily accessible points along Walker Prong were chosen for the Morton sampling sites.

Heavy vegetation made it difficult to distinguish the Morton drainage basin from adjacent basins. National Park personnel and aerial photographs (via terraserver.com) revealed that the "upstream" sample (USMO) taken on the initial visit was actually just downstream of the basin draining Morton Tunnel. A new upstream station was selected on the second pre-construction visit and subsequent samples were taken at this new point.

#### Construction and Disposal Sampling Sites

Construction plans were used to locate potential sampling points for all construction site samples to monitor BMP performance at both construction and waste

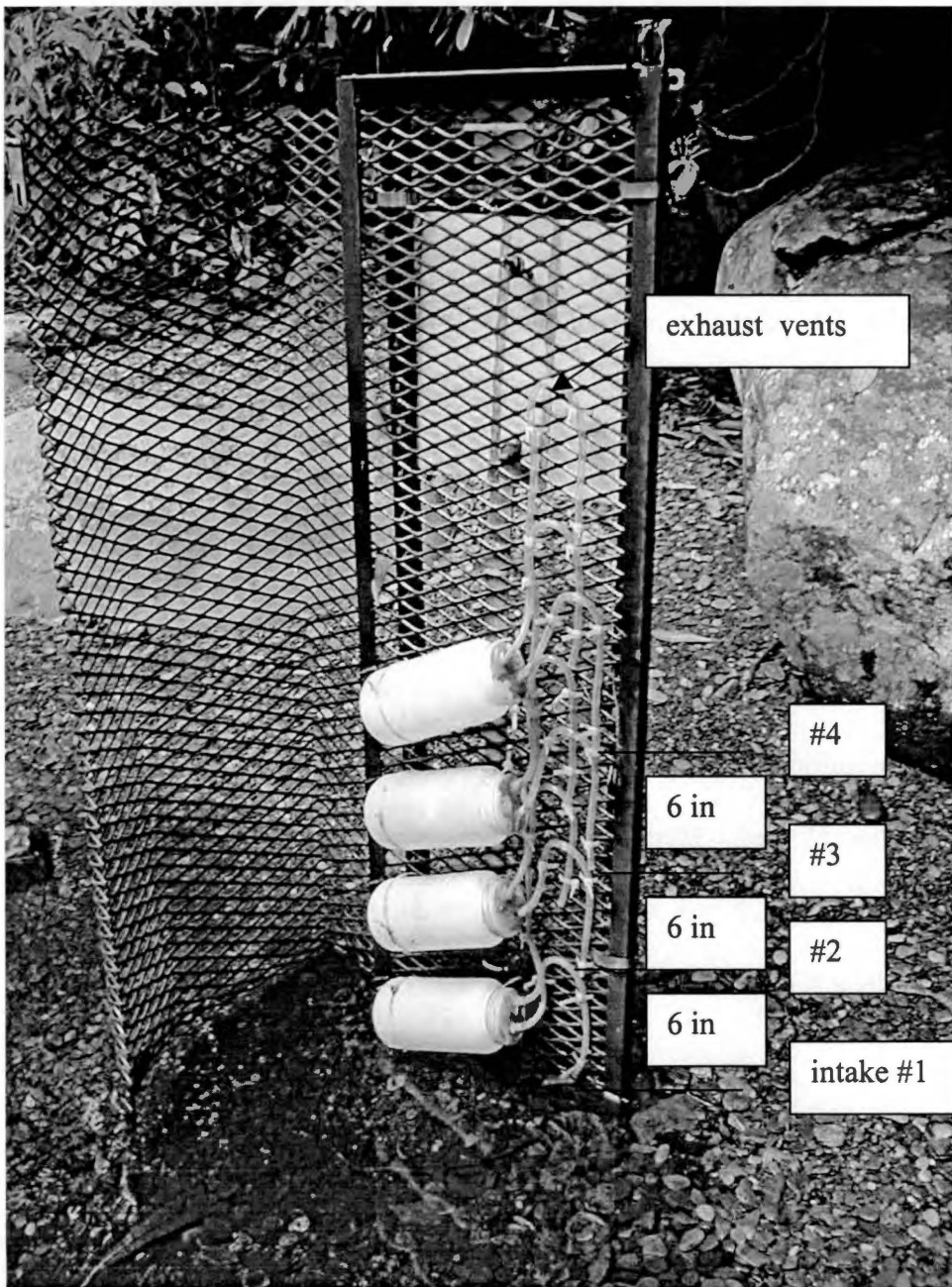


Figure 3-1. Photograph showing four collection stages of a typical stream sampler

disposal sites. Final collection sites were selected after making a field visit to observe runoff conditions during a storm event. Samples were collected as discussed below for one inlet protection device, for a single rock check dam, for a series of rock check dams and for additional areas of interest (such as runoff samples just above the construction sites). Several silt fences and rock check dams were installed but not evaluated because they were located in upslope shoulder drainage ways that did not receive significant construction runoff. They did not receive flow because excavation of the roadbed prior to shoulder excavation left the drainage ways stranded at a higher elevation than the roadbed and receiving very little erosion runoff.

Disposal site sample locations were chosen in the same manner as construction site sampling points. Initial rain events were not sufficient to generate leachate seepage from beneath the disposal piles. Once the disposal material and filters below became saturated, leachate production began and samples were collected. Initially, preexisting seeps near the two disposal areas were to be monitored. However, no nearby seeps were found.

### ***BMPs***

#### **Rock Check Dams**

Check dams were originally installed across the construction site ditches according to plans. They were constructed of limestone to neutralize stormwater runoff and allow sediment to be trapped. The erosion control narrative in the construction plans called for installation and removal of erosion and sediment control measures in such a way that economical, effective and continuous erosion and sediment control was provided.

The contractor also installed supplemental rock check dams, not called for in the original construction plans, where necessary. The water that contributed to runoff from the excavated roadbed was largely limited to the rainfall that fell directly on the roadbed. Both the Morton and Chimney Tops sites experienced insignificant upstream run-on. At the Chimney Tops site, construction runoff was channeled to the bottom of the area of roadbed construction (See Figure 3-2). It then flowed along a curb, in a paved pull off area, before exiting the site off a steep bank. As stated earlier, the roadbed was excavated before shoulder excavation leaving rock check dams and silt fences along the shoulders useless, at a higher elevation than the roadbed (See Figure 3-3). Limited by the steep terrain and narrow road shoulder, a series of rock check dams not called for in the original construction plans was installed in the paved pull off area (See Figures 3-4 and 3-5). Samples were collected in the flow-path above the first check dam and just below the final dam (See Figure 3-2).

The contractor also installed a supplemental rock check dam at the Old Trace Road disposal area (See Figures 3-6 and 3-7). Runoff ran down a clay and gravel entrance road to a low point before falling off a steep bank (See Figure 3-8). Initially, a reinforced silt fence was installed to intercept this flow. However, the fence was overwhelmed by the flow, and a rock check dam was subsequently installed. This check dam actually functioned more as thePonding of runoff frequently occurred behind this dam. After the ponding area had become filled with sediment, an additional reinforced silt fence was installed at the base of the dam.

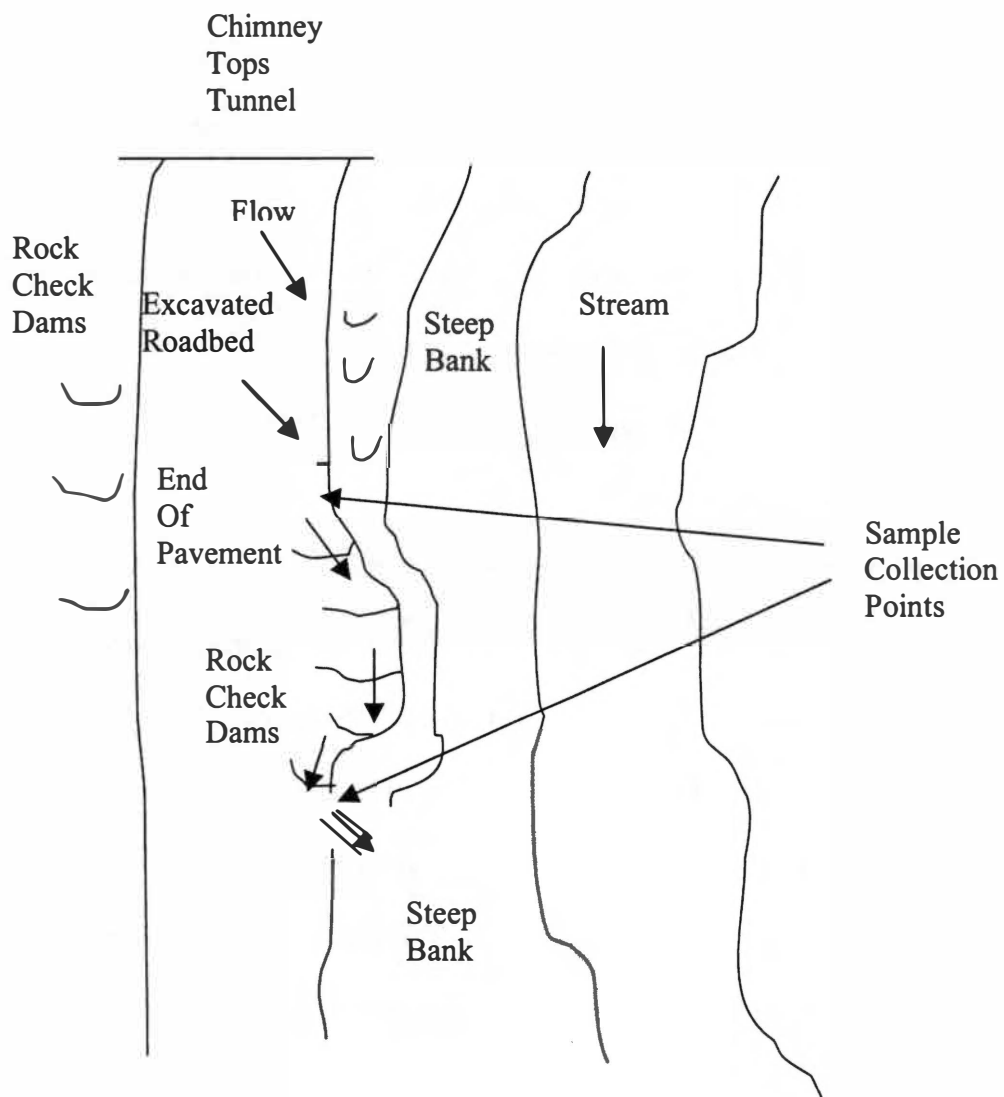
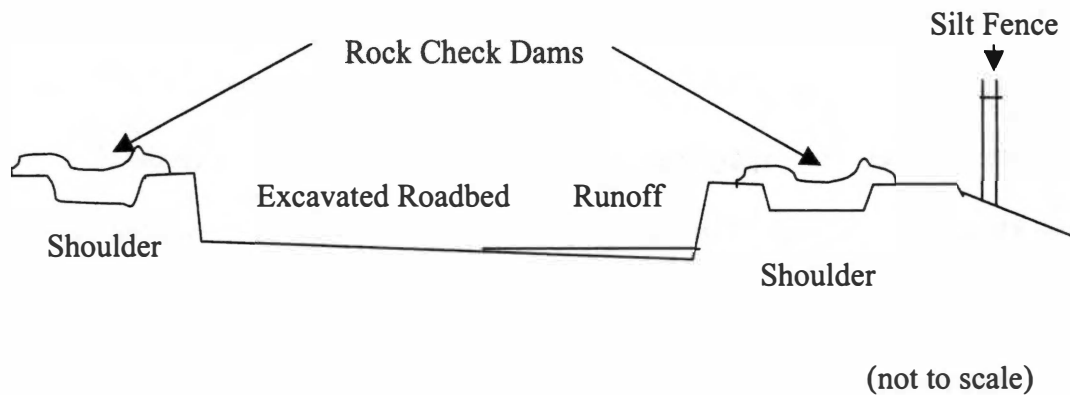


Figure 3-2. Sketch of Chimney Tops check dams (not to scale)



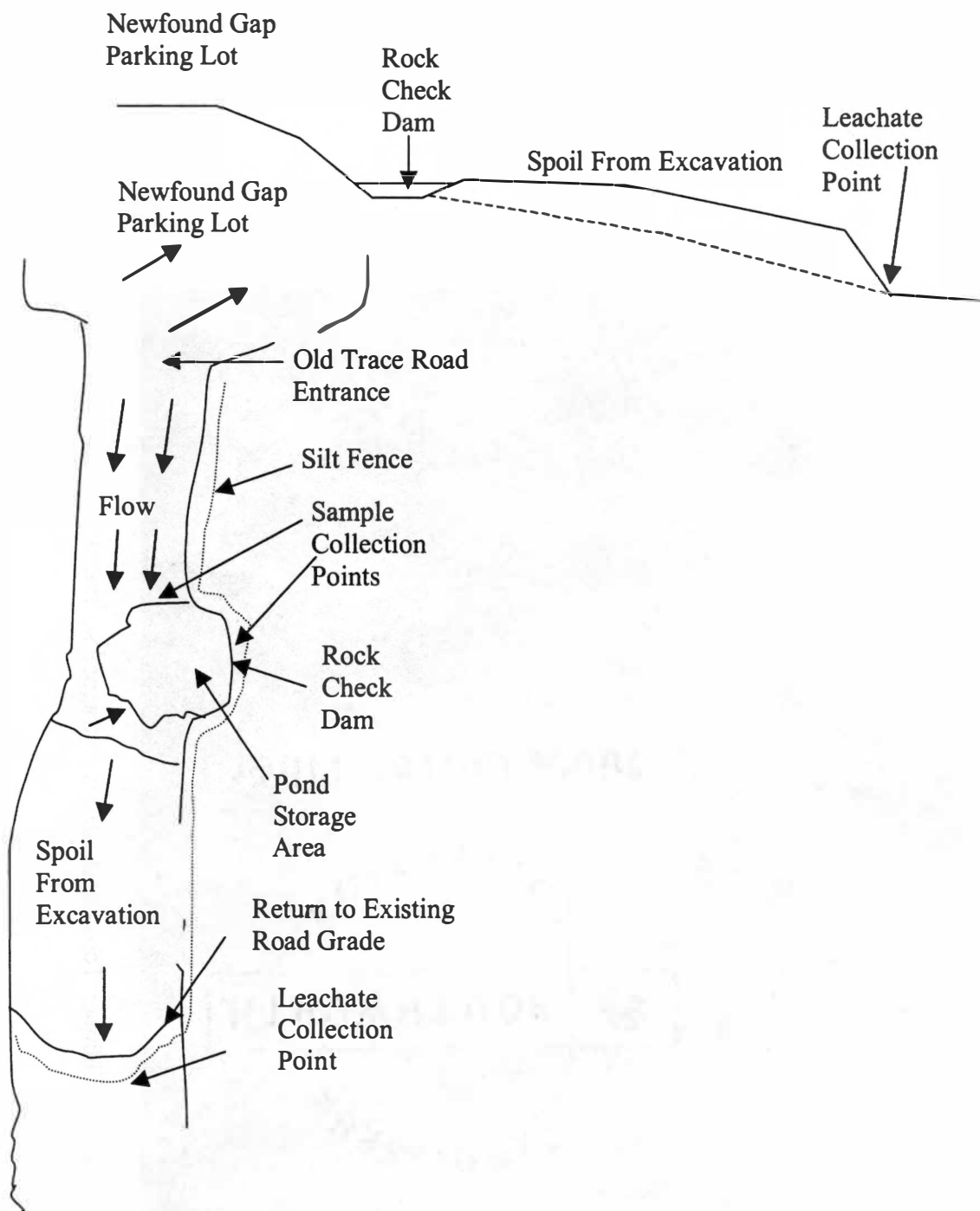
Figure 3-3. Photographs of elevated check dams



Figure 3-4. Photograph of Chimney Tops check dams



Figure 3-5. Photograph of Chimney Tops check dam with trapped sediment



(drawings not to scale)

Figure 3-6. Sketch of Old Trace Road (Newfound Gap disposal area)



Figure 3-7. Entrance road to Old Trace road



Figure 3-8. Old Trace Road rock check dam

### Inlet Protection

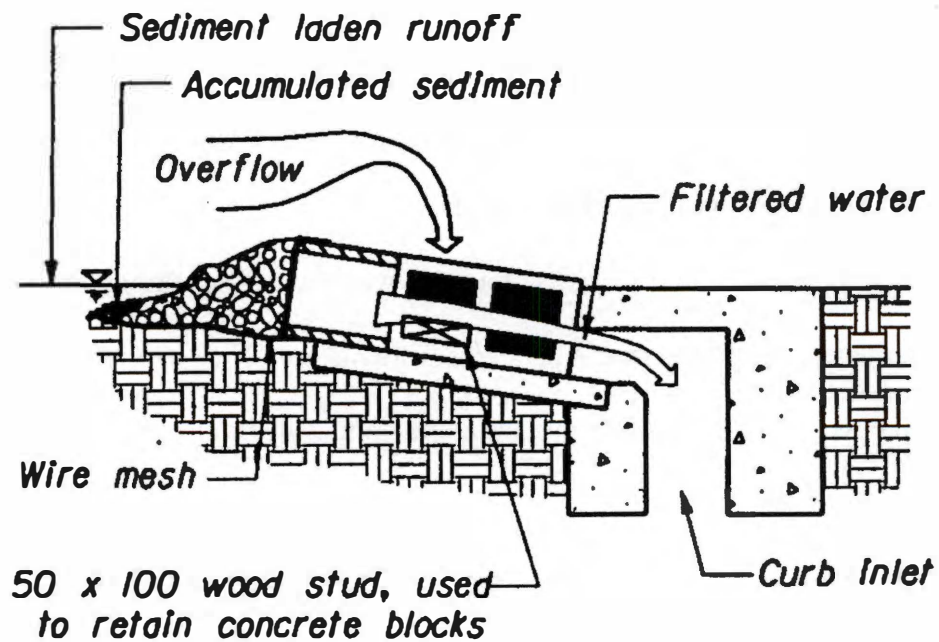
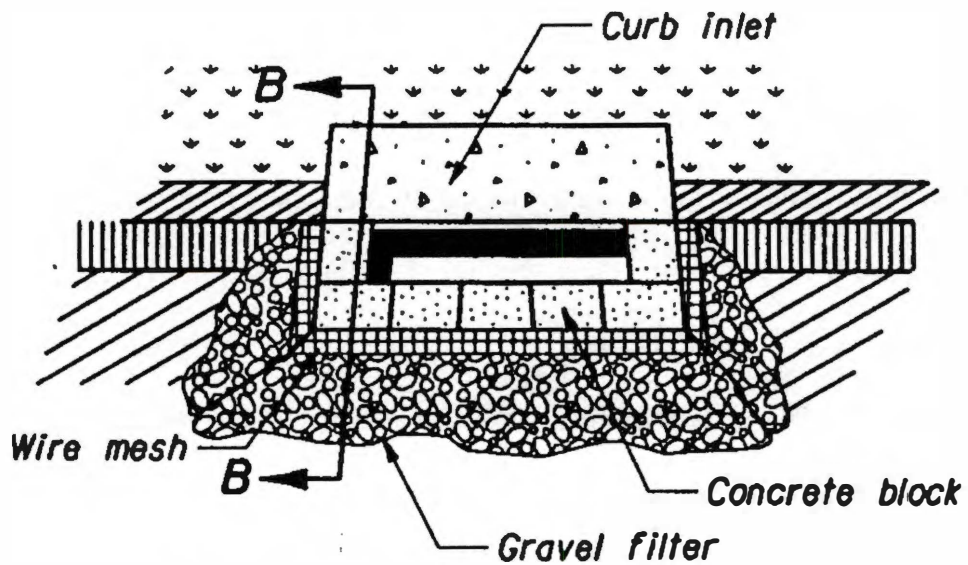
Structures composed of wire, block and stone were placed at a number of inlets to reduce sediment concentrations and help neutralize acidic runoff before runoff left the site. Inlet protection received notable flow in only one location, at a drain just below the lower extent of excavation at the Morton Mountain site. There runoff was filtered through a Type D curb inlet protection structure (See Figure 3-9).

### Disposal Sites

Plans called for the encapsulation of excavated material to prevent acidic runoff from exposed Anakeesta formation. Old Trace Road near Newfound Gap Road and an abandoned dump East of Spur Road were selected as disposal sites for excavated material from Morton Mountain and Chimney Tops Tunnels respectively. The contractor spread a 0.3 m layer of crushed limestone over the areas where excavated materials were to be placed. Geotextile was sandwiched above and below this layer of stone. The excavated material was then placed in 0.6 m lifts. Each lift was treated with agricultural limestone, applied at the rate of 244 kilograms per 100 square meters. The material was capped with a soil cover of 1.2 m to 1.8 m and the slope stabilized with native vegetation.

### Seeding

Unlike the other BMPs in this report, seeding is a measure designed to prevent erosion as opposed to controlling sediment after it has been dislodged. Erosion prevention is always a preferred treatment to sediment control because once the soil particles are dislodged, they are difficult to trap or keep from becoming suspended in the runoff. However, sediment control provides a backup system to erosion control if properly designed, constructed and maintained. The construction plans call for the



## SECTION B-B

Figure 3-9. Type D inlet protection (taken from FHWA plans for project PRA-GSM IA23, B16)

stabilization of all disturbed areas as soon as practical, but not more than 14 days after construction has temporarily or permanently ceased. Despite the importance of seeding, effectiveness could not be directly monitored due to inconsistent and insufficient runoff flows in seeded areas.

## ***Sampling Methodology***

### **Grab Samples**

During pre- and post-construction periods, grab samples from the streams were collected every two weeks at each of four locations: upstream and downstream of the Morton Mountain and Chimney Tops Tunnels as shown in Figure 1-1. Additional samples were taken during the post-construction period at Road Prong just prior to confluence with Walker Prong. During construction, samples were collected more frequently in an effort to better monitor runoff from storm events.

Storm grab samples were distinguished from base flow grab samples. A sample was considered a storm grab sample if it was raining at the time of sampling, or the river was flowing at an elevated stage. The classification was somewhat arbitrary but helped to separate out samples not truly representative of base flow conditions. This separation proved useful when contrasting base flow grab samples and storm event passive samples.

Samples were collected in clean pre-labeled 250 ml polyethylene bottles. Bottles were rinsed at the collection site three times. The bottle was then submerged and capped under water.

### **Passive Samples**

The initial runoff during a rain event, i.e. the first flush, generally contains the greatest pollutant loadings. Therefore, sampling the streams as the water level rose

during storms was of great interest. Given the logistical difficulties and erratic weather patterns that would hamper regular and uniform sampling of rising water by hand, passive samplers were installed to collect these samples. Auto-samplers were considered but were too costly (especially given the potential for vandalism). Also, they were not equipped to collect individual samples at multiple stages during a single runoff event.

A number of constraining factors influenced the final design of the samplers. The samplers (See Figure 3-1) were designed after speaking with numerous USGS personnel and examining report no.13, "The Single-Stage Sampler for Suspended Sediment," as recommended by Federal Interagency Sedimentation Project contacts. The original design called for bottles to be attached to a wooden plank (GPO, 1961). However, a cage made of expanded metal sheeting and angle iron offered significant advantages over wood for about the same cost. The reduced cross section better withstood the water forces. Holes in the metal allowed water to flow through the sampler and reduced the buoyant pressures that would be experienced with wood. The holes also provided for easy attachment and adjustability of the sample bottles. The metal was painted to prevent rusting and help conceal the device.

The samplers were designed to hold four one liter Nalgene HDPE bottles. Nalgene was chosen over glass because of concerns about breakage. Since sample bottles would require frequent removal and replacement, accessibility was important. Nylon cable ties were used to attach the bottles. These bottles were spaced vertically at six-inch increments to allow for samples to be collected at successive stages during the rising limb of a storm event. The original plan was to clip, remove and replace the ties each time a bottle was changed. However, researchers found that bottles could be

replaced by sliding the straps free of the filled bottles and sliding empty sample bottles back into place.

The stage height at which the sample collects is determined by the arrangement of the tubing leading into the bottles. Each bottle has two pieces of Fisherbrand clear PVC tubing inserted in the cap. One serves as the intake and the other is an exhaust vent. The sampler is designed to collect once water reaches the bend in the intake hose. Samplers with nozzles that point into oncoming flow will, at high velocity, sample prematurely taking samples near the water surface (GPO, 1961). USGS personnel suggested that the problem could be eliminated by orienting the tubing vertically. Of the samplers outlined in FISP Report No.13, the samplers designed for this project most closely resemble Fig. 39- Single- Stage Sampler US U-59 A. " This sampler is highly resistant to the effects of drift and debris and to both surge enrichment and circulation through the sampler" (FISP 1961). The only sacrifice is the accuracy of collecting larger particles for suspended sediment analysis. The U-59A sampler can accurately sample only sediments finer than 62 microns.

Once built, the samplers had to be placed and secured in the streams. There were no bridge piers, to which the samplers would be attached, located in the stream. Since the project was located within a National Park, it was important to minimize the disturbance of the streambed: making it undesirable to pour concrete or insert rebar into rocks. Therefore, the samplers were anchored in place with two 6 ft metal fence posts. Each post was driven 1.5 to 2.0 feet deep.

A passive sampling station was located at each of the four aforementioned stream sampling stations. The first sampler was put into service at the downstream Chimney

Tops station in August 2001. Installation of the other three samplers took place in September 2001. Each sampler held four bottles. The identification labels were US or DS (upstream or downstream), C or M (Chimney Tops or Morton Mountain respectively), followed by a number, 1-4, depending upon its vertical location (1 being the lowest). So, for example, the second bottle from the bottom at the station located downstream of the Chimney Tops Tunnel was labeled DSC2.

One of the limitations of the samplers is the need for the river to recede before samples can be retrieved. The date associated with each passive sample is the date that the sample was removed from the sampler, not the date water was sampled from the stream. The nature of passive sampling is such that the exact date the bottle was filled is unknown, although precipitation records can be helpful. Therefore, caution should be made in relating grab samples with passive samples on a temporal basis. Care should also be taken if comparing passive samples of the same stage at different stations (comparing the USM2 with DSM2). Channel characteristics including differences in stage vs. discharge relationships also limit comparison of water quality sample results between stations.

#### Sample Custody and Preservation

All samples were collected by UT field personnel and brought to the University within 2 to 5 hours of collection. Upon arrival at the UT, samples were stored in either a Roper refrigerator (similar to a household unit) or a walk-in refrigeration room at 4° C. When samples were sent to an external laboratory, chain of custody forms were signed.

## *Laboratory Equipment and Methods of Analysis*

### De-ionized Water

The de-ionized water was prepared by passing city water through a US Filter Brand carbon filtration system and then through an Aquafine ultraviolet disinfection unit, model CSL-4R. Samples of the de-ionized water had conductivities less than 1  $\mu\text{S}/\text{cm}$ . Three samples of the de-ionized water were tested for trace metals. The first sample was unfiltered. The second sample was an unfiltered sample carried from the laboratory to the field, poured into another bottle (to simulate field sampling conditions) and sent for analysis. The final sample was passed through a filter used for trace metals analysis. No metals were detected in any of these samples.

### Analytical Balance

The balance used for this project was a Sartorius 820, able to weigh with precision to 0.0001 grams.

### Major Ions

A Dionex model DX-100 was operated by John Shubzda to analyze samples for anions ( $\text{Cl}^-$ ,  $\text{NO}_3^-$ , and  $\text{SO}_4^{2-}$ ) and cations ( $\text{Na}^+$ ,  $\text{K}^+$  and  $\text{NH}_4^+$ ). The DX-100 is a compact ion chromatograph system that is capable of running anions and cations using either chemical or hydrolytic suppression techniques. The system is operated with an attached autosampler. An Instrumentation Laboratory Video 12 atomic absorption spectrophotometer was operated by Mr. Shubzda and/or Thomas Barnett to analyze for  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$ .

### Conductivity

Conductance was measured with a Jenway model 4010 conductance meter using a standard platinum electrode. The samples were prepared by removing them from refrigeration and allowing them to come to room temperature. When it was desirable to expedite the warming process, the lids were checked for tightness and the samples were placed in a water bath. The cell constant was checked each time the meter was used. The electrode was rinsed with deionized water after each use and cleaned thoroughly every month. When excessive drift was noticed, the electrode was cleaned.

### pH and Acid Neutralizing Capacity (ANC)

Sample pH and acid neutralizing capacity (ANC) were measured by a Radiometer Brand autotitrator system with an 18-position autosampler and triburette station. Each autotitrator run included a standard inserted into one of the 18 positions of the autosampler to check for accuracy. If more than one run was performed during the day, the same standard solution was used for all runs which allowed an assessment of precision to be made as well. Maintenance was conducted according to manufacturers specifications, which included soaking the pH probe in pH 4.00 buffer and periodically cleaning the burettes and tubing.

### Suspended Solids

The tests for suspended solids and volatile solids were conducted according to Standard Methods 2540D and 2540E, Total Suspended Solids Dried at 103°-105°C and Fixed and Volatile Solids Ignited at 550°C (Eaton, 1995).

## Oil and Grease

Initial oil and grease analyses were conducted using EPA Method 1664, Revision A: N-Hexane Extractable Material (HEM; Oil and Grease). After experiencing several unsatisfactory spike recoveries, the research team decided to switch to Hach Corporation's Total Petroleum Hydrocarbons (TPH) Immunoassay Method (before the "during construction" monitoring period). This method has a reported detection limit of 2 mg/L according to the manufacturer. Water samples were spiked with diesel fuel (and mixed by vigorously shaking by hand) to test the accuracy of the TPH method. Contrary to the manufacturer's 2 mg/L detection limit claim, high concentration samples (~200 mg/L) were required for the method to detect diesel fuel. The construction sample that appeared to have the highest content of oil and grease was sent to an outside laboratory. Results for this sample, like all other monitoring samples, showed oil and grease concentrations below the laboratory's detection limit and thus, was considered insignificant.

## Trace Metals

Trace metal concentrations for select grab and passive samples were measured by an outside laboratory and are reported with comments. Samples taken before April (2002) were unfiltered. All remaining samples were filtered with Millipore Brand 0.45um pore size, 47mm diameter filters before being sent for testing. Filtration left only dissolved species by removing any solids that may have been collected.

## Statistical Tests

The Mann-Whitney U test and the Wilcoxon signed-rank test were used to analyze all water quality data. The Mann-Whitney U test is a nonparametric test

equivalent to the t-test that determines whether two independent samples are from the same population. Nonparametric tests were preferred and were more robust than parametric tests because the water quality data are often not normally distributed. It is more powerful than the median test since it uses the ranks of the cases. The test requires that values be sorted in ascending order. U is the number of times a value in the first group precedes a value in the second group. The Wilcoxon signed-rank test is a nonparametric procedure used with two related variables (paired samples) to test the hypothesis that the two variables have the same distribution. It makes no assumptions about the shapes of the distributions of the two variables. This test takes into account information about the magnitude of differences within pairs and gives more weight to pairs that show large differences than to pairs that show small differences. The test statistic is based on the ranks of the absolute values of the differences between the two variables. A 5% level of significance was used.

#### QA/QC

For assurance of reproducibility duplicate samples (for 4.7% of all samples) were analyzed for pH, conductivity, ANC and major anions/cations. Suspended solids analyses were performed in duplicate for 12.9% of samples, and results can be found in Table A1-1 of the Appendix.

## CHAPTER IV. RESULTS AND DISCUSSION

As stated earlier, the objectives of this study were to assess the impact of road and tunnel reconstruction on water quality of adjacent streams and evaluate the effectiveness of BMPs used.

- Stream water quality impacts were assessed by analyzing periodic stream grab samples and passive storm samples collected upstream and downstream of each reconstruction site. ANC, pH, conductivity, major ions and suspended solids were measured for each sample.
- Changes in construction site runoff were monitored by collecting and analyzing grab samples of storm runoff taken above and below the areas of disturbance. These samples were taken in the drainageways onsite before reaching the adjacent streams.
- Effectiveness of BMPs was evaluated by analyzing grab storm samples taken above and below check dams, before and after inlet protection and immediately below the two disposal sites (leachate). These samples were also tested for pH, ANC, conductivity, major ions and suspended solids.

### ***Construction Impact Potential***

The area of disturbance at each of the construction sites was small in relationship to the watershed in which they were located. Estimating 1.25 acres of disturbance (not including the area within the tunnel) for the Morton site, the disturbed area represents only 0.09% of the area draining to the downstream Morton sampling station. Estimating that the area of disturbance for the Chimney Tops site was 1.31 acres, the combined construction areas for the two tunnels represented only 0.03% of the total drainage area

of 8,533 acres (see Table 1-3 for areas) draining to the downstream Chimney Tops site. Assuming that areas from the watershed contributed runoff equally during a storm event, runoff from the construction sites contained 10,000 mg/L of suspended solids and the stream suspended solids concentration was 100 mg/L. In this situation, the suspended solids concentration in the stream would increase to 103 mg/L. Granted that the disturbed areas would have a higher percentage of precipitation as runoff than the undisturbed areas (as assumed in this calculation), the point remains that the stream has the potential to greatly dilute high suspended sediment concentration runoff from the sites. Sample Calculations can be found in the Appendix.

### ***Streams***

Table 4-1 shows pH, ANC and conductivity by site for all three test periods (pre-construction, construction and post-construction). Figure 4-1 shows base flow (non-storm event) grab samples pH at the primary sampling stations. Figures 4-2 and 4-3 show conductivities for grab and passive samples taken at the Morton Mountain and Chimney Tops sampling stations respectively. Higher than normal conductivities were observed at both tunnel sites during the early stages of the construction period, but values returned to the pre-construction range by February. Figures 4-4 and 4-5 show ANC results for each tunnel's stream station pairs. ANC values appear to decline slightly at both sites during construction, but return to pre-construction levels. However, this decline is not necessarily due to construction since seasonal trends are known to occur for many parameters (Robinson, et al. 2001). The statistical tests discussed below will test for differences between pre-construction, construction and post-construction water quality and will account for seasonal effects by examining paired differences.

Table 4-1. pH, ANC and conductivity at each sampling site by construction period

| Period            | Sample | Number Collected | pH   |        |                    |           | ANC µeq/L |        |                    |               | Conductivity µS/cm |        |                    |            |
|-------------------|--------|------------------|------|--------|--------------------|-----------|-----------|--------|--------------------|---------------|--------------------|--------|--------------------|------------|
|                   |        |                  | Mean | Median | Standard Deviation | Range     | Mean      | Median | Standard Deviation | Range         | Mean               | Median | Standard Deviation | Range      |
| Pre-construction  | DSC    | 15               | 6.10 | 6.15   | 0.27               | 5.19-6.39 | 36.99     | 32.76  | 15.22              | 21.72         | 18.60              | 17.71  | 1.92               | 16.10-23   |
|                   | DSC-1  | 5                | 6.17 | 6.11   | 0.12               | 6.10-6.37 | 42.77     | 41.54  | 13.88              | 28.94-58.83   | 20.12              | 21.30  | 2.31               | 17.2-22.4  |
|                   | DSC-2  | 4                | 6.17 | 6.17   | 0.05               | 6.13-6.22 | 39.59     | 34.13  | 18.61              | 23.99-66.13   | 21.90              | 20.95  | 4.51               | 17.6-28.1  |
|                   | DSC-3  | 3                | 6.06 | 6.12   | 0.14               | 5.9-6.16  | 31.28     | 21.60  | 23.53              | 14.14-58.11   | 21.58              | 23.10  | 3.16               | 17.95-23.7 |
|                   | DSC-4  | 2                | 6.06 | 6.06   | 0.19               | 5.92-6.19 | 35.85     | 35.85  | 21.41              | 20.71-50.99   | 20.84              | 20.84  | 5.88               | 16.68-25   |
|                   | DSM    | 15               | 6.16 | 6.13   | 0.12               | 5.81-6.48 | 30.86     | 31.10  | 12.70              | 6.3-50.74     | 24.51              | 25.00  | 2.15               | 20.4-27.5  |
|                   | DSM-1  | 5                | 6.11 | 6.09   | 0.22               | 5.86-6.39 | 42.11     | 31.49  | 27.37              | 22.79-82.68   | 27.93              | 29.75  | 4.31               | 21.5-30.7  |
|                   | DSM-2  | 2                | 5.10 | 5.10   | 0.11               | 4.99-5.21 | -2.40     | -2.40  | 2.94               | -4.48-(-0.32) | 36.45              | 36.45  | 13.22              | 27.1-45.8  |
|                   | DSM-3  | 1                | 4.98 | 4.98   | 0.00               | 4.98      | -3.03     | -3.03  | 0.00               | -3.03         | 37.10              | 37.10  | 0.00               | 37.10      |
|                   | DSM-4  | 1                | 4.77 | 4.77   | 0.00               | 4.77      | -9.58     | -9.58  | 0.00               | -9.58         | 35.60              | 35.60  | 0.00               | 35.60      |
|                   | USC    | 15               | 6.21 | 6.19   | 0.11               | 6.06-6.48 | 32.28     | 32.45  | 11.88              | 11.94-53.4    | 19.94              | 19.80  | 1.77               | 17.5-23    |
|                   | USC-1  | 3                | 6.21 | 6.19   | 0.06               | 6.13-6.24 | 32.28     | 32.45  | 8.33               | 32.85-49.21   | 19.94              | 19.80  | 1.03               | 20.7-22.7  |
|                   | USC-2  | 3                | 6.17 | 6.21   | 0.14               | 6.01-6.29 | 38.53     | 33.47  | 22.87              | 18.61-63.51   | 22.90              | 21.60  | 2.88               | 20.9-26.2  |
|                   | USC-3  | 2                | 5.90 | 5.90   | 0.30               | 5.68-6.11 | 25.59     | 25.59  | 0.00               | 5.81-45.37    | 24.20              | 24.20  | 0.00               | 21.8-26.6  |
|                   | USC-4  | 1                | 6.12 | 6.12   | 0.00               | 6.12      | 55.60     | 55.60  | 0.00               | 55.60         | 27.00              | 27.00  | 0.00               | 55.60      |
|                   | USM    | 15               | 5.60 | 5.63   | 0.30               | 5.05-6.12 | 4.82      | 4.63   | 7.79               | 1.93-(-15.1)  | 22.04              | 21.90  | 2.35               | 18.7-26.7  |
|                   | USM-1  | 2                | 4.89 | 4.89   | 0.21               | 4.74-5.03 | -14.15    | -14.15 | 12.99              | 23.33-(-4.96) | 25.85              | 25.85  | 1.77               | 24.6-27.1  |
|                   | USM-2  | 2                | 4.65 | 4.65   | 0.11               | 4.57-4.57 | -23.15    | -23.15 | 1.48               | -24.2-(-22.1) | 40.60              | 40.60  | 18.81              | 27.3-53.9  |
|                   | USM-3  | 1                | 4.72 | 4.72   | 0.00               | 4.72      | -16.13    | -16.13 | 0.00               | -16.13        | 35.50              | 35.50  | 0                  | 4.72       |
|                   | USM-4  | 1                | 4.53 | 4.53   | 0.00               | 4.53      | -23.25    | -23.25 | 0.00               | -23.25        | 42.80              | 42.80  | 0                  | 4.53       |
| Construction      | DSC    | 23               | 5.85 | 5.91   | 0.3                | 5.28-6.57 | 34.33     | 26.29  | 27.7               | 16.6-28.2     | 20.57              | 19.7   | 3.22               | 16.6-28.2  |
|                   | DSC-1  | 11               | 5.85 | 5.87   | 0.19               | 5.4-6.12  | 25.577    | 24.64  | 10.27              | 11.65-47.42   | 19.81              | 20     | 2.7                | 13.86-23.4 |
|                   | DSC-2  | 11               | 5.97 | 6.03   | 0.14               | 5.69-6.12 | 29.52     | 35.49  | 13.86              | 1.34-44.69    | 18.67              | 19     | 1.48               | 16-20.9    |
|                   | DSC-3  | 9                | 5.93 | 5.91   | 0.21               | 5.64-6.23 | 39.77     | 24.37  | 46.75              | 6.49-160.07   | 19.3               | 3.61   | 39.77              | 17.4-27.7  |
|                   | DSC-4  | 7                | 5.91 | 5.91   | 0.18               | 5.72-6.21 | 36.42     | 24.7   | 43.64              | -6.1-45.73    | 20.6               | 19.1   | 4.2                | 17.22-27.2 |
|                   | DSM    | 23               | 5.83 | 5.82   | 0.2                | 5.38-6.2  | 21.29     | 21.5   | 10.11              | -3.28-36.96   | 26.81              | 26.2   | 3.7                | 21.6-33.5  |
|                   | DSM-1  | 12               | 5.82 | 5.77   | 0.21               | 5.47-6.16 | 23.94     | 26.01  | 13.35              | -87-43.34     | 26.99              | 27.4   | 3.26               | 23.7-31.1  |
|                   | DSM-2  | 10               | 5.35 | 5.2    | 0.53               | 4.83-6.67 | 41.85     | -3.4   | 136.8              | -13.15-430.0  | 30.55              | 31     | 4.17               | 24.2-37.9  |
|                   | DSM-3  | 4                | 5.16 | 5.06   | 0.53               | 4.68-5.84 | -9.05     | -11.5  | 11.49              | -19.56-6.35   | 32                 | 32.05  | 0.73               | 31.1-32.8  |
|                   | DSM-4  | 1                | 6.28 | 6.28   | 0                  | 6.28      | 185.93    | 185.93 | 0                  | 183.93        | 42.7               | 42.7   | 0                  | 42.7       |
|                   | USC    | 23               | 5.83 | 5.81   | 0.24               | 5.32-6.22 | 20.92     | 24.06  | 9.95               | -5.52-31.58   | 22.09              | 21     | 3.89               | 18.1-29.2  |
|                   | USC-1  | 7                | 5.82 | 5.84   | 0.14               | 5.59-5.98 | 28.31     | 31.17  | 11.91              | 19.14-29.5    | 23.11              | 22.2   | 3.73               | 19.14-29.5 |
|                   | USC-2  | 11               | 5.96 | 5.93   | 0.18               | 5.74-6.2  | 27.42     | 28.88  | 10.31              | 12.98-42.71   | 19.67              | 19.6   | 2.96               | 18-24.6    |
|                   | USC-3  | 10               | 5.92 | 5.89   | 0.14               | 5.74-6.1  | 20.38     | 21.65  | 10.85              | -1.49-32.05   | 21.66              | 21.15  | 3.06               | 18-27.1    |
|                   | USC-4  | 5                | 5.81 | 5.85   | 0.18               | 5.51-5.99 | 10.43     | 8.7    | 10.5               | -2.23-24.84   | 22.65              | 24.7   | 3.53               | 18.3-25.6  |
|                   | USM    | 23               | 5.37 | 5.33   | 0.27               | 4.82-6.14 | -2.7      | -3.99  | 10.68              | -27.62-28.3   | 24.66              | 23.4   | 4.77               | 18.5-36.2  |
|                   | USM-1  | 10               | 5.53 | 5.41   | 0.35               | 5.86-6.2  | 12.09     | 6.2    | 19.83              | -7.76-49.61   | 25.22              | 25.25  | 2.52               | 20.6-28.5  |
|                   | USM-2  | 10               | 4.99 | 4.78   | 0.67               | 4.55-6.69 | 7.35      | -17.35 | 87.19              | 55.55-251.2   | 33.72              | 33.1   | 5.53               | 25.3-44.9  |
|                   | USM-3  | 8                | 4.76 | 4.73   | 0.34               | 4.44-4.84 | -20.57    | -19.64 | 20.08              | -60.34-8.4    | 30.9               | 30.9   | 5.57               | 24.4-39.1  |
|                   | USM-4  | 4                | 4.67 | 4.63   | 0.26               | 4.41-5.01 | -21.43    | -24.35 | 10.7               | 6.38-(-30.6)  | 30.38              | 32.45  | 7.26               | 20.3-36.3  |
| Post-Construction | DSC    | 8                | 6.27 | 6.39   | 0.48               | 5.57-6.75 | 20.63     | 17.01  | 13.25              | 8.37-46.6     | 19.21              | 18.65  | 4.03               | 13-26.6    |
|                   | DSC-1  | 5                | 6.41 | 6.54   | 0.38               | 5.74-6.65 | 16.04     | 13.95  | 6.34               | 11.65-27.17   | 22.7               | 18.31  | 11.37              | 13.2-42.3  |
|                   | DSC-2  | 5                | 6.4  | 6.57   | 0.47               | 6.56-6.66 | 16.84     | 14.79  | 8.08               | 10.24-30.6    | 18.82              | 19.91  | 3.78               | 13.1-22.7  |
|                   | DSC-3  | 3                | 6.4  | 6.42   | 0.09               | 6.31-6.48 | 16.91     | 12.39  | 8.38               | 11.77-26.58   | 19.46              | 19.79  | 3.21               | 16.1-22.5  |
|                   | DSC-4  | 2                | 6.32 | 6.32   | 0.22               | 6.17-6.48 | 17.2      | 17.2   | 9.35               | 10.58-23.81   | 20.45              | 20.45  | 2.19               | 18.9-22    |
|                   | DSM    | 8                | 6.19 | 6.56   | 0.63               | 5.09-6.69 | 16.91     | 12.03  | 11.94              | 8.27-36.2     | 23.83              | 24.85  | 4.83               | 14.7-28.4  |
|                   | DSM-1  | 6                | 6.32 | 6.49   | 0.57               | 5.53-6.87 | 42        | 13.73  | 70.83              | 10.71-186.5   | 25.58              | 27.95  | 4.86               | 16.9-29.4  |
|                   | DSM-2  | 5                | 5.49 | 5.88   | 0.57               | 4.82-5.92 | 10.64     | 10.46  | 2.27               | 8.4-13.06     | 30.7               | 34.5   | 7.7                | 19-37.8    |
|                   | DSM-3  | 2                | 4.99 | 4.99   | 0.08               | 4.93-5.05 | 8.33      | 8.33   | 0.32               | 8.1-8.55      | 30.6               | 30.6   | 3.81               | 27.9-33.3  |
|                   | DSM-4  | 1                | 5.01 | 5.01   | 0                  | 5.01      | 9.54      | 9.54   | 0                  | 9.54          | 29.2               | 29.2   | 0                  | 29.2       |
|                   | USC    | 8                | 6.36 | 6.5    | 0.49               | 5.58-6.59 | 16.96     | 11.59  | 11.18              | 10.02-41.47   | 20.68              | 20.5   | 3.74               | 14-26.5    |
|                   | USC-1  | 6                | 6.55 | 6.69   | 0.46               | 5.72-6.95 | 16.62     | 15.03  | 6.06               | 11.62-28.33   | 26.35              | 22.6   | 11.93              | 15.9-49.2  |
|                   | USC-2  | 4                | 6.34 | 6.48   | 0.37               | 5.79-6.6  | 16.33     | 12.8   | 8.42               | 10.83-28.88   | 20.18              | 20.75  | 4.31               | 14.8-24.4  |
|                   | USC-3  | 3                | 6.24 | 6.24   | 0.18               | 6.11-6.37 | 12.81     | 11.29  | 3                  | 10.88-16.26   | 20.9               | 22.1   | 2.43               | 18.1-22.5  |
|                   | USC-4  | 2                | 6.27 | 6.27   | 0.11               | 6.2-6.34  | 10.1      | 10.1   | 2.74               | 8.16-12.04    | 23.9               | 23.9   | 6.22               | 19.5-28.3  |
|                   | USM    | 8                | 5.49 | 5.67   | 0.54               | 4.52-6.08 | 8.87      | 11.58  | 5.97               | -2.12-13.32   | 20.28              | 20.4   | 3.36               | 13.5-24.2  |
|                   | USM-1  | 6                | 5.69 | 5.35   | 0.9                | 4.61-6.89 | 13.32     | 12.82  | 3.69               | 8.94-18.53    | 22.72              | 23.9   | 4.79               | 14.9-27.1  |
|                   | USM-2  | 4                | 4.81 | 4.77   | 0.36               | 4.42-5.28 | 17.3      | 8.81   | 14.61              | -20.18-9.48   | 30.03              | 28.9   | 5.26               | 25-37.3    |
|                   | USM-3  | 5                | 4.62 | 4.59   | 0.35               | 4.19-5.17 | 3.9       | 9.83   | 13.95              | -21.01-10.4   | 25.3               | 25.7   | 7.79               | 16.5-34.2  |
|                   | USM-4  | 1                | 4.77 | 4.77   | 0                  | 4.77      | 8.21      | 8.21   | 0                  | 8.21          | 25.7               | 25.7   | 0                  | 25.7       |
|                   | RP     | 8                | 6.24 | 6.45   | 0.48               | 5.39-6.69 | 16.27     | 13.32  | 6.55               | 10.45-28.07   | 14.53              | 15.41  | 3.26               | 9.2-17.75  |

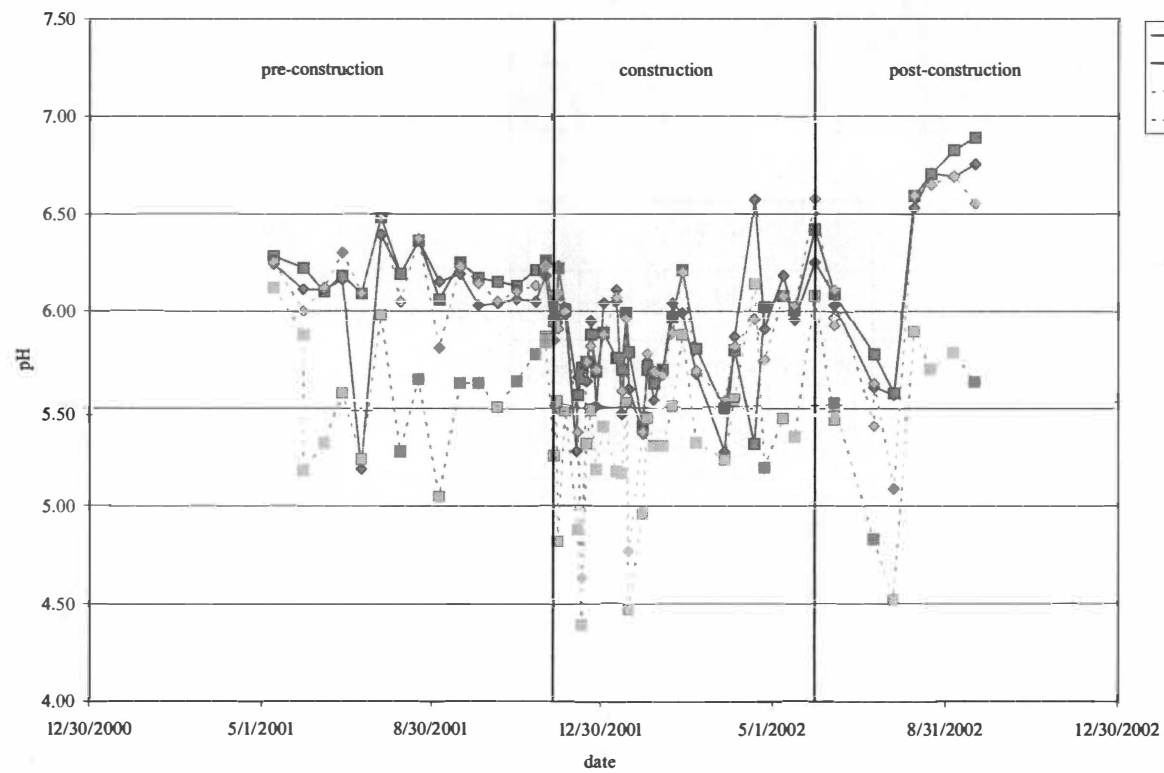


Figure 4-1. Baseflow grab sample pH at primary sites

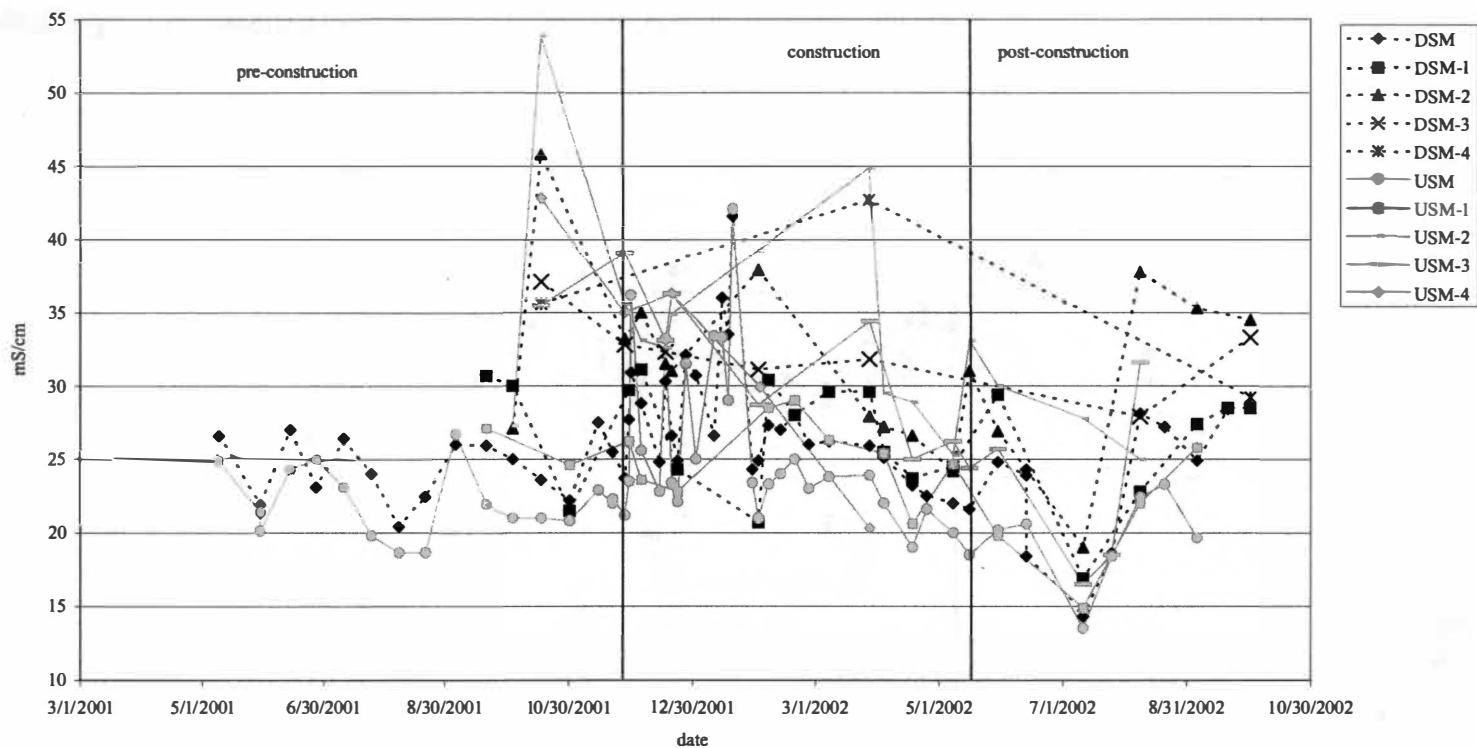


Figure 4-2. Conductivity of Morton Mountain Tunnel grab samples vs. date

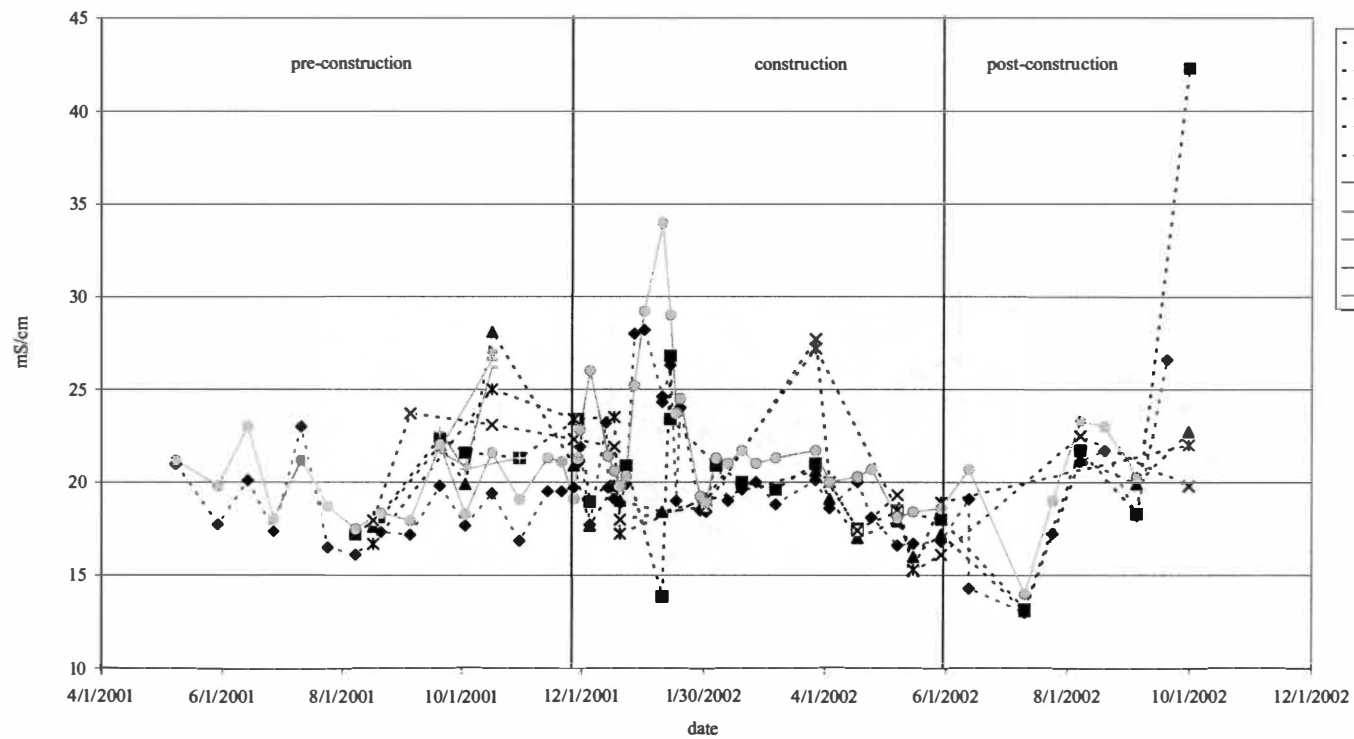


Figure 4-3. Conductivity of Chimney Tops Tunnel grab samples vs. date

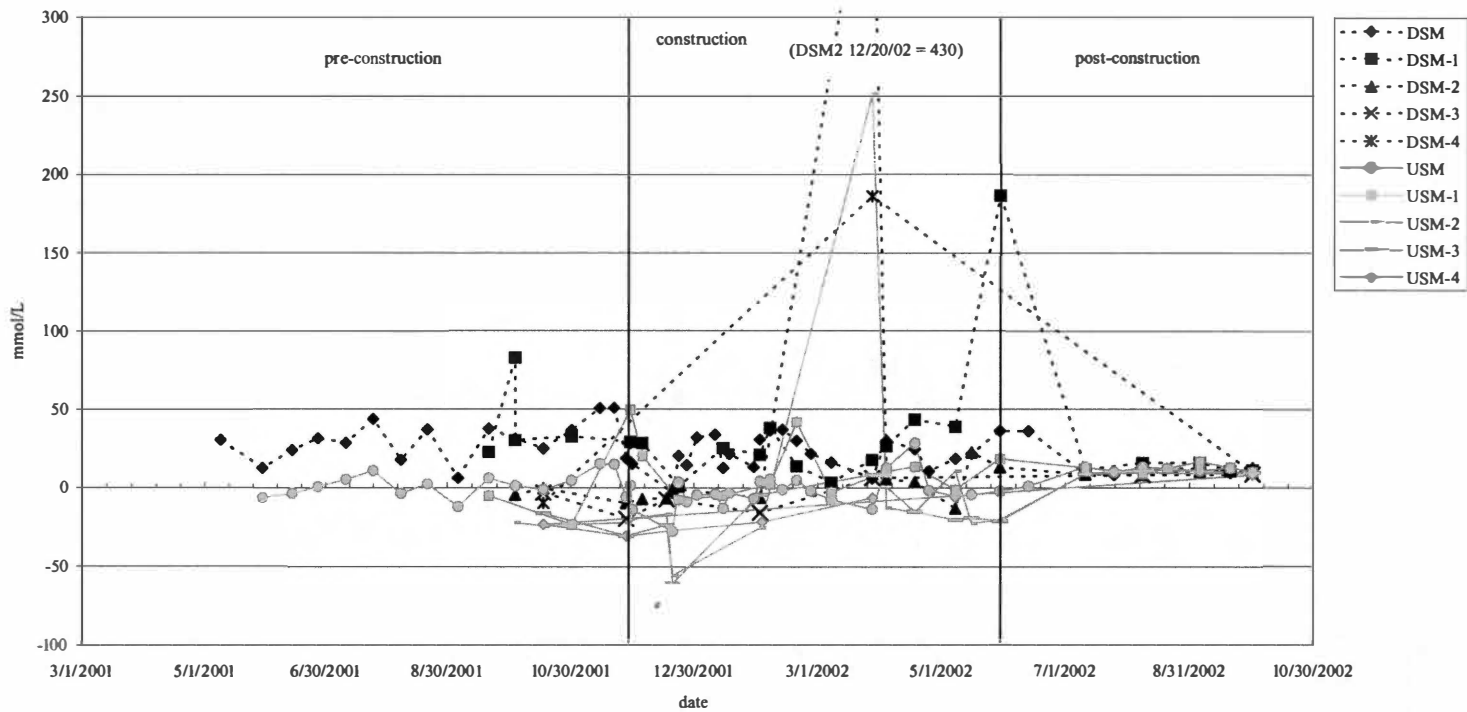


Figure 4-4. ANC of Morton Mountain Tunnel grab samples vs. date

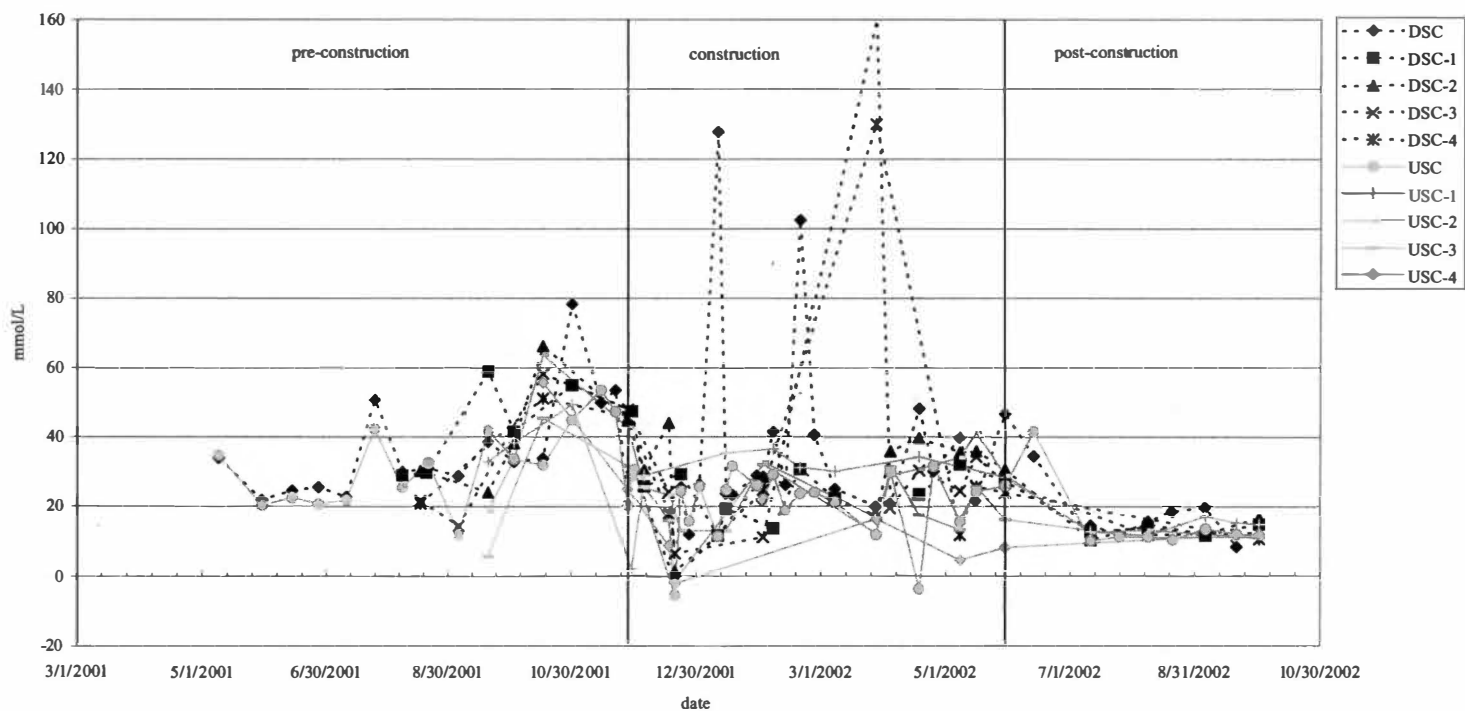


Figure 4-5. ANC of Chimney Tops Tunnel grab samples vs. date

The pH, conductivity, ANC, hydrogen ion, magnesium, and calcium of stream baseflow grab samples were tested for a statistical difference (Mann-Whitney test) between the upstream and downstream stations (see Table 4-2) at each tunnel. The samples were grouped according to their collection period (pre-construction, construction and post-construction periods). Table 4-2 shows that there were some statistical differences at the 95% confidence interval ( $p = 0.05$ ) between upstream and downstream parameters at the Chimney Tops Tunnel, and there were statistically significant differences in all parameters at Morton. Generally, the parameters that differed during construction are the same parameters that differed during the pre-construction period and imply that differences may not be due to construction.

One factor that could result in differences between upstream and downstream analyte measurements would be spatial variation or areal distribution of rainfall. For instance, a convection storm might result in rainfall in the drainage basin that drains the Morton Tunnel site while the upstream basin remains dry. This could cause water quality changes at the downstream site. Also, hydrologic anomalies from contributing sub-basins between the sampling points may result in variation. Possible sampling errors and small sample sizes are other confounding considerations.

The fact that two major streams come together between the two Chimney Tops sampling stations could explain differences between these stations. Baseflow conditions were collected in both streams during the post-construction monitoring period. Conductivity, ANC and pH were compared using Wilcoxon signed ranks analysis. Road Prong was found to have lower pH values ( $p=0.036$ ) and lower conductivities ( $p=0.012$ ) than Walker Camp Prong. No difference was detected in ANC.

Table 4-2. Statistical differences between upstream and downstream baseflow grab sample chemistry

| Objective                                                                          | Location     | Period                             | Analyte      | Statistical Test | Result        | p-value |
|------------------------------------------------------------------------------------|--------------|------------------------------------|--------------|------------------|---------------|---------|
| Examine differences between upstream and downstream baseflow grab sample chemistry | Chimney Tops | Pre-construction<br>(n = 15 vs 15) | pH           | Mann-Whitney     | no difference | 0.123   |
|                                                                                    |              |                                    | conductivity | Mann-Whitney     | US higher     | 0.032   |
|                                                                                    |              |                                    | ANC          | Mann-Whitney     | no difference | 0.461   |
|                                                                                    |              |                                    | H+ ion       | Mann-Whitney     | no difference | 0.123   |
|                                                                                    |              |                                    | Mg           | Mann-Whitney     | US higher     | 0       |
|                                                                                    |              |                                    | Ca           | Mann-Whitney     | no difference | 0.074   |
|                                                                                    |              | Construction<br>(n = 23 vs 23)     | pH           | Mann-Whitney     | no difference | 0.935   |
|                                                                                    |              |                                    | conductivity | Mann-Whitney     | US higher     | 0.043   |
|                                                                                    |              |                                    | ANC          | Mann-Whitney     | no difference | 0.053   |
|                                                                                    |              |                                    | H+ ion       | Mann-Whitney     | no difference | 0.935   |
|                                                                                    |              |                                    | Mg           | Mann-Whitney     | US higher     | 0       |
|                                                                                    |              |                                    | Ca           | Mann-Whitney     | no difference | 0.245   |
|                                                                                    |              | Post-construction<br>(n = 8 vs 8)  | pH           | Mann-Whitney     | no difference | 0.645   |
|                                                                                    |              |                                    | conductivity | Mann-Whitney     | no difference | 0.442   |
|                                                                                    |              |                                    | ANC          | Mann-Whitney     | no difference | 0.505   |
|                                                                                    |              |                                    | H+ ion       | Mann-Whitney     | no difference | 0.593   |
|                                                                                    |              |                                    | Mg           | Mann-Whitney     | no difference | 0.195   |
|                                                                                    |              |                                    | Ca           | Mann-Whitney     | no difference | 0.382   |
|                                                                                    | Morton       | Pre-construction<br>(n = 13 vs 15) | pH           | Mann-Whitney     | DS higher     | 0       |
|                                                                                    |              |                                    | conductivity | Mann-Whitney     | DS higher     | 0.004   |
|                                                                                    |              |                                    | ANC          | Mann-Whitney     | DS higher     | 0       |
|                                                                                    |              |                                    | H+ ion       | Mann-Whitney     | US higher     | 0       |
|                                                                                    |              |                                    | Mg           | Mann-Whitney     | DS higher     | 0.001   |
|                                                                                    |              |                                    | Ca           | Mann-Whitney     | DS higher     | 0       |
|                                                                                    |              | Construction<br>(n = 23 vs 23)     | pH           | Mann-Whitney     | DS higher     | 0       |
|                                                                                    |              |                                    | conductivity | Mann-Whitney     | DS higher     | 0.017   |
|                                                                                    |              |                                    | ANC          | Mann-Whitney     | DS higher     | 0       |
|                                                                                    |              |                                    | H+ ion       | Mann-Whitney     | US higher     | 0       |
|                                                                                    |              |                                    | Mg           | Mann-Whitney     | DS higher     | 0       |
|                                                                                    |              |                                    | Ca           | Mann-Whitney     | DS higher     | 0       |
|                                                                                    |              | Post-construction<br>(n = 8 vs 8)  | pH           | Mann-Whitney     | DS higher     | 0.05    |
|                                                                                    |              |                                    | conductivity | Mann-Whitney     | no difference | 0.065   |
|                                                                                    |              |                                    | ANC          | Mann-Whitney     | no difference | 0.798   |
|                                                                                    |              |                                    | H+ ion       | Mann-Whitney     | US higher     | 0       |
|                                                                                    |              |                                    | Mg           | Mann-Whitney     | DS higher     | 0.001   |
|                                                                                    |              |                                    | Ca           | Mann-Whitney     | DS higher     | 0.05    |

Note: US represents upstream and DS represents downstream. Samples were tested at 95% confidence level

Results for statistical tests comparing baseflow samples taken at the same location during different collection periods are shown in Table 4-3. For example, grab samples taken upstream of the Morton Tunnel (USM) prior to construction were compared to samples taken upstream of the Morton Tunnel during construction. Importantly, multiple analytes changed at USM between the pre- and during stages. Since USM is above any of the impacts of all construction, the changes must be due to some factor (perhaps season) other than construction and again imply that changes in the water quality at the construction influenced sites may not be due to construction.

Figures 4-6, 4-7, 4-8 and 4-9 show stream grab and passive pH as a function of time. Each of the stations was tested for a difference between baseflow grab and passive storm sample (a composite of the 4 levels) chemistry for each of the collection periods (Table 4-4). Results in Table 4-4 indicate that the Morton stations are more likely than the Chimney Tops stations to vary in water chemistry during storm events (See Figure 4-10 for daily precipitation totals). However, passive samples are not collected immediately after a storm and it is not known to what extent the pH may change before they are collected. This should be considered when comparing baseflow grab and storm passive samples.

### ***Paired Differences***

Stream pH tended to decline during the construction period (as shown in the preceding figures). Given that potential stream pH alteration due to construction was a major concern for this monitoring project, it is important to try to account for the variation that was observed (construction influence or seasonal variation). Paired differences of upstream vs. downstream samples for both tunnel sites were examined to

Table 4-3. Statistical differences between time periods for baseflow grab samples at the same sampling location

| Objective                                                              | Location | Period                             | Analyte      | Statistical Test | Result        | p-value |
|------------------------------------------------------------------------|----------|------------------------------------|--------------|------------------|---------------|---------|
| Examine differences between time periods at the same sampling location | DSC      | Pre-construction vs. Construction  | pH           | Mann-Whitney     | pre- higher   | 0.001   |
|                                                                        |          |                                    | conductivity | Mann-Whitney     | con higher    | 0.044   |
|                                                                        |          |                                    | ANC          | Mann-Whitney     | no difference | 0.107   |
|                                                                        |          |                                    | H+ ion       | Mann-Whitney     | con higher    | 0.001   |
|                                                                        |          |                                    | Mg           | Mann-Whitney     | no difference | 0.947   |
|                                                                        |          |                                    | Ca           | Mann-Whitney     | no difference | 0.165   |
|                                                                        |          | Construction vs. Post-Construction | pH           | Mann-Whitney     | post-higher   | 0.02    |
|                                                                        |          |                                    | conductivity | Mann-Whitney     | no difference | 0.406   |
|                                                                        |          |                                    | ANC          | Mann-Whitney     | con higher    | 0.038   |
|                                                                        |          |                                    | H+ ion       | Mann-Whitney     | con higher    | 0.02    |
|                                                                        |          |                                    | Mg           | Mann-Whitney     | post-higher   | 0.053   |
|                                                                        |          |                                    | Ca           | Mann-Whitney     | post-higher   | 0.023   |
|                                                                        | USC      | Pre-construction vs. Construction  | pH           | Mann-Whitney     | pre- higher   | 0       |
|                                                                        |          |                                    | conductivity | Mann-Whitney     | no difference | 0.074   |
|                                                                        |          |                                    | ANC          | Mann-Whitney     | pre- higher   | 0.007   |
|                                                                        |          |                                    | H+ ion       | Mann-Whitney     | con higher    | 0       |
|                                                                        |          |                                    | Mg           | Mann-Whitney     | no difference | 0.982   |
|                                                                        |          |                                    | Ca           | Mann-Whitney     | no difference | 0.621   |
|                                                                        |          | Construction vs. Post-Construction | pH           | Mann-Whitney     | post-higher   | 0.009   |
|                                                                        |          |                                    | conductivity | Mann-Whitney     | no difference | 0.557   |
|                                                                        |          |                                    | ANC          | Mann-Whitney     | no difference | 0.1     |
|                                                                        |          |                                    | H+ ion       | Mann-Whitney     | con higher    | 0.009   |
|                                                                        |          |                                    | Mg           | Mann-Whitney     | post-higher   | 0.001   |
|                                                                        |          |                                    | Ca           | Mann-Whitney     | post-higher   | 0.001   |
|                                                                        | DSM      | Pre-construction vs. Construction  | pH           | Mann-Whitney     | pre- higher   | 0       |
|                                                                        |          |                                    | conductivity | Mann-Whitney     | no difference | 0.062   |
|                                                                        |          |                                    | ANC          | Mann-Whitney     | pre- higher   | 0.018   |
|                                                                        |          |                                    | H+ ion       | Mann-Whitney     | con higher    | 0       |
|                                                                        |          |                                    | Mg           | Mann-Whitney     | no difference | 0.215   |
|                                                                        |          |                                    | Ca           | Mann-Whitney     | no difference | 0.716   |
|                                                                        |          | Construction vs. Post-Construction | pH           | Mann-Whitney     | no difference | 0.08    |
|                                                                        |          |                                    | conductivity | Mann-Whitney     | no difference | 0.312   |
|                                                                        |          |                                    | ANC          | Mann-Whitney     | no difference | 0.121   |
|                                                                        |          |                                    | H+ ion       | Mann-Whitney     | no difference | 0.08    |
|                                                                        |          |                                    | Mg           | Mann-Whitney     | post-higher   | 0.005   |
|                                                                        |          |                                    | Ca           | Mann-Whitney     | no difference | 0.172   |
|                                                                        | USM      | Pre-construction vs. Construction  | pH           | Mann-Whitney     | pre- higher   | 0.05    |
|                                                                        |          |                                    | conductivity | Mann-Whitney     | con higher    | 0.045   |
|                                                                        |          |                                    | ANC          | Mann-Whitney     | pre- higher   | 0.028   |
|                                                                        |          |                                    | H+ ion       | Mann-Whitney     | con higher    | 0.05    |
|                                                                        |          |                                    | Mg           | Mann-Whitney     | no difference | 0.283   |
|                                                                        |          |                                    | Ca           | Mann-Whitney     | no difference | 0.696   |
|                                                                        |          | Construction vs. Post-Construction | pH           | Mann-Whitney     | no difference | 0.183   |
|                                                                        |          |                                    | conductivity | Mann-Whitney     | con higher    | 0.021   |
|                                                                        |          |                                    | ANC          | Mann-Whitney     | post-higher   | 0.002   |
|                                                                        |          |                                    | H+ ion       | Mann-Whitney     | no difference | 0.183   |
|                                                                        |          |                                    | Mg           | Mann-Whitney     | no difference | 0.617   |
|                                                                        |          |                                    | Ca           | Mann-Whitney     | no difference | 0.362   |

Note: 1. "pre-higher" means that the pre-construction samples showed higher concentrations compared to the construction samples tested at the 5% level. 2. "con higher" means that the construction samples showed higher concentrations compared to the pre-construction samples tested at the 5% level.

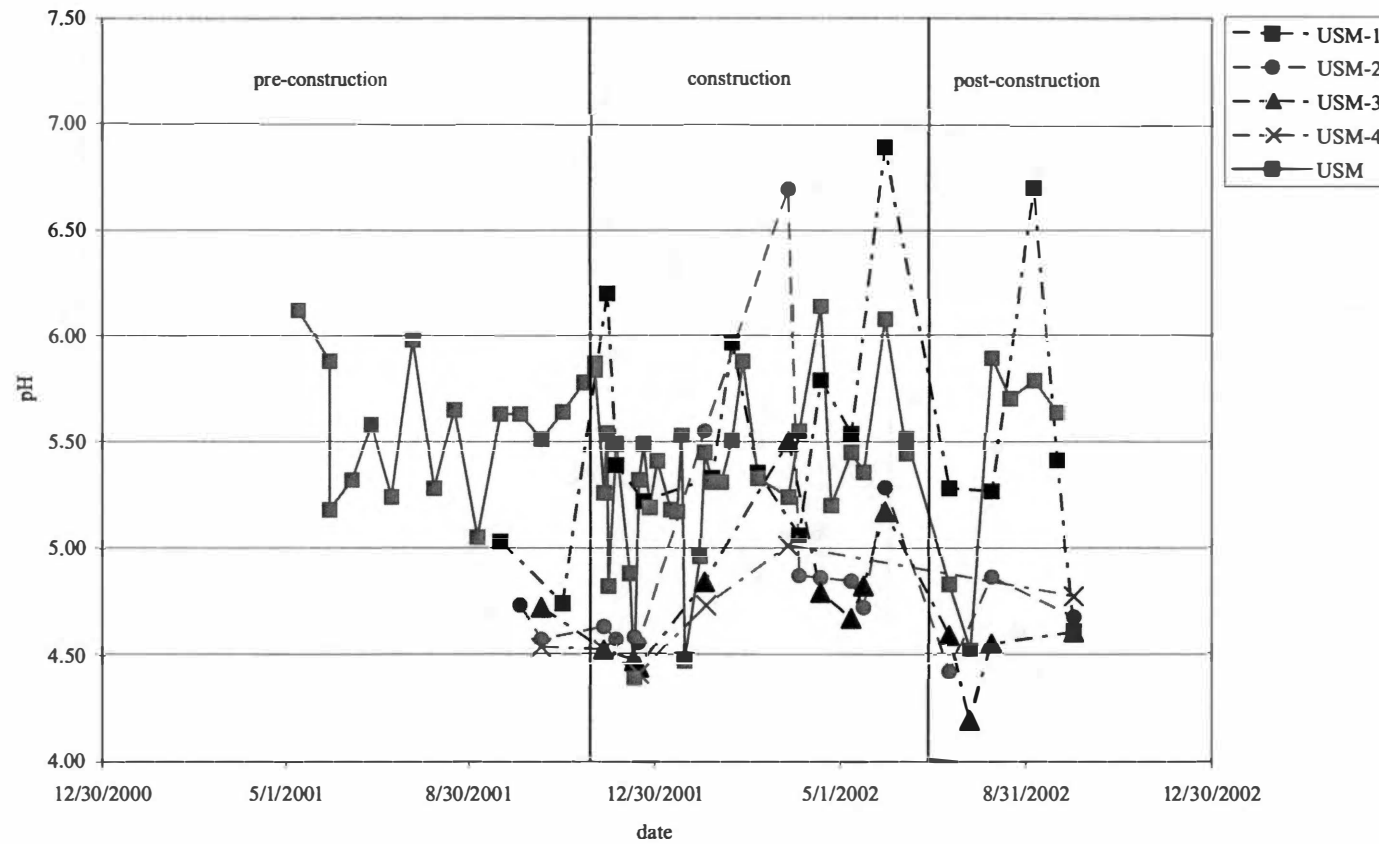


Figure 4-6. Upstream Morton Mountain Tunnel grab and passive pH vs. date

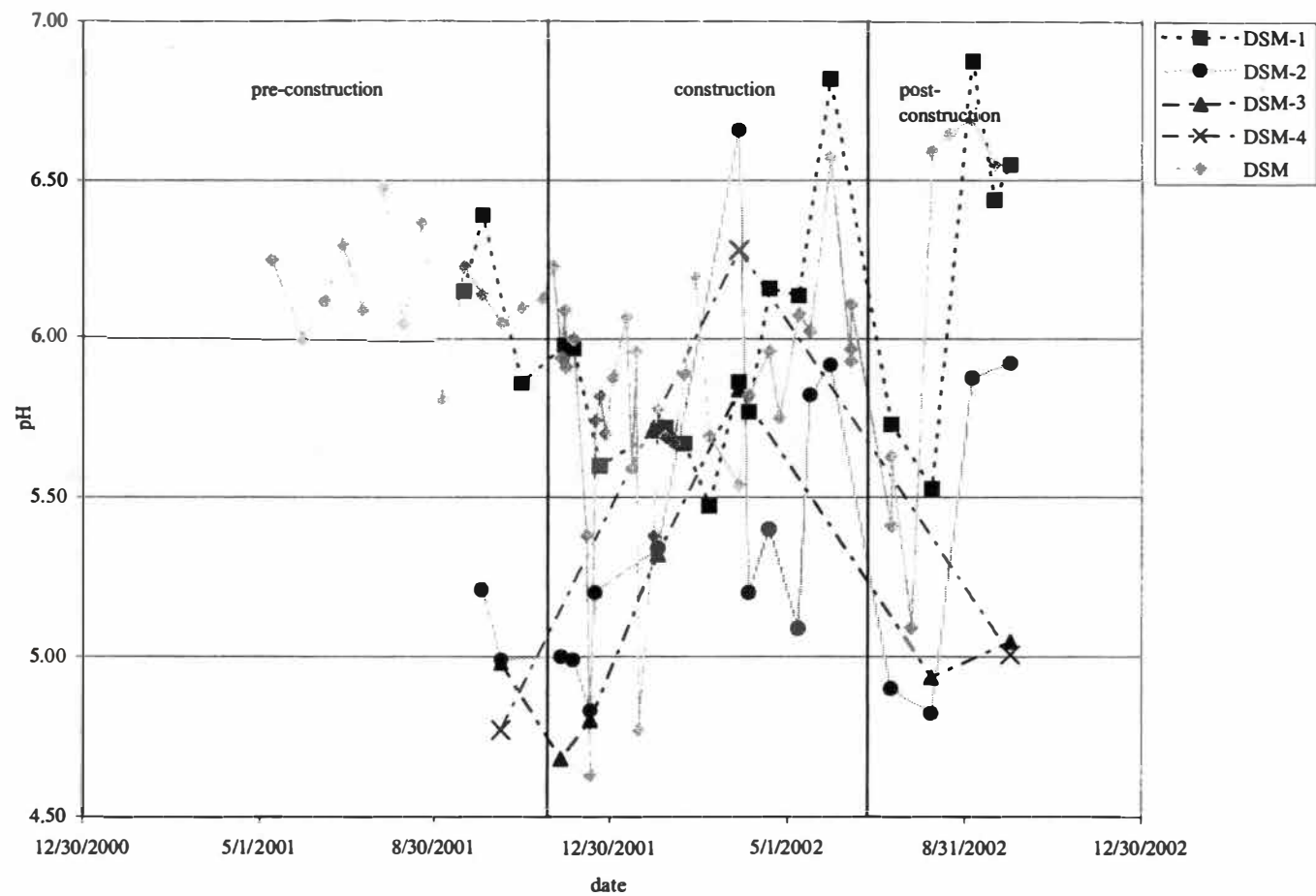


Figure 4-7. Downstream Morton Mountain Tunnel grab and passive pH vs. date

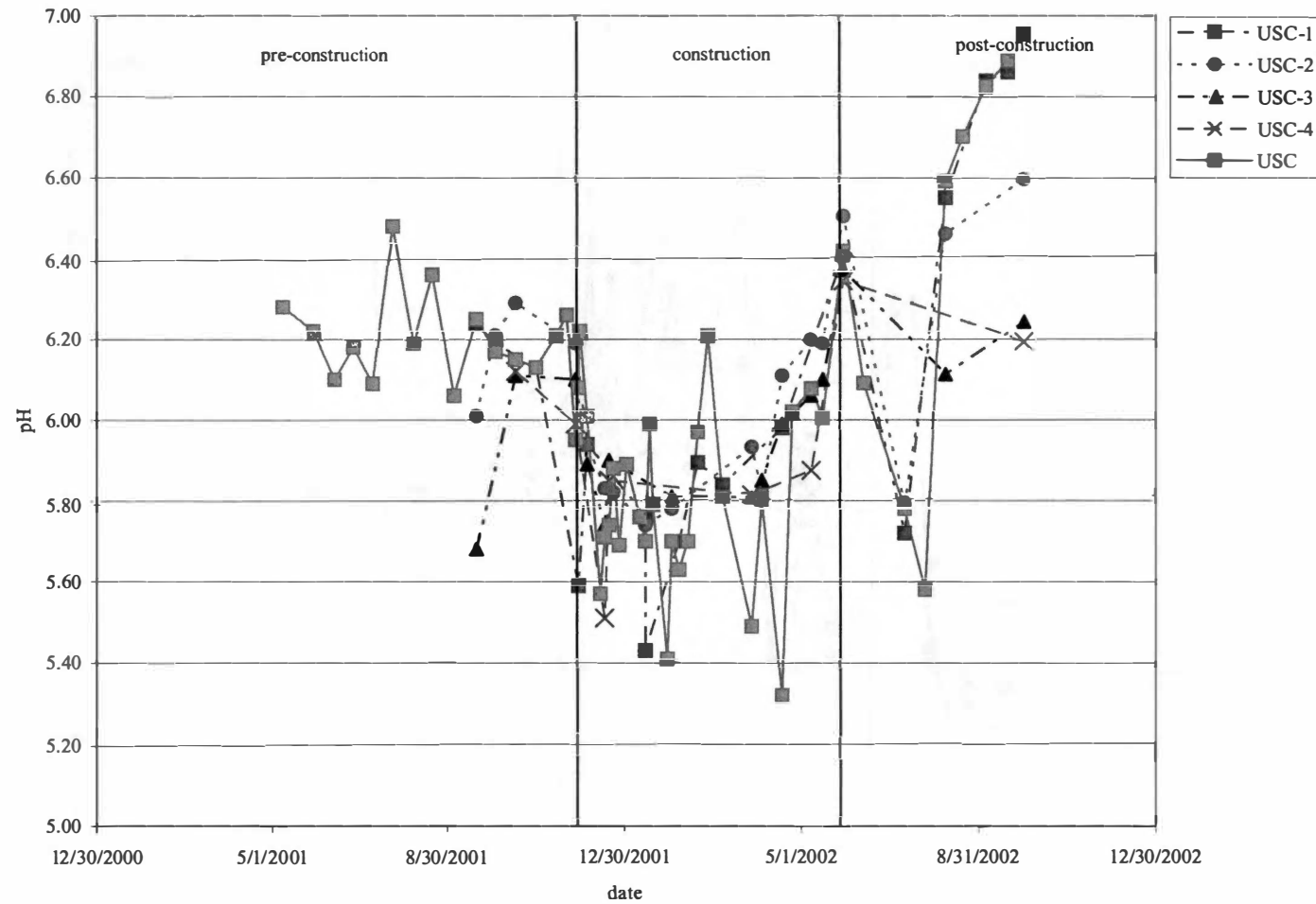


Figure 4-8. Upstream Chimney Tops Tunnel grab and passive pH vs. date

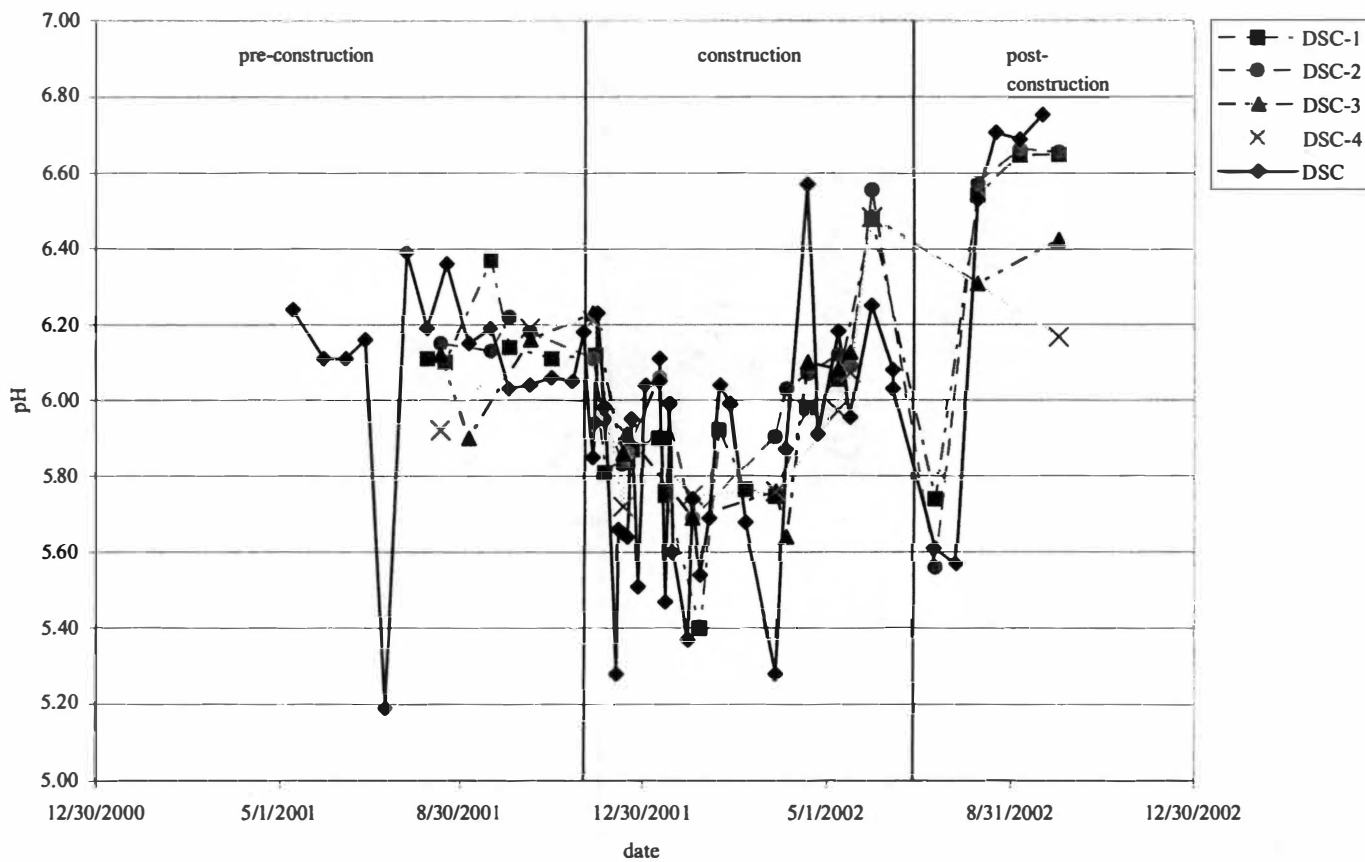


Figure 4-9. Downstream Chimney Tops Tunnel grab and passive pH vs. date

Table 4-4. Statistical differences between baseflow grab and storm passive sample chemistry

| Objective                                                                           | Location | Period                          | Analyte      | Statistical Test | Result          | p-value |
|-------------------------------------------------------------------------------------|----------|---------------------------------|--------------|------------------|-----------------|---------|
| Examine differences between baseflow grab sample and storm passive sample chemistry | DSC      | Pre-construction (n = 15 vs 14) | pH           | Mann-Whitney     | no difference   | 0.923   |
|                                                                                     |          |                                 | conductivity | Mann-Whitney     | storm higher    | 0.025   |
|                                                                                     |          |                                 | ANC          | Mann-Whitney     | no difference   | 0.914   |
|                                                                                     |          |                                 | H+ ion       | Mann-Whitney     | no difference   | 0.923   |
|                                                                                     |          |                                 | Mg           | Mann-Whitney     | no difference   | 0.788   |
|                                                                                     |          |                                 | Ca           | Mann-Whitney     | no difference   | 0.337   |
|                                                                                     |          | Construction (n = 23 vs 35)     | pH           | Mann-Whitney     | no difference   | 0.262   |
|                                                                                     |          |                                 | conductivity | Mann-Whitney     | no difference   | 0.365   |
|                                                                                     |          |                                 | ANC          | Mann-Whitney     | no difference   | 0.695   |
|                                                                                     |          |                                 | H+ ion       | Mann-Whitney     | no difference   | 0.262   |
|                                                                                     |          |                                 | Mg           | Mann-Whitney     | no difference   | 0.991   |
|                                                                                     |          |                                 | Ca           | Mann-Whitney     | no difference   | 0.926   |
|                                                                                     |          | Post-construction (n = 8 vs 15) | pH           | Mann-Whitney     | no difference   | 1       |
|                                                                                     |          |                                 | conductivity | Mann-Whitney     | no difference   | 0.624   |
|                                                                                     |          |                                 | ANC          | Mann-Whitney     | no difference   | 0.728   |
|                                                                                     |          |                                 | H+ ion       | Mann-Whitney     | no difference   | 1       |
|                                                                                     |          |                                 | Mg           | Mann-Whitney     | no difference   | 0.238   |
|                                                                                     |          |                                 | Ca           | Mann-Whitney     | no difference   | 0.925   |
|                                                                                     | USC      | Pre-construction (n = 15 vs 12) | pH           | Mann-Whitney     | no difference   | 0.269   |
|                                                                                     |          |                                 | conductivity | Mann-Whitney     | storm higher    | 0.006   |
|                                                                                     |          |                                 | ANC          | Mann-Whitney     | no difference   | 0.347   |
|                                                                                     |          |                                 | H+ ion       | Mann-Whitney     | no difference   | 0.269   |
|                                                                                     |          |                                 | Mg           | Mann-Whitney     | no difference   | 0.558   |
|                                                                                     |          |                                 | Ca           | Mann-Whitney     | no difference   | 0.682   |
|                                                                                     |          | Construction (n = 23 vs 30)     | pH           | Mann-Whitney     | no difference   | 0.276   |
|                                                                                     |          |                                 | conductivity | Mann-Whitney     | no difference   | 0.782   |
|                                                                                     |          |                                 | ANC          | Mann-Whitney     | no difference   | 0.276   |
|                                                                                     |          |                                 | H+ ion       | Mann-Whitney     | no difference   | 0.276   |
|                                                                                     |          |                                 | Mg           | Mann-Whitney     | no difference   | 0.566   |
|                                                                                     |          |                                 | Ca           | Mann-Whitney     | storm higher    | 0.002   |
|                                                                                     |          | Post-construction (n = 8 vs 15) | pH           | Mann-Whitney     | no difference   | 1       |
|                                                                                     |          |                                 | conductivity | Mann-Whitney     | no difference   | 0.602   |
|                                                                                     |          |                                 | ANC          | Mann-Whitney     | no difference   | 0.548   |
|                                                                                     |          |                                 | H+ ion       | Mann-Whitney     | no difference   | 0.987   |
|                                                                                     |          |                                 | Mg           | Mann-Whitney     | no difference   | 0.213   |
|                                                                                     |          |                                 | Ca           | Mann-Whitney     | no difference   | 0.392   |
|                                                                                     | DSM      | Pre-construction (n = 15 vs 9)  | pH           | Mann-Whitney     | baseflow higher | 0.027   |
|                                                                                     |          |                                 | conductivity | Mann-Whitney     | storm higher    | 0.002   |
|                                                                                     |          |                                 | ANC          | Mann-Whitney     | no difference   | 0.087   |
|                                                                                     |          |                                 | H+ ion       | Mann-Whitney     | storm higher    | 0.027   |
|                                                                                     |          |                                 | Mg           | Mann-Whitney     | storm higher    | 0.011   |
|                                                                                     |          |                                 | Ca           | Mann-Whitney     | no difference   | 0.059   |
|                                                                                     |          | Construction (n = 23 vs 26)     | pH           | Mann-Whitney     | baseflow higher | 0.035   |
|                                                                                     |          |                                 | conductivity | Mann-Whitney     | storm higher    | 0.02    |
|                                                                                     |          |                                 | ANC          | Mann-Whitney     | no difference   | 0.087   |
|                                                                                     |          |                                 | H+ ion       | Mann-Whitney     | storm higher    | 0.034   |
|                                                                                     |          |                                 | Mg           | Mann-Whitney     | storm higher    | 0.015   |
|                                                                                     |          |                                 | Ca           | Mann-Whitney     | no difference   | 0.15    |
|                                                                                     |          | Post-construction (n = 8 vs 14) | pH           | Mann-Whitney     | no difference   | 0.114   |
|                                                                                     |          |                                 | conductivity | Mann-Whitney     | storm higher    | 0.04    |
|                                                                                     |          |                                 | ANC          | Mann-Whitney     | no difference   | 0.714   |
|                                                                                     |          |                                 | H+ ion       | Mann-Whitney     | no difference   | 0.114   |
|                                                                                     |          |                                 | Mg           | Mann-Whitney     | no difference   | 0.441   |
|                                                                                     |          |                                 | Ca           | Mann-Whitney     | no difference   | 0.238   |
|                                                                                     | USM      | Pre-construction (n = 13 vs 12) | pH           | Mann-Whitney     | baseflow higher | 0       |
|                                                                                     |          |                                 | conductivity | Mann-Whitney     | storm higher    | 0       |
|                                                                                     |          |                                 | ANC          | Mann-Whitney     | baseflow higher | 0       |
|                                                                                     |          |                                 | H+ ion       | Mann-Whitney     | storm higher    | 0       |
|                                                                                     |          |                                 | Mg           | Mann-Whitney     | storm higher    | 0.014   |
|                                                                                     |          |                                 | Ca           | Mann-Whitney     | no difference   | 0.424   |
|                                                                                     |          | Construction (n = 23 vs 28)     | pH           | Mann-Whitney     | baseflow higher | 0.007   |
|                                                                                     |          |                                 | conductivity | Mann-Whitney     | storm higher    | 0       |
|                                                                                     |          |                                 | ANC          | Mann-Whitney     | no difference   | 0.096   |
|                                                                                     |          |                                 | H+ ion       | Mann-Whitney     | storm higher    | 0.007   |
|                                                                                     |          |                                 | Mg           | Mann-Whitney     | no difference   | 0.198   |
|                                                                                     |          |                                 | Ca           | Mann-Whitney     | no difference   | 0.757   |
|                                                                                     |          | Post-construction (n = 8 vs 15) | pH           | Mann-Whitney     | no difference   | 0.085   |
|                                                                                     |          |                                 | conductivity | Mann-Whitney     | storm higher    | 0.04    |
|                                                                                     |          |                                 | ANC          | Mann-Whitney     | no difference   | 0.548   |
|                                                                                     |          |                                 | H+ ion       | Mann-Whitney     | no difference   | 0.087   |
|                                                                                     |          |                                 | Mg           | Mann-Whitney     | no difference   | 0.392   |
|                                                                                     |          |                                 | Ca           | Mann-Whitney     | no difference   | 0.975   |

Note: "storm higher" means that the concentrations during the storm sampling were significantly higher compared to baseflow conditions

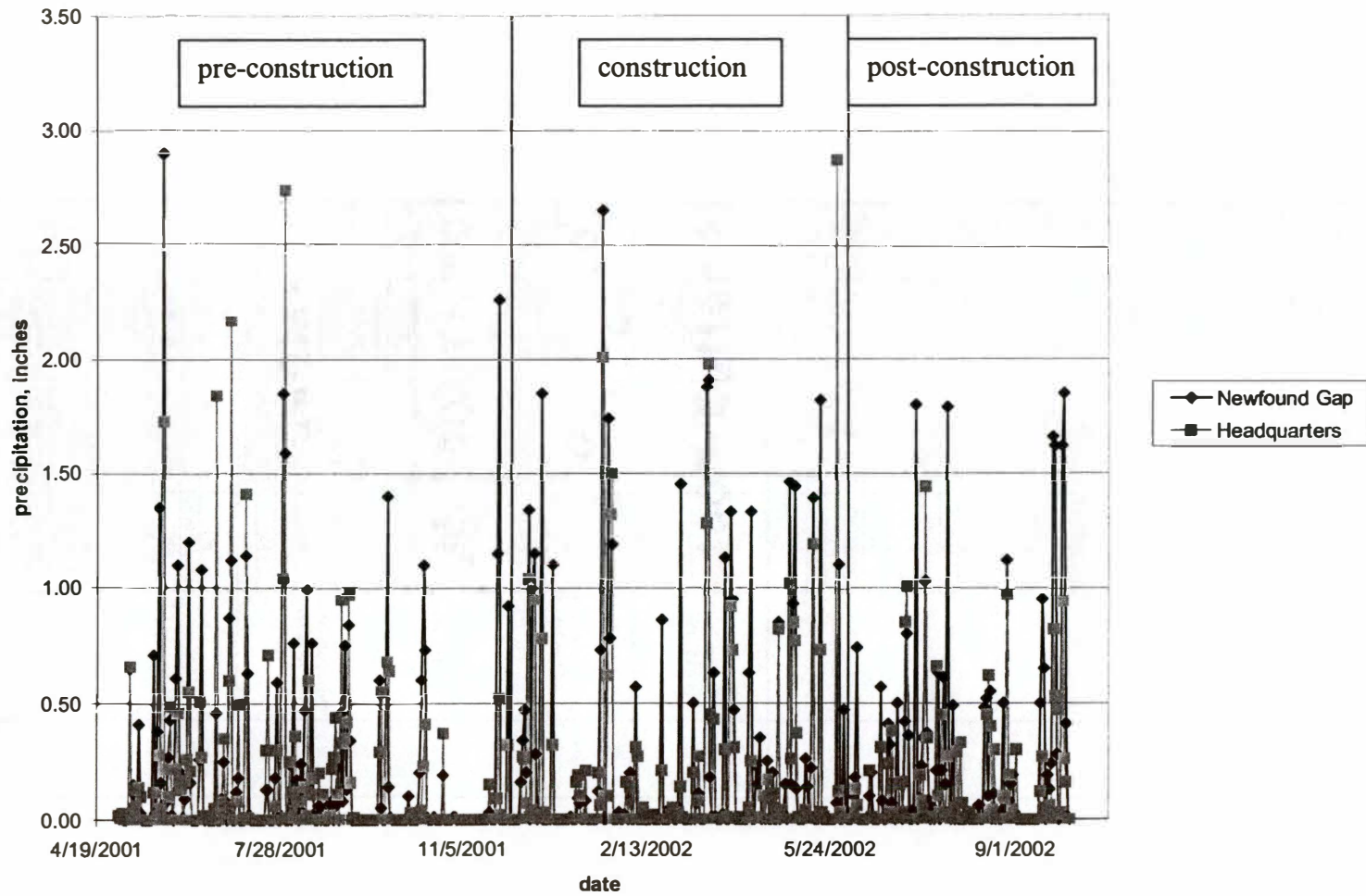


Figure 4-10. Precipitation data from Newfound Gap and Park Headquarters

see if these pH trends were a result of seasonal variation. The paired differences (pH, hydrogen ion concentration and calcium) for upstream and downstream grab samples were calculated for both tunnels by subtracting the upstream value from the downstream value for each tunnel for each collection date. The paired differences were then tested to see if their magnitudes were the same for pre-construction, construction, and post-construction. No analyte showed a statistically significant difference between pre- and during construction time periods for the Chimney Tops Tunnel stations, and pH was the only measurement showing a statistically significant difference between time periods for the Morton Mountain Tunnel stations ( $p=0.015$ ). Realizing that a significantly different magnitude of concentrations for the three time periods might result in a significant difference in paired differences, ratios of upstream and downstream concentrations for pH were examined in an attempt to normalize or filter out the magnitude of the concentrations. However, this normalization did not significantly change the outcome ( $p=0.017$ ).

The reduction in the amount that downstream pH increased between the Morton stations (0.63 for pre-construction vs. 0.46 for during construction) could be cause for concern. The results would mean that streams are maintaining a higher level of acidity at lower elevations. However, these differences are not attributable to road construction. Seasonal variation is likely responsible for the difference. As discussed below differences for nearby paired stream survey samples show this natural variation in differences.

Figure 4-11 shows the pH differences between paired samples at the upstream and downstream stations at both tunnels. The change is consistent (about zero) throughout

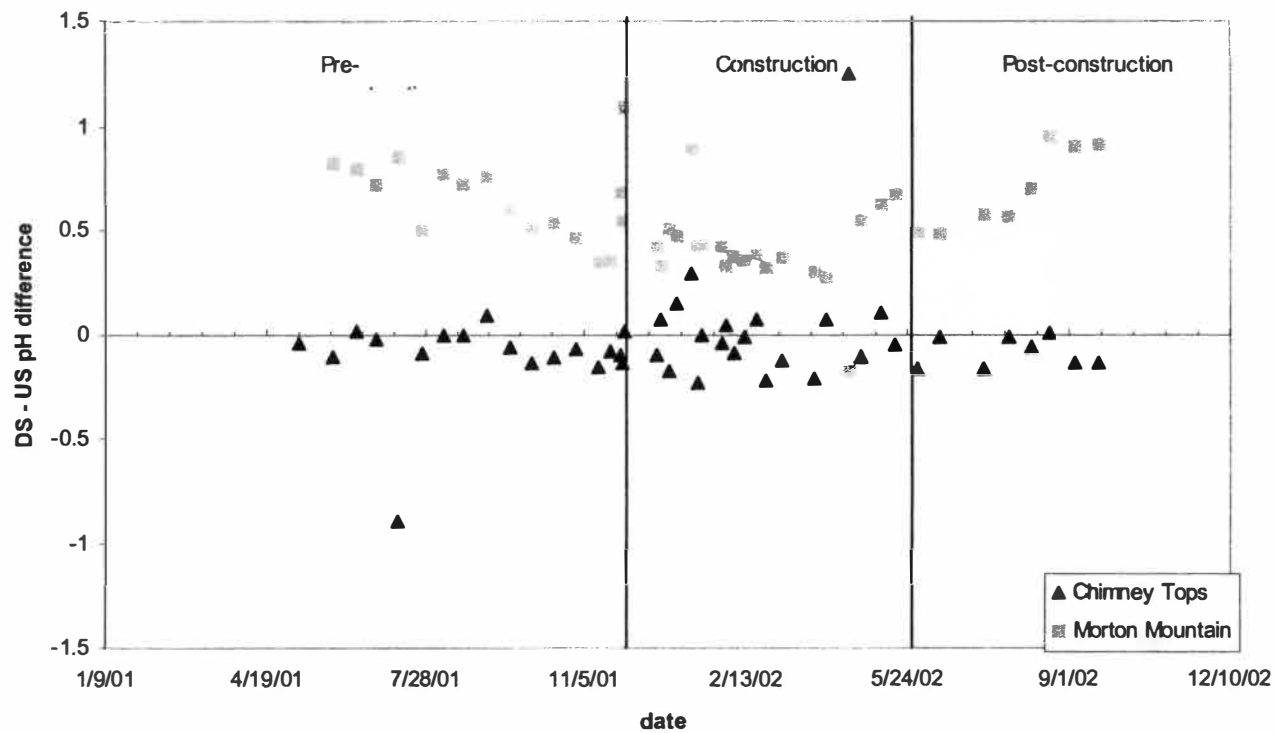


Figure 4-11. The pH differences (DS pH – US pH) in baseflow between upstream and downstream stations by event (examines paired differences)

sampling for the Chimneys Tunnel. However, a decrease in the differences between the upstream and downstream differences prior to and continuing into the construction period is observed for the Morton Tunnel. This gradual decrease in the pre-construction results would indicate that the statistically significant differences in the pH change between upstream and downstream stations are likely due to season rather than construction. If the changes had been the result of construction, the change would not have occurred until after construction had started.

To examine typical seasonal effects, data from two of the quarterly stream survey sites used in UT's ongoing Park-wide monitoring program were used to determine the natural influence of season on the paired differences (pH, hydrogen ion concentration and  $\text{SO}_4$ ) for upstream and downstream grab samples. Sulfate was chosen as a significant ion because calcium data were unavailable. June through October were classified as pre-construction months. November through May were classified as during-construction months. Sites 66 (WPLPR at the Chimney Tops Picnic Area) and 73 (Walker Camp Prong above Road Prong) were paired (See Figure 1-2 for sample locations). These sites showed a statistically significant difference in differences for pH and hydrogen ion concentrations for the two time periods ( $p=0.049$  and  $0.023$ , respectively). This is consistent with the differences observed at the Morton sites.

Potential erosion during construction and consequent high suspended solids concentrations in the streams was a major concern to all involved parties. Passive samplers were the primary method for monitoring suspended solids in the streams. Table 4-5 shows total suspended solids concentrations for the different time periods by site. Sample descriptors that end in E (DSCE for example) indicate that the sample was taken

Table 4-5. Total suspended solids summary chart by site

|                   | Sample | Mean mg/L | Median mg/L | Standard Deviation mg/L | Range mg/L | Number of Samples |
|-------------------|--------|-----------|-------------|-------------------------|------------|-------------------|
| Pre-construction  | USM-1  | 11        | 14          | 8.8                     | 1-22       | 5                 |
|                   | USM-2  | 24        | 11          | 26.6                    | 7-55       | 3                 |
|                   | USM-3  | 21        | 21          | 6.6                     | 16-25      | 2                 |
|                   | USM-4  | 44        | 44          | 42.2                    | 14-74      | 2                 |
|                   | DSM-1  | 6         | 9           | 2.4                     | 4-9        | 3                 |
|                   | DSM-2  | 21        | 17          | 15.6                    | 8-39       | 3                 |
|                   | DSM-3  | 34        | 34          | 29.6                    | 13-55      | 2                 |
|                   | DSM-4  | 103       | 103         | 0.0                     | 103        | 1                 |
|                   | USC-1  | 4         | 5           | 1.3                     | 3-5        | 3                 |
|                   | USC-2  | 23        | 18          | 20.2                    | 5-52       | 4                 |
|                   | USC-3  | 21        | 23          | 9.8                     | 10-29      | 3                 |
|                   | USC-4  | 33        | 33          | 9.1                     | 27-40      | 2                 |
|                   | DSC-1  | 11        | 9           | 2.8                     | 9-14       | 3                 |
|                   | DSC-2  | 15        | 10          | 8.6                     | 4-23       | 5                 |
|                   | DSC-3  | 20        | 24          | 9.7                     | 9-28       | 3                 |
|                   | DSC-4  | 59        | 53          | 33.6                    | 30-96      | 3                 |
| Construction      | USM    | 0         | 0           | 0.4                     | 0-1        | 22                |
|                   | USM-1  | 43        | 2           | 120.3                   | 0-363      | 9                 |
|                   | USM-2  | 31        | 7           | 57.4                    | 2-181      | 9                 |
|                   | USM-3  | 28        | 11          | 41.3                    | 7-121      | 7                 |
|                   | USM-4  | 24        | 25          | 17                      | 6-40       | 3                 |
|                   | USME   | 3         | 1           | 4.4                     | 0-15       | 11                |
|                   | DSM    | 0         | 0           | 0.8                     | 0-2        | 21                |
|                   | DSM-1  | 5         | 4           | 4.4                     | 1-15       | 12                |
|                   | DSM-2  | 44        | 13          | 85.3                    | 3-383      | 10                |
|                   | DSM-3  | 33        | 26          | 30.5                    | 6-66       | 3                 |
|                   | DSM-4  | 384       | 384         | NA                      | 384        | 1                 |
|                   | DSME   | 3         | 2           | 4.2                     | 0-15       | 11                |
|                   | USC    | 1         | 0           | 2.7                     | 0-12       | 20                |
|                   | USC-1  | 1         | 1           | 0.9                     | 0-2        | 7                 |
|                   | USC-2  | 4         | 4           | 2.6                     | 1-10       | 10                |
|                   | USC-3  | 10        | 11          | 5.7                     | 4-20       | 9                 |
|                   | USC-4  | 15        | 13          | 7.6                     | 9-26       | 4                 |
|                   | USCE   | 3         | 2           | 3.7                     | 0-11       | 11                |
|                   | DSC    | 0         | 0           | 0                       | 0-1        | 22                |
|                   | DSC-1  | 14        | 4           | 31.3                    | 0-107      | 11                |
|                   | DSC-2  | 6         | 6           | 2.8                     | 1-9        | 10                |
|                   | DSC-3  | 194       | 10          | 518.9                   | 2-1478     | 8                 |
|                   | DSC-4  | 336       | 12          | 793.2                   | 10-1956    | 6                 |
|                   | DSCE   | 4         | 1           | 5                       | 0-16       | 11                |
| Post-construction | USM    | 2         | 1           | 2.4                     | 0-6        | 9                 |
|                   | USM1   | 39        | 19          | 52.4                    | 3-141      | 6                 |
|                   | USM2   | 78        | 78          | 59.4                    | 18-137     | 3                 |
|                   | USM3   | 27        | 20          | 17.1                    | 8-50       | 5                 |
|                   | USM4   | 24        | 24          | 0.0                     | 24         | 1                 |
|                   | USME   | 1         | 1           | 0.0                     | 1          | 1                 |
|                   | DSM    | 3         | 1           | 4.6                     | 0-14       | 8                 |
|                   | DSM1   | 11        | 8           | 10.6                    | 2-28       | 6                 |
|                   | DSM2   | 43        | 19          | 35.2                    | 16-90      | 5                 |
|                   | DSM3   | 46        | 46          | 13.5                    | 36-55      | 2                 |
|                   | DSM4   | 76        | 76          | 0.0                     | 76         | 1                 |
|                   | DSME   | 2         | 2           | 0.0                     | 2          | 1                 |
|                   | USC    | 4         | 1           | 6.8                     | 0-20       | 8                 |
|                   | USC1   | 10        | 11          | 5.7                     | 2-16       | 6                 |
|                   | USC2   | 32        | 21          | 26.1                    | 15-70      | 4                 |
|                   | USC3   | 38        | 14          | 42.6                    | 13-87      | 3                 |
|                   | USC4   | 35        | 35          | 33.1                    | 12-58      | 2                 |
|                   | USCE   | 3         | 3           | 0.0                     | 3          | 1                 |
|                   | RP     | 2         | 1           | 3.7                     | 0-11       | 8                 |
|                   | RPE    | 4         | 4           | 0.0                     | 4          | 1                 |
|                   | DSC    | 2         | 1           | 3.5                     | 0-11       | 8                 |
|                   | DSC1   | 47        | 24          | 53.0                    | 2-125      | 5                 |
|                   | DSC2   | 63        | 18          | 100.7                   | 8-242      | 5                 |
|                   | DSC3   | 37        | 30          | 27.1                    | 14-67      | 3                 |
|                   | DSC4   | 75        | 75          | 93.6                    | 9-142      | 2                 |
|                   | DSCE   | 2         | 2           | 0.0                     | 2          | 1                 |

during rainfall or as the river was at an elevated stage. Figures 4-12, 4-13 and 4-14 show median passive suspended solid concentrations for passive samples collected for pre-construction, construction, and post-construction periods respectively. Notice that the median values are significantly lower during the construction period than during the other two monitoring periods. In only one instance is there an increase in the median suspended solids total (USM4) in going from the pre-construction to the construction period (Figures 4-12 and 4-13). The low suspended solids totals during the construction period are likely because the ground was frozen during much of the period and had a low erosion potential. The graphs also show that suspended solids concentrations increase with increasing stage. Table 4-6 shows the results of statistical comparisons for storm suspended solids concentrations taken at the same stations during the different monitoring periods. Results show that the lowest suspended solids totals occurred during the construction period. Table 4-6 also shows results of comparisons between upstream and downstream stations for each of the monitoring periods.

Results for all trace metal testing are shown in Table 4-7. As stated earlier, samples taken before April 2002 were unfiltered. Those taken afterwards were filtered. The stream sample with the highest aluminum concentration (0.421 mg/L) was collected at the uppermost sampling station (USM). Lead, mercury, arsenic, silver and cadmium were not detected in any samples. Samples 425-428 seem to indicate that aluminum concentration decreased as the stream flowed to a lower elevation. However, this was not a consistent trend for the other samples.

Samples collected on the construction site (sample E-30 in particular as shown in Table 4-7) were not filtered and were analyzed using a digestion process (measuring

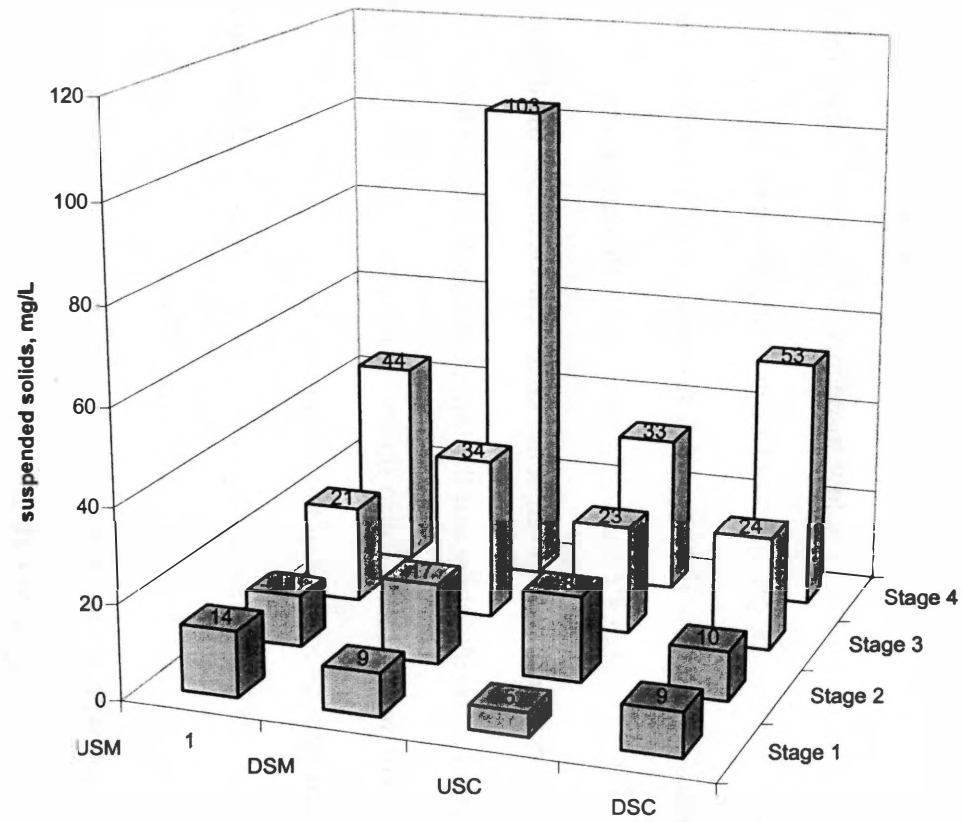


Figure 4-12. Before construction median total suspended solids totals by passive collection bottle and stage

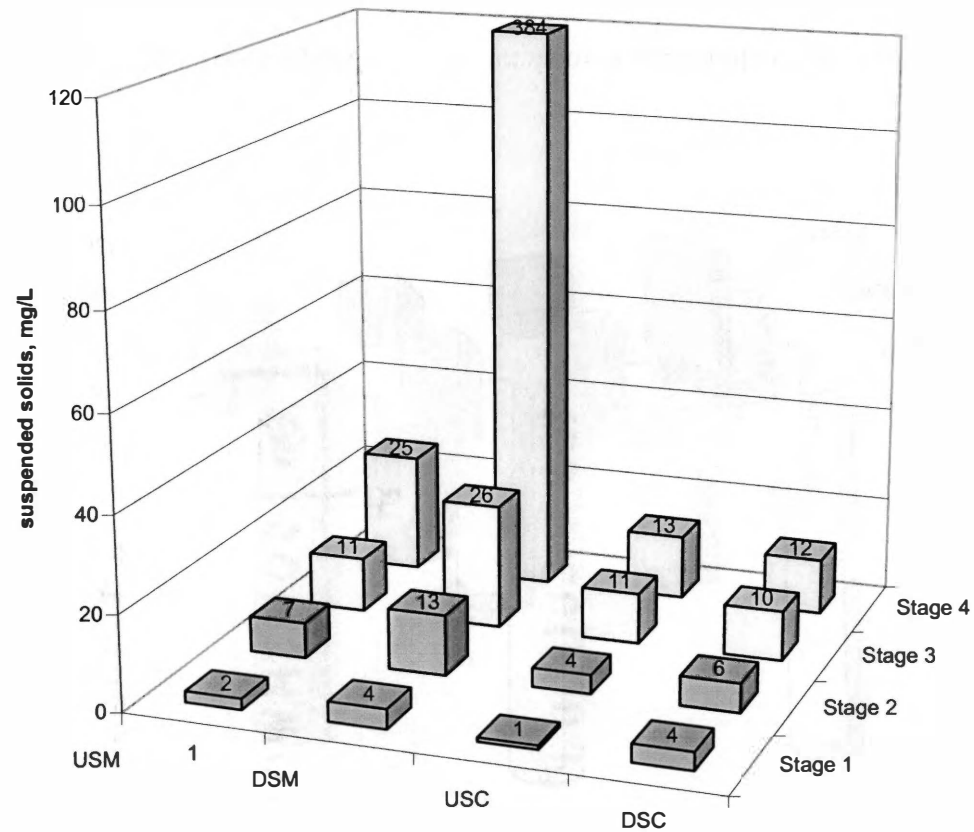


Figure 4-13. During construction median total suspended solids totals by passive collection bottle and stage

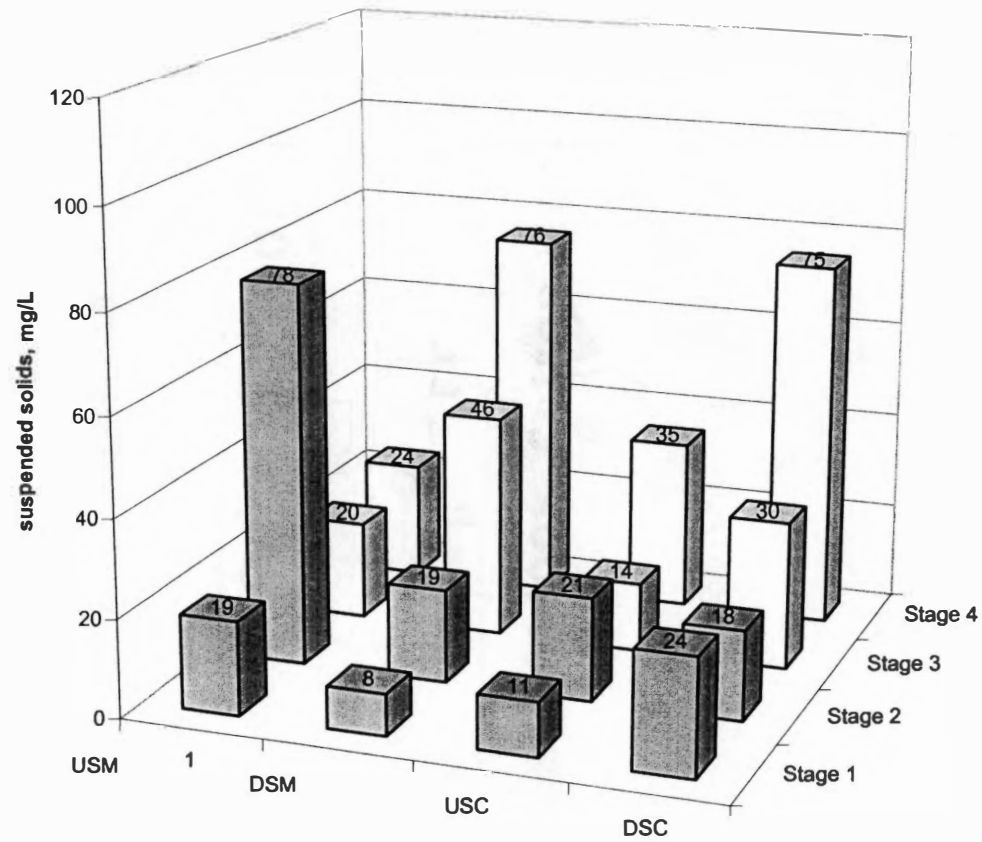


Figure 4-14. After construction median total suspended solids totals by passive collection bottle and stage

Table 4-6. Statistical differences in storm suspended solids concentrations at the same location for different time periods and comparison between upstream and downstream stations

| Objective                                                                                                    | Location     | Period                                 | # of Samples | Analyte          | Statistical Test | Result              | p-value |
|--------------------------------------------------------------------------------------------------------------|--------------|----------------------------------------|--------------|------------------|------------------|---------------------|---------|
| Examine differences in storm suspended solids concentrations at the same location for different time periods | DSC          | Pre-construction vs. Construction      | 14 vs 35     | suspended solids | Mann-Whitney     | <b>Pre- higher</b>  | 0.012   |
|                                                                                                              |              | Construction vs. Post construction     | 35 vs 15     | suspended solids | Mann-Whitney     | <b>Post- higher</b> | 0.005   |
|                                                                                                              |              | Pre-construction vs. Post-construction | 14 vs 15     | suspended solids | Mann-Whitney     | no difference       | 0.425   |
|                                                                                                              | USC          | Pre-construction vs. Construction      | 12 vs 30     | suspended solids | Mann-Whitney     | <b>Pre- higher</b>  | 0.002   |
|                                                                                                              |              | Construction vs. Post construction     | 30 vs 15     | suspended solids | Mann-Whitney     | <b>Post- higher</b> | 0       |
|                                                                                                              |              | Pre-construction vs. Post-construction | 12 vs 15     | suspended solids | Mann-Whitney     | no difference       | 0.981   |
|                                                                                                              | DSM          | Pre-construction vs. Construction      | 9 vs 26      | suspended solids | Mann-Whitney     | no difference       | 0.235   |
|                                                                                                              |              | Construction vs. Post construction     | 26 vs 14     | suspended solids | Mann-Whitney     | no difference       | 0.066   |
|                                                                                                              |              | Pre-construction vs. Post-construction | 9 vs 14      | suspended solids | Mann-Whitney     | no difference       | 0.61    |
|                                                                                                              | USM          | Pre-construction vs. Construction      | 12 vs 28     | suspended solids | Mann-Whitney     | no difference       | 0.194   |
|                                                                                                              |              | Construction vs. Post construction     | 28 vs 15     | suspended solids | Mann-Whitney     | <b>Post- higher</b> | 0.009   |
|                                                                                                              |              | Pre-construction vs. Post-construction | 12 vs 15     | suspended solids | Mann-Whitney     | no difference       | 0.156   |
| Examine differences in storm suspended solids concentrations between upstream and downstream stations        | Chimney-Tops | Pre-construction                       | 14 vs 12     | suspended solids | Mann-Whitney     | no difference       | 0.676   |
|                                                                                                              |              | Construction                           | 35 vs 30     | suspended solids | Mann-Whitney     | no difference       | 0.089   |
|                                                                                                              |              | Post-construction                      | 15 vs 15     | suspended solids | Mann-Whitney     | no difference       | 0.35    |
|                                                                                                              | Morton       | Pre-construction                       | 9 vs 12      | suspended solids | Mann-Whitney     | no difference       | 1       |
|                                                                                                              |              | Construction                           | 26 vs 28     | suspended solids | Mann-Whitney     | no difference       | 0.901   |
|                                                                                                              |              | Post-construction                      | 14 vs 15     | suspended solids | Mann-Whitney     | NA                  | NA      |

Table 4-7. Trace metals concentrations (mg/L) by site

| Sample ID      | Detection Limit | Recommended Standards       |        |         |                      | QA/QC Samples        |            |            |
|----------------|-----------------|-----------------------------|--------|---------|----------------------|----------------------|------------|------------|
|                |                 | Recommended Detection Limit | CMC    | CCC     | CMC                  | CCC                  | H-21       | FP-1       |
| Date Collected |                 |                             |        |         |                      |                      | 12/10/2001 | 03/28/2002 |
| Date Analyzed  |                 |                             |        |         |                      |                      | 12/19/2001 | 04/11/2002 |
| Mercury        | 0.0002          | 0.0002                      | 0.0014 | 0.00077 | 0.00169              | 0.00098              |            |            |
| Aluminum       | 0.05            |                             | 0.75   | 0.087   |                      |                      |            |            |
| Arsenic        | 0.005           | 0.001                       | 0.34   | 0.15    | 0.36                 | 0.19                 |            |            |
| Cadmium        | 0.001           | 0.001                       | 0.0043 | 0.0022  | 0.0018/0.0039/0.005  | 0.0007/0.011/0.002   |            |            |
| Calcium        | 1               |                             |        |         |                      |                      |            |            |
| Copper         | 0.01            | 0.001                       | 0.013  | 0.009   | 0.0082/0.0177/0.0341 | 0.0053/0.0118/0.0214 |            |            |
| Lead           | 0.003           | 0.0001                      | 0.065  | 0.0025  | 0.038/0.0817/0.187   | 0.0013/0.0032/0.0077 |            |            |
| Magnesium      | 1               |                             |        |         |                      |                      |            |            |
| Manganese      | 0.015           |                             |        |         |                      |                      |            |            |
| Silver         | 0.005           | 0.001                       | 0.0034 |         | 0.0123/0.041/0.0134  |                      |            |            |
| Zinc           | 0.02            | 0.001                       | 0.12   | 0.12    | 0.085/0.177/0.211    | 0.0589/0.108/0.191   |            |            |

|                |                 | Pre-construction |            |            |            | Construction |            |            |            |            |            |            |            |            |            |            |            | Post-construction |            |            |            |            |
|----------------|-----------------|------------------|------------|------------|------------|--------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|-------------------|------------|------------|------------|------------|
| Sample ID      | Detection Limit | DS1-1            | US2-1      | E-28       | E-30       | E-33         | G-75       | G-76       | G-78       | G-82       | G-83       | G-80       | C404       | C405       | C425       | C426       | C427       | C428              | C515       | C516       | C517       | C518       |
| Date Collected |                 | 10/01/2001       | 10/03/2001 | 12/10/2001 | 12/10/2001 | 12/10/2001   | 12/19/2001 | 12/19/2001 | 12/10/2001 | 12/10/2001 | 12/10/2001 | 12/10/2001 | 04/09/2002 | 04/09/2002 | 05/01/2002 | 05/01/2002 | 05/01/2002 | 05/01/2002        | 07/11/2002 | 07/11/2002 | 07/11/2002 | 07/11/2002 |
| Date Analyzed  |                 | 10/06/2001       | 10/06/2001 | 12/19/2001 | 12/19/2001 | 12/19/2001   | 12/19/2001 | 12/19/2001 | 12/19/2001 | 12/19/2001 | 12/19/2001 | 12/19/2001 | 04/16/2002 | 04/16/2002 | 05/03/2002 | 05/03/2002 | 05/03/2002 | 05/03/2002        | 07/18/2002 | 07/18/2002 | 07/18/2002 | 07/18/2002 |
| Mercury        | 0.0002          |                  |            |            |            |              |            |            |            |            |            |            |            |            |            |            |            |                   |            |            |            |            |
| Aluminum       | 0.05            | 0.262            | 0.392      | 136        | 199        |              |            |            | 0.097      | 0.248      | 0.136      | 0.092      | 0.124      |            | 0.2        | 0.151      | 0.167      | 0.364             | 0.421      | 0.228      | 0.322      | 0.058      |
| Arsenic        | 0.005           |                  |            | 0.039      | 0.056      |              |            |            |            |            |            |            |            |            |            |            |            |                   |            |            |            |            |
| Cadmium        | 0.001           |                  |            | 0.014      | 0.018      |              |            |            |            |            |            |            |            |            |            |            |            |                   |            |            |            |            |
| Calcium        | 1               | 1.66             | 3.1        | 1603       | 810        | 2.12         | 184        | 1.92       | 2.17       | 2.49       | 1.86       | 2.05       | 449        | 4.78       | 2.17       | 2.09       | 1.76       | 1.31              | 3.18       | 177        | 2.47       | 3.02       |
| Copper         | 0.01            |                  |            | 0.284      | 0.39       |              |            |            |            |            |            |            | 0.024      | 0.043      | 0.013      |            |            |                   | 0.012      |            |            |            |
| Lead           | 0.003           |                  |            | 0.738      | 1.06       |              |            |            |            |            |            |            |            |            |            |            |            |                   |            |            |            |            |
| Magnesium      | 1               |                  |            |            |            |              |            |            |            |            |            |            | 43         | 1.04       |            |            |            |                   |            |            |            |            |
| Manganese      | 0.015           | 0.04             | 0.057      | 18.8       | 15.8       |              |            |            | 0.025      | 0.034      | 0.018      |            | 0.028      |            |            |            |            |                   | 0.077      | 0.063      | 0.025      |            |
| Silver         | 0.005           |                  |            |            |            |              |            |            |            |            |            |            |            |            |            |            |            |                   |            |            |            |            |
| Zinc           | 0.02            |                  |            | 1.4        | 1.96       |              |            |            |            |            |            |            | 0.026      | 0.04       |            | 0.035      | 0.024      | 0.024             | 0.033      | 0.033      |            |            |

| Sample ID | Description                                                                                               |
|-----------|-----------------------------------------------------------------------------------------------------------|
| DS1-1     | Pre-construction stream: Lowest passive sample bottle downstream of Chimney Tops Tunnel                   |
| US2-1     | Pre-construction stream: Lowest passive sample bottle upstream of Morton Mountain Tunnel                  |
| E-28      | Construction BMP: Sample taken below Chimney Tops construction site prior to rock check dams              |
| E-30      | Construction BMP: Sample taken below Chimney Tops construction site after passing through rock check dams |
| E-33      | Construction stream: Sample taken downstream of the Chimney Tops Tunnel                                   |
| G-75      | Construction stream: Grab sample taken downstream of the Chimney Tops Tunnel                              |
| G-76      | Construction stream: Grab sample taken upstream of Morton Mountain Tunnel                                 |
| G-79      | Construction stream: Lowest passive sample bottle downstream of Chimney Tops Tunnel                       |
| G-82      | Construction stream: Lowest passive sample bottle upstream of Morton Mountain Tunnel                      |
| G-83      | Construction stream: Lowest passive sample bottle downstream of Chimney Tops Tunnel                       |
| G-90      | Construction stream: Lowest passive sample bottle upstream of Morton Mountain Tunnel                      |
| H-21      | Lab: Test of deionized water purity                                                                       |
| FP-1      | Lab: Test of deionized water purity after being taken to the field and poured in a sample bottle          |
| LF-1      | Lab: Test of deionized water purity after filtration through filter                                       |
| C404      | Disposal: Leachate from New Found Gap Disposal Site                                                       |
| C405      | Disposal: Runoff to New Found Gap Disposal Site from US 441                                               |
| C425      | Construction stream: Grab sample taken downstream of the Chimney Tops Tunnel                              |
| C426      | Construction stream: Grab sample taken upstream of the Chimney Tops Tunnel                                |
| C427      | Construction stream: Grab sample taken downstream of Morton Mountain Tunnel                               |
| C428      | Construction stream: Grab sample taken upstream of Morton Mountain Tunnel                                 |
| C515      | Post-construction stream: 2nd lowest passive sample bottle downstream of Chimney Tops Tunnel              |
| C516      | Post-construction stream: 3rd lowest passive sample bottle upstream of Chimney Tops Tunnel                |
| C517      | Post-construction stream: Lowest passive sample bottle upstream of Morton Mountain Tunnel                 |
| C518      | Post-construction stream: Lowest passive sample bottle downstream of Morton Mountain Tunnel               |

metals contained in the solids as well as dissolved species). Therefore the results do not necessarily indicate the concentration of dissolved or biologically available metals. They do, however, indicate that the metals are present in the soil and could potentially be released under certain conditions.

Oil and grease concentrations for all stream samples (grab, storm and passive) were found to be less than detection limits.

### ***Construction Sites and BMPs***

Storm runoff samples were taken in drainage ways immediately above and below each of the construction sites to determine if construction site disturbance altered pH or suspended solids concentrations in the runoff. Check dams and inlet protection devices were tested for runoff pH alteration and sediment removal efficiency using the Wilcoxon signed ranks test, which compares paired samples taken above and below the BMPs (i.e. check dams and inlet devices).

The pH differences are shown in Figure 4-15. A statistically significant difference was not detected (Table 4-8) in the pH between the above and below disturbance areas at either the Chimney Tops site ( $p=0.375$ ) or Morton ( $p=0.109$ ). Visually it looks as though a difference exists for the Morton area, but statistically this claim could only be made by using a confidence level of 89% or less. Statistically a difference might have been shown if a greater number of samples had been collected. A statistically significant difference was not detected in the pH above and below the rock check dams and inlet protection (See Table 4-8) at Chimney Tops ( $p=0.813$ ) and Morton ( $p=0.250$ ).

However, it is important to note that the above site sampling point was not truly free from construction impacts. This was particularly true of the Morton site. Construction

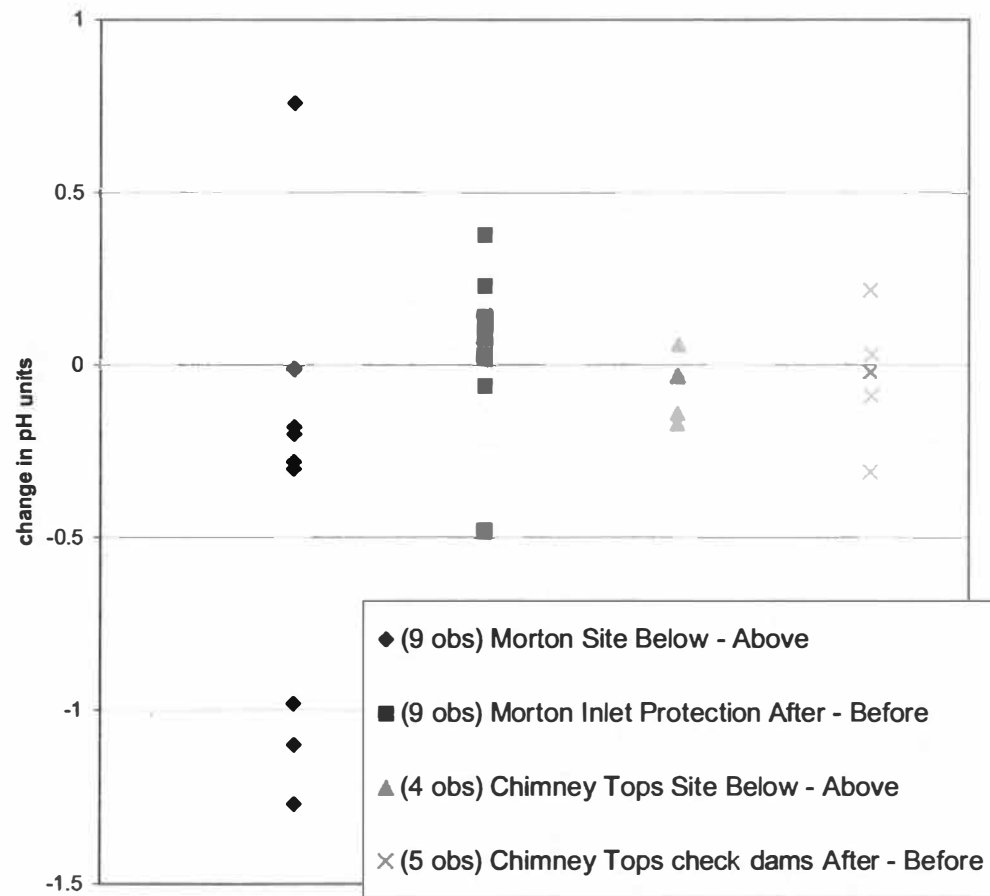


Figure 4-15. Difference in pH for construction sites (below minus above), Chimney Tops rock check dams and Morton inlet protection

Table 4-8. Statistical results for construction sites and BMP pH and suspended solids

| Objective                                                                  | Location       | Analyte          | Statistical Test      | Result        | p-value |
|----------------------------------------------------------------------------|----------------|------------------|-----------------------|---------------|---------|
| Examine differences in runoff samples above and below disturbance areas    | Chimney Tops   | pH               | Wilcoxon signed ranks | no difference | 0.375   |
|                                                                            |                | Suspended Solids | Wilcoxon signed ranks | no difference | 0.375   |
|                                                                            | Morton         | pH               | Wilcoxon signed ranks | no difference | 0.109   |
|                                                                            |                | Suspended Solids | Wilcoxon signed ranks | no difference | 0.742   |
| Examine differences between samples taken above and below rock check dams  | Chimney Tops   | pH               | Wilcoxon signed ranks | no difference | 0.813   |
|                                                                            |                | Suspended Solids | Wilcoxon signed ranks | no difference | 0.813   |
|                                                                            | Old Trace Road | pH               | Wilcoxon signed ranks | no difference | 1       |
|                                                                            |                | Suspended Solids | Wilcoxon signed ranks | no difference | 0.5     |
| Examine differences between samples taken above and below inlet protection | Morton         | pH               | Wilcoxon signed ranks | no difference | 0.25    |
|                                                                            |                |                  |                       |               |         |
|                                                                            |                | Suspended Solids | Wilcoxon signed ranks | no difference | 0.195   |

vehicles tracked mud from the excavated areas onto the roadway. The roadway above Morton served as the haul road for excavated material and experienced significant amounts of tracked mud from the upper extent of excavation all the way to Newfound Gap. During rain events this mud was washed into the drainage ways. It is also important to note that the rate of runoff flow through the excavated roadbeds and adjacent drainage ways at both sites was generally dwarfed by much higher flows in the streams.

A statistically significant difference was not detected in the amount of suspended sediment concentration between the above and below disturbance site samples collected for the Chimney Tops ( $p=0.375$ ) and Morton ( $p=0.742$ ) sites (See Figures 4-16 and 4-17). The same is true of rock check dams and inlet protection at Chimney Tops ( $p=0.813$ ) and Morton ( $p=0.195$ ). Despite these findings field observance did indicate sediment releases due to disturbance based on visual inspection: trapped sediment behind rock check dams and turbid runoff. The failure to show this statistically likely comes from failure to select an above site sampling point that was truly free from construction impacts such as from tracked mud mentioned earlier.

Removal efficiencies for the rock dam at the Old Trace Road disposal area during two storm events resulting in high suspended solid concentration (23,567 and 42,527 mg/L) runoff were 90% and 65% (Figure 4-18), which was consistent with visual observations of trapped sediment. By the end of the construction period the pond's storage volume was effectively filled. Runoff sediment concentrations increased slightly during one sampling visit as the water entering the pond increased from 113 to 321 mg/L. The increased effectiveness of this dam of this dam (compared with the check dams at the Chimney Tops site and the inlet filter at the Morton site) was likely due to greater

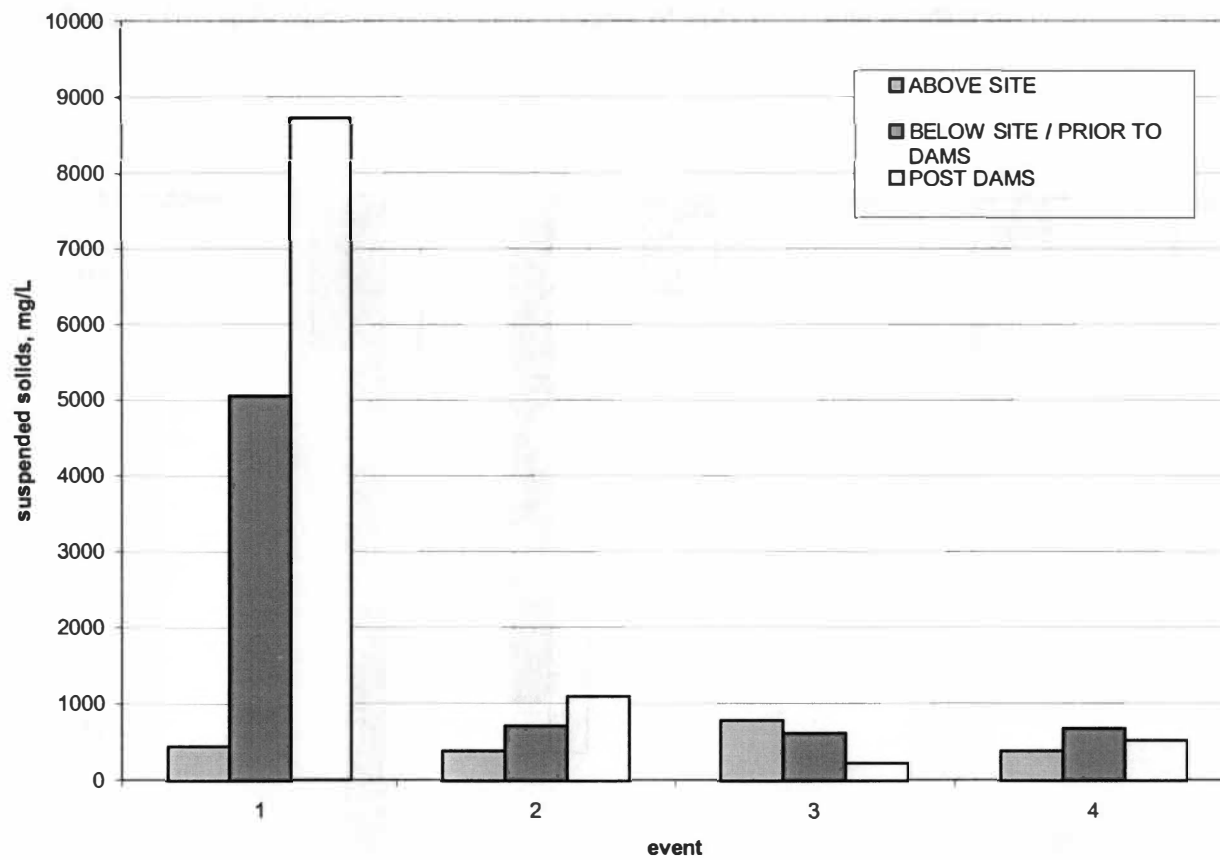


Figure 4-16. Bar chart of suspended solids at Chimney Tops rock check dams

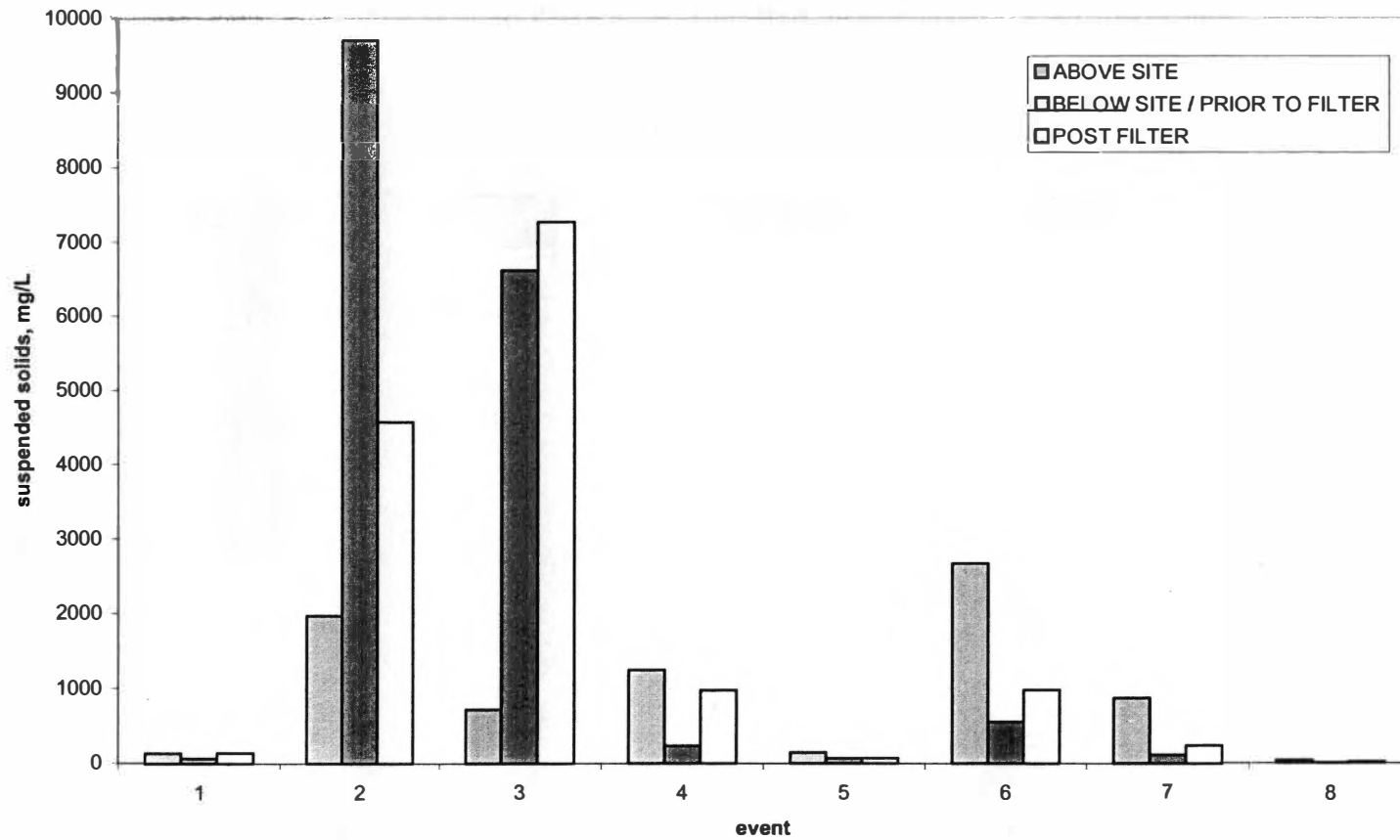


Figure 4-17. Bar chart of suspended solids at Morton Mountain inlet protection

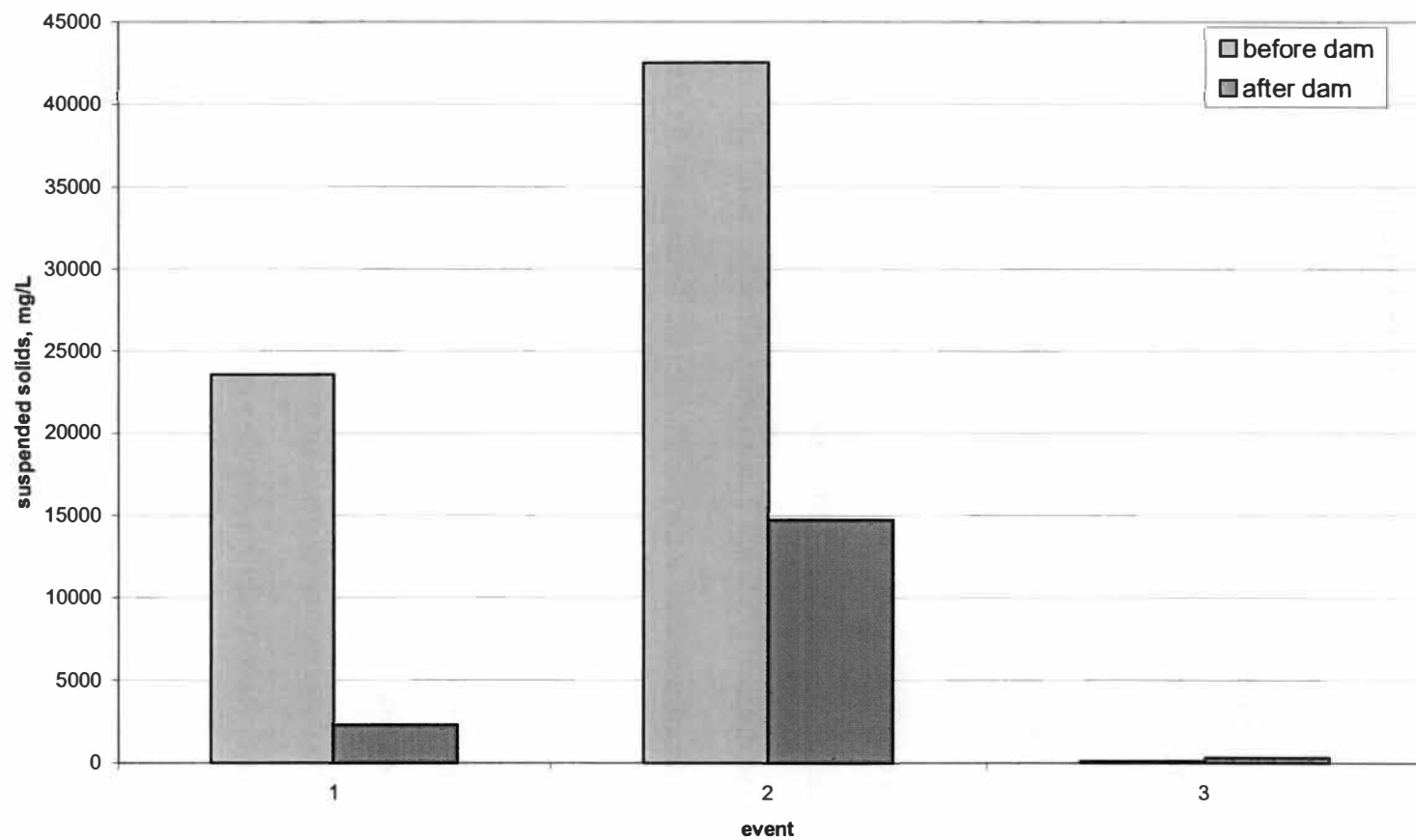


Figure 4-18. Bar Chart of suspended solids at Old Trace Road check dam

storage/ponding volume available above the dam. This volume allowed for ponding of the runoff and settlement of suspended solids.

Based on observed surface color, visual inspection of select samples collected on the construction sites did suggest that small amounts of petroleum might be present in areas of heavy equipment operation and at mobile traffic signal stations. However, these samples tested negative for oil and grease.

### ***Disposal Site Leachate***

The pH of leachate that flowed from beneath the disposal mounds following rain events was measured to determine if the disposal practices were effective in neutralizing acidity. The leachate at Old Trace Road had pH values ranging from 6.9 (5 samples) to 7.7. Gnatty Branch leachate pH measured 7.2 (5 samples) or greater. Average leachate pH at the Old Trace Road disposal site was 7.2, the same as that for runoff collected just below the construction disturbance area at the Morton tunnel. Average pH for the leachate at the Natty Branch disposal site was 7.3, slightly lower than the pH for runoff samples collected below the disturbance area at the Chimney Tops Tunnel (7.6). The high pH values at the disturbance sites was likely due to the crushed limestone that was present in the road base on site. Runoff pH from flows draining slopes adjacent to the disposal piles was measured on two occasions. This runoff filtered into the disposal piles and contributed to leachate. Runoff pH measured an average of 5.7 and 6.7 for the Old Trace and Gnatty sites respectively. This indicates an increase in pH values as the water filtered through the system, as desired. Leachate could not be collected at the Gnatty Branch site for the last two storm events that were monitored. Apparently, the clay layer capping the disposal pile was effective in reducing the amount of precipitation that

passed through the pile. Leachate continues to flow from the disposal pile at Old Trace Road.

## CHAPTER V. CONCLUSIONS

Based on the stream water quality monitoring and statistical analyses, tunnel reconstruction had no statistically discernable significant impacts on adjacent streams:

- Statistical results did not indicate that construction altered the pH or suspended solids concentration of the stream. Tracked soil as discussed earlier may have somewhat increased stream suspended solids. However, this was not monitored and was believed to be a minor concern in this project.
- Median suspended solids concentrations for the stream sampling locations were lower during construction than the in the pre- and post-construction periods.
- Seasonal variation is believed to account for differences in the water quality between the construction period and the pre- and post-construction periods. For example, although pH was lower during the winter construction period paired differences analysis on past stream samples collected in the West Prong Little Pigeon River watershed showed the same seasonal trend. Additionally, paired differences of upstream vs downstream at the Chimney Tops Tunnel showed no statistical differences in pH or other parameters for the most part. At the Morton site, the pH actually improved from upstream to down stream.
- The water quality parameters that varied between the upstream and downstream sampling during the construction periods were the same ones that varied prior to construction.
- The area of disturbance was small in relationship to the watershed. Approximate calculations of potential impact showed that little impact should be expected

because the runoff volume from the construction site was very small in comparison to the stream flow from the watershed during a storm event.

BMP performance varied. Success or failure was tied to proper/improper location, design, construction and maintenance:

- Many BMPs were installed according to the plans but were not constructed in locations where they would receive runoff from construction activities.
- Multiple BMPs needed to be added and/or altered after construction began. Structures were added because other structures failed or no structure was provided in an area that needed a BMP. Pollution can be minimized by BMP maintenance and early detection of problems.
- The efficiency of a check dam was dependent upon its ability to pond water (i.e. the detention time) and the pond volume available for storage. The rock check dam at the Old Trace Road Disposal site provided area for storage and offered good settleable solids trapping efficiency. The rock check dams installed at the Chimneys site provided very little ponding area and therefore negligible trapping efficiency. The failure to show statistical differences in water quality above and below BMPs does not indicate failure or success on the part of the contractor. The results are not surprising and are similar to some other studies.
- Silt fences were not observed ponding water at any location
- The disposal practices used for the excavated materials were effective in neutralizing any acidic leachate that may have resulted from Anakeesta. The leachate at Old Trace Road had pH values ranging from 6.9 (5 samples) to 7.7. Gnatty Branch leachate pH measured 7.2 (5 samples) or greater.

Information in addition to construction impact or BMP performance was gained from this project:

- Storm runoff lowered stream pH values. The effect was more pronounced at the Morton locations. Similarly, the Morton site experienced greater changes in other water chemistry parameters than the Chimney's site during storm events.
- Higher flows also result in higher suspended solids concentrations.
- The passive sampling stations provided much of the information used to monitor storm events and draw conclusion about the impacts of construction. They were relatively inexpensive to build and proved durable throughout high flows and seasonal temperature fluctuations.
- Regular inspection and maintenance is required for BMPs to function properly.
- Excavated material was tracked onto the haul road. In subsequent rain events the material contaminated runoff. Much of this material may have been recovered if a street sweeping truck had been called for in the project plans.

## CHAPTER VI. RECOMMENDATIONS FOR FUTURE RESEARCH

Monitoring should begin well in advance (at least one year) of construction projects so that baseline conditions can be monitored, and natural variation can be detected. The monitoring should continue after construction is finished for about the same length of time. Construction site inspection and maintenance are very important so that problems are recognized early and adjustments in BMPs can be made. Continuous maintenance is particularly important in areas where BMPs (such as check dams) have limited storage areas (because the BMPs are ineffective after they are filled).

In a monitoring project such as this one it is important to have as much background baseline data as possible (longer pre-construction monitoring). The best way to obtain this information is to install multi-parameter monitoring probes. Multi-parameter probes that continuously measure and record pH stage height and turbidity should be installed in the stream of interest at the beginning of the project and remain in place until monitoring ceases. Stream flow and rainfall monitoring for future studies should be included to help explain changes in pH, sediment and other parameters.

Significant changes in water chemistry were observed between base flow conditions and storm events. This trend should be further investigated. A stormwater monitoring program is suggested.

Tracking of soil and mud off site by dump truck tires and deposited on the haul roads should be more closely monitored and preventative measures such as street sweepers considered.

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## LITERATURE CITED

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## **APPENDIX**

Table A1-1. Reproducibility for duplicate / replicate suspended solids analysis

| Sample ID  | VOL | Pre    | Post 103 | Post 550 | TOTAL mg/l | VOLATILE mg/l | % Volatile | X     | s <sup>2</sup> | s    | Relative Standard Deviation (ppm) |
|------------|-----|--------|----------|----------|------------|---------------|------------|-------|----------------|------|-----------------------------------|
| Standard 1 | 50  | 1.0826 | 1.1165   | 1.1095   | 878        | 140           | 21         |       |                |      |                                   |
| Standard 1 | 25  | 1.0917 | 1.1124   | 1.1077   | 828        | 188           | 23         |       |                |      |                                   |
| Standard 1 | 10  | 1.0807 | 1.0921   | 1.0902   | 1140       | 190           | 17         |       |                |      |                                   |
| Standard 1 | 10  | 1.0906 | 1.1031   | 1.1002   | 1250       | 290           | 23         |       |                |      |                                   |
| Standard 1 | 10  | 1.0704 | 1.081    | 1.0793   | 1060       | 170           | 16         | 991   | 54645          | 234  | 24                                |
| G31        | 150 | 1.081  | 1.0815   | 1.0813   | 3          | 1             | 40         |       |                |      |                                   |
| G31        | 150 | 1.0818 | 1.082    | 1.0817   | 1          | 2             | 150        | 2     | 2              | 1    | 61                                |
| G33        | 300 | 1.0933 | 1.0964   | 1.095    | 10         | 5             | 45         |       |                |      |                                   |
| G33        | 300 | 1.1015 | 1.104    | 1.1029   | 8          | 4             | 44         | 9     | 2              | 1    | 15                                |
| G59        | 325 | 1.0914 | 1.0959   | 1.0934   | 14         | 8             | 56         |       |                |      |                                   |
| G59        | 455 | 1.0997 | 1.1095   | 1.1049   | 22         | 10            | 47         | 18    | 30             | 5    | 31                                |
| G68        | 380 | 1.0911 | 1.0952   | 1.093    | 11         | 6             | 54         |       |                |      |                                   |
| G68        | 380 | 1.1024 | 1.1075   | 1.1048   | 13         | 7             | 63         | 12    | 3              | 2    | 15                                |
| G81        | 420 | 1.0823 | 1.0856   | 1.0838   | 8          | 4             | 55         |       |                |      |                                   |
| G81        | 420 | 1.0965 | 1.0998   | 1.098    | 8          | 4             | 55         | 8     | 0              | 0    | 0                                 |
| G91        | 430 | 1.0933 | 1.0965   | 1.0949   | 7          | 4             | 50         |       |                |      |                                   |
| G91        | 430 | 1.0822 | 1.0856   | 1.0837   | 8          | 4             | 56         | 8     | 0              | 0    | 4                                 |
| G104       | 400 | 1.1042 | 1.1052   | 1.1047   | 2          | 1             | 50         |       |                |      |                                   |
| G104       | 400 | 1.0952 | 1.0972   | 1.0962   | 5          | 2             | 50         | 4     | 3              | 2    | 47                                |
| G128       | 270 | 1.1086 | 1.1085   | 1.1084   | 0          | 0             | 0          |       |                |      |                                   |
| G128       | 300 | 1.1062 | 1.1066   | 1.1066   | 1          | 0             | 0          | 0     | 1              | 1    | 250                               |
| E13        | 50  | 1.1064 | 1.1587   | 1.0497   | 1046       | 2180          | 208        |       |                |      |                                   |
| E13        | 50  | 1.0984 | 1.1507   | 1.1419   | 1046       | 176           | 17         | 1046  | 0              | 0    | 0                                 |
| E15        | 50  | 1.1009 | 1.1313   | 1.1253   | 608        | 120           | 20         |       |                |      |                                   |
| E15        | 50  | 1.0956 | 1.1366   | 1.1293   | 820        | 146           | 18         | 714   | 22472          | 150  | 21                                |
| E20        | 25  | 1.1009 | 1.2151   | 1.1933   | 4568       | 872           | 19         |       |                |      |                                   |
| E20        | 25  | 1.1007 | 1.2184   | 1.1957   | 4708       | 908           | 19         | 4638  | 9800           | 99   | 2                                 |
| E45        | 10  | 1.0997 | 1.1503   | 1.1412   | 5060       | 810           | 16         |       |                |      |                                   |
| E45        | 10  | 1.1053 | 1.1418   | 1.1354   | 3650       | 640           | 18         | 4355  | 994050         | 997  | 23                                |
| E46        | 10  | 1.0978 | 1.2106   | 1.1909   | 11280      | 1970          | 17         |       |                |      |                                   |
| E46        | 10  | 1.0987 | 1.202    | 1.1842   | 10330      | 1780          | 17         | 10805 | 451250         | 672  | 6                                 |
| E62        | 50  | 1.0978 | 1.1523   | 1.1453   | 1090       | 140           | 13         |       |                |      |                                   |
| E62        | 50  | 1.1099 | 1.1656   | 1.1582   | 1114       | 148           | 13         |       |                |      |                                   |
| E62        | 50  | 1.1094 | 1.164    | 1.1571   | 1092       | 138           | 13         |       |                |      |                                   |
| E62        | 50  | 1.1057 | 1.1672   | 1.1606   | 1230       | 132           | 11         | 1132  | 4430           | 67   | 6                                 |
| E68        | 240 | 1.0991 | 1.1159   | 1.1137   | 70         | 9             | 13         |       |                |      |                                   |
| E68        | 240 | 1.0961 | 1.1171   | 1.1146   | 87         | 10            | 12         | 79    | 153            | 12   | 16                                |
| E73        | 25  | 1.1008 | 1.1676   | 1.1627   | 2672       | 196           | 7          |       |                |      |                                   |
| E73        | 50  | 1.1038 | 1.2451   | 1.236    | 2826       | 182           | 6          | 2749  | 11858          | 109  | 4                                 |
| E91        | 50  | 1.0968 | 1.1322   | 1.1229   | 708        | 188           | 26         |       |                |      |                                   |
| E91        | 51  | 1.0846 | 1.1197   | 1.1108   | 688        | 175           | 25         | 698   | 195            | 14   | 2                                 |
| E92        | 80  | 1.0824 | 1.1238   | 1.1133   | 517        | 131           | 25         |       |                |      |                                   |
| E92        | 52  | 1.0919 | 1.1185   | 1.1122   | 512        | 121           | 24         | 515   | 18             | 4    | 1                                 |
| E95        | 15  | 1.0842 | 1.7221   | 1.6839   | 42527      | 2547          | 6          |       |                |      |                                   |
| E95        | 15  | 1.0797 | 1.7451   | 1.644    | 44360      | 6740          | 15         | 43443 | 1680556        | 1296 | 3                                 |
| E107       | 150 | 1.0918 | 1.1095   | 1.1057   | 118        | 25            | 21         |       |                |      |                                   |
| E107       | 150 | 1.0842 | 1.1      | 1.0968   | 105        | 23            | 22         |       |                |      |                                   |
| E107       | 150 | 1.0856 | 1.1035   | 1.0998   | 119        | 25            | 21         | 114   | 60             | 8    | 7                                 |
| G164       | 300 | 1.0905 | 1.0942   | 1.0926   | 12         | 5             | 43         |       |                |      |                                   |
| G164       | 300 | 1.0898 | 1.094    | 1.0922   | 14         | 6             | 43         | 13    | 1              | 1    | 9                                 |
| G165       | 300 | 1.0855 | 1.0869   | 1.0857   | 5          | 4             | 86         |       |                |      |                                   |
| G165       | 300 | 1.0917 | 1.0925   | 1.0918   | 3          | 2             | 87         | 4     | 2              | 1    | 39                                |
| G162       | 300 | 1.0811 | 1.0838   | 1.083    | 9          | 3             | 30         |       |                |      |                                   |
| G162       | 300 | 1.086  | 1.0876   | 1.0866   | 5          | 3             | 63         | 7     | 7              | 3    | 36                                |
| G163       | 300 | 1.0843 | 1.0878   | 1.086    | 12         | 6             | 51         |       |                |      |                                   |
| G163       | 300 | 1.0794 | 1.081    | 1.0795   | 5          | 5             | 94         | 9     | 20             | 4    | 53                                |
| G192       | 335 | 1.0695 | 1.07     | 1.0699   | 1          | 0             | 20         |       |                |      |                                   |
| G192       | 305 | 1.0699 | 1.0701   | 1.0696   | 1          | 2             | 250        | 1     | 0              | 1    | 55                                |
| G197       | 285 | 1.0763 | 1.0759   | 1.0759   | -1         | 0             | 0          |       |                |      |                                   |
| G197       | 285 | 1.0653 | 1.0652   | 1.0652   | 0          | 0             | 0          | -1    | 1              | 1    | -85                               |
| G214       | 100 | 1.0696 | 1.2174   | 1.1646   | 1478       | 528           | 36         |       |                |      |                                   |
| G214       | 100 | 1.0756 | 1.2627   | 1.1953   | 1871       | 674           | 36         | 1675  | 77225          | 278  | 17                                |
| G222       | 150 | 1.0656 | 1.1232   | 1.1026   | 384        | 137           | 36         |       |                |      |                                   |
| G222       | 150 | 1.0675 | 1.1313   | 1.1078   | 425        | 157           | 37         | 405   | 854            | 29   | 7                                 |
| G229       | 350 | 1.0691 | 1.0692   | 1.0692   | 0          | 0             | 0          |       |                |      |                                   |
| G229       | 200 | 1.0652 | 1.0652   | 1.0653   | 0          | 0             | 0          | 0     | 0              | 0    | 141                               |
| G230       | 300 | 1.0631 | 1.0633   | 1.0631   | 1          | 1             | 100        |       |                |      |                                   |
| G230       | 300 | 1.0641 | 1.06446  | 1.0641   | 1          | 1             | 100        | 1     | 0              | 0    | 40                                |
| G242       | 285 | 1.0714 | 1.0713   | 1.0713   | 0          | 0             | 0          |       |                |      |                                   |
| G242       | 285 | 1.0683 | 1.0687   | 1.0682   | 1          | 2             | 125        | 1     | 2              | 1    | 236                               |
| G255       | 320 | 1.0699 | 1.0739   | 1.0718   | 13         | 7             | 52         |       |                |      |                                   |
| G255       | 430 | 1.0612 | 1.066    | 1.0637   | 11         | 5             | 48         | 12    | 1              | 1    | 8                                 |
| G266       | 295 | 1.0685 | 1.0696   | 1.0693   | 4          | 1             | 27         |       |                |      |                                   |
| G266       | 292 | 1.0654 | 1.0669   | 1.0664   | 5          | 2             | 33         | 4     | 1              | 1    | 22                                |
| G272       | 320 | 1.0675 | 1.0727   | 1.071    | 16         | 5             | 33         |       |                |      |                                   |
| G272       | 200 | 1.0706 | 1.0732   | 1.0726   | 13         | 3             | 23         | 15    | 5              | 2    | 16                                |
| G283       | 305 | 1.073  | 1.0799   | 1.0766   | 23         | 11            | 48         |       |                |      |                                   |
| G283       | 315 | 1.0652 | 1.0748   | 1.07     | 30         | 15            | 50         | 27    | 31             | 6    | 21                                |
| G287       | 355 | 1.0628 | 1.0783   | 1.0705   | 44         | 22            | 50         |       |                |      |                                   |
| G287       | 310 | 1.0656 | 1.0791   | 1.0726   | 44         | 21            | 48         | 44    | 0              | 0    | 0                                 |
| G306       | 352 | 1.0957 | 1.0985   | 1.0969   | 8          | 5             | 57         |       |                |      |                                   |
| G306       | 365 | 1.0975 | 1.1017   | 1.1      | 12         | 5             | 40         | 10    | 6              | 3    | 26                                |
| G307       | 372 | 1.095  | 1.1018   | 1.0982   | 18         | 10            | 53         |       |                |      |                                   |
| G307       | 305 | 1.0997 | 1.105    | 1.1024   | 17         | 9             | 49         | 18    | 0              | 1    | 4                                 |
| G352       | 275 | 1.119  | 1.12     | 1.1197   | 4          | 1             | 30         |       |                |      |                                   |
| G352       | 275 | 1.1258 | 1.1268   | 1.1259   | 4          | 3             | 90         | 4     | 0              | 0    | 0                                 |
| G353       | 275 | 1.1197 | 1.1201   | 1.1197   | 1          | 1             | 100        |       |                |      |                                   |
| G353       | 275 | 1.118  | 1.1179   | 1.1168   | 7          | 4             | 58         | 4     | 15             | 4    | 92                                |
| G354       | 265 | 1.1214 | 1.1229   | 1.1223   | 6          | 2             | 40         |       |                |      |                                   |
| G354       | 285 | 1.1275 | 1.1292   | 1.1281   | 6          | 4             | 65         | 6     | 0              | 0    | 4                                 |
| G355       | 262 | 1.1195 | 1.1201   | 1.1197   | 2          | 2             | 67         |       |                |      |                                   |
| G355       | 288 | 1.1211 | 1.1218   | 1.1214   | 2          | 1             | 57         | 2     | 0              | 0    | 4                                 |
| G365       | 220 | 1.1217 | 1.1374   | 1.1296   | 71         | 35            | 50         |       |                |      |                                   |
| G365       | 350 | 1.1211 | 1.1453   | 1.1329   | 69         | 35            | 51         | 70    | 2              | 2    | 2                                 |
| G366       | 290 | 1.1104 | 1.1229   | 1.1174   | 43         | 19            | 44         |       |                |      |                                   |
| G366       | 430 | 1.1278 | 1.1467   | 1.1388   | 44         | 18            | 42         | 44    | 0              | 1    | 1                                 |
| G392       | 230 | 1.124  | 1.1585   | 1.1402   | 141        | 71            | 50         |       |                |      |                                   |
| G392       | 240 | 1.1277 | 1.1622   | 1.1453   | 144        | 70            | 49         | 143   | 3              | 2    | 1                                 |
| G394       | 275 | 1.1297 | 1.1407   | 1.1343   | 40         | 23            | 58         |       |                |      |                                   |
| G394       | 245 | 1.1342 | 1.142    | 1.1377   | 32         | 18            | 55         | 36    | 33             | 6    | 16                                |
| G395       | 240 | 1.1281 | 1.1338   | 1.1319   | 24         | 8             | 33         |       |                |      |                                   |
| G395       | 200 | 1.126  | 1.1314   | 1.128    | 27         | 17            | 63         | 25    | 5              | 2    | 9                                 |

Note: Sample IDs that begin with "G" may be either grab or passive stream samples. IDs begin with "E" were storm samples collected on the construction site. "VOL" is the volume of sample tested. Pre, Post 103 and Post 550 are filter weights before sample, after drying for volatile solids and after drying for total solids, respectively.

## A1-2. Sample Calculations

$Q_1$  = Stream flow rate

$Q_2$  = Construction site runoff flow rate

$Q_1 + Q_2$  = Combined flow rate

$C_1$  = Stream suspended solids concentration

$C_2$  = Runoff suspended solids concentration

$C_3$  = Combined suspended solids concentration

$$Q_1 (C_1) + Q_2 (C_2) = (Q_1 + Q_2)C_3$$

$$99.97(100) + 0.03(10,000) = (100)C_3$$

$$C_3 = 103$$

## **VITA**

Kevin P. Hedrick was raised in Sevier County, TN. He graduated from Sevier County High School in May, 1996. In the fall he entered Maryville College to begin pre-engineering coursework and continue in athletics. In the spring of 1999 he entered the University of Tennessee at Knoxville to study civil engineering. May of 2000 he received a liberal arts degree from Maryville College (summa cum laude). In May, 2001 he received a Bachelor of Science degree (summa cum laude). Upon graduation he accepted a graduate research assistant position and began coursework in Environmental Engineering.

