Final Report

Effects of Bridge and Road Construction on Spring Creek:
Route 26 Transportation Improvements Project

Submitted to:

Pennsylvania Department of Transportation
and
Pennsylvania Fish and Boat Commission

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EXECUTIVE SUMMARY

The goal of this project was to monitor stream sediment loads, stream substrate composition, macroinvertebrate communities, and trout spawning sites during and immediately after construction of segments of Interstate 99 to determine effects, if any, of construction activities adjacent to Spring Creek. This project began in September 1999, about the same time that construction activities were started near the Park Avenue interchange and the Rock Road bridge crossing. This final report summarizes data collected from September 1999 through May 2003.

Water monitoring equipment was installed on Spring Creek upstream and downstream of construction areas near the Park Avenue interchange and the Rock Road bridge crossing. Water samples were collected at hourly intervals during 118 storm events. Total suspended solids at the upstream and downstream stations near the Park Avenue interchange were similar indicating no measurable sediment loading from this construction site until July 2001 when concrete drainage channels were constructed at the site. After concrete drainage channels were added to the site, total suspended solids increased at the downstream monitoring station. At the Rock Road bridge crossing, total suspended solids at the downstream station were frequently higher than at the upstream station. Total sediment load was about 14% higher at the downstream station compared to the upstream station, which indicates sediment contribution attributable to construction activities. Stream substrate composition and other variables measured at both construction sites (benthic macroinvertebrate

communities, and numbers of trout spawning sites) were similar at the upstream and downstream sampling stations

INTRODUCTION

Spring Creek, Centre County, is classified by the Department of Environmental Protection as a High Quality Coldwater stream. It supports a dense population of wild brown trout (Carline et al. 1991) and it ranks among the best Class A trout streams in the state. The stream provides a substantial amount of recreational fishing, which makes a significant contribution to the local economy (Shaffer et al. 1993).

Since 1990 local conservation groups and state agencies have implemented several projects designed to reduce sediment loading to Spring Creek. Road construction near the Park Avenue interchange and bridge construction across Spring Creek downstream of Houserville is at the upper end of a stream reach that has been targeted for sediment reduction. Local conservation groups and state agencies have expressed concern over the possibility of increased sediment loads as a result of these construction activities.

Highway construction in riparian zones can increase sediment loading in streams (e.g. Barton, 1977; Hainly,1980; Downs and Appel, 1986). This increase in sedimentation can have negative effects on macroinvertebrate communities (e.g. Chisholm and Downs, 1978; Cline et al., 1982; Taylor and Roff, 1986; Shaver et al., 1997; Haynes, 1999) and salmonid spawning success (e.g. Lisle,1989; Witzel and McCrimmon, 1989; Alcornley and Sear, 1999; Soulsby et.

al., 2001; Lisle and Lewis, 1992), both major factors in maintaining a productive trout stream. The goal of this project was to monitor stream sediment loads, stream substrate composition, macroinvertebrate communities, and trout spawning sites during and immediately after construction to determine effects, if any, of construction activities in the vicinity of Spring Creek.

This project began in September 1999, about the same time that construction activities were started near the Park Avenue interchange and the Rock Road bridge crossing. This report summarizes data collected from late September 1999 through May 2003.

OBJECTIVES

1. Determine the sediment load attributable to construction activities near the Park Avenue interchange and the bridge crossing Spring Creek along Rock Road.
2. Assess composition of stream substrates upstream and downstream of the construction sites.
3. Assess benthic macroinvertebrate communities upstream and downstream of construction sites.
4. Assess distribution and density of trout spawning sites upstream and downstream of construction sites.

METHODS

STUDY SITE

We installed automatic water samplers upstream and downstream of construction activities at the Park Avenue interchange and at the Rock Road bridge crossing. Water level recorders and staff gages were installed between the upstream and downstream monitoring stations.

Park Avenue Interchange. – Most of the construction occurred on a hill overlooking a streamside pasture (Figure 1). Areas disturbed by construction activities were separated from Spring Creek by a large (75 m –200 m) buffer area consisting primarily of grasses. The upstream water sampler (40°49’19”N, 77°50’12”W) was located on the right bank (looking upstream) 60 m upstream from the bridge on the Pennsylvania State University sheep farm. The downstream water sampler (40°49’30”N, 77°50’17”W) was located on the right stream bank 345 m downstream from the bridge. Drainage from a total of 4.91 ha reached the stream between the upstream and downstream sampler, and 4.63 ha (94.2%) were disturbed by construction. The water level recorder (40°49’20”N, 77°50’13”W) was located on the left stream bank 18 m downstream of the bridge. Sediment control measures at this site included a storm water retention pond (approximately 0.3 ha) constructed between the two sampling stations and silt fencing along the stream.

Rock Road Bridge Crossing. – Construction activities at Rock Road consisted of a 4-lane bridge directly over Spring Creek (Figure 1). Rock Road

Picture 1. View of construction area soon after installation of silt fence (November 1999) at the Park Avenue site. Notice the large buffer area between future construction on the hill side and the stream (right of person in blue jacket).

Picture 2. This picture was taken at the Park Avenue site before much land disturbance had occurred. The tree line follows along Spring Creek.

Picture 3. Stormwater runoff entering Spring Creek from the lower concrete drainage channel, at the Park Avenue site, shortly after a thunderstorm.

Picture 4. An overlook of the Park Avenue site from the Rt. 322 exit to the new highway at the completion of construction activities. A stormwater detention basin is in the middle of the picture and concrete drainage channel is to the left.

Picture 5. The Rock Road site after the initial land clearing a few months after construction started. Spring Creek can be seen in the lower left of the photo.

Picture 6. The Rock Road site as it appeared in November 2000. Spring Creek can be seen in the lower left of the photo.

Picture 7. Lower sampling station at the Rock Road site. The water sampler is in the box. The sampler intake tubing was attached to the staff gauge.

Picture 8. Picture taken from the highway bridge constructed at the Rock Road site. This picture was taken a few months after sampling had been completed.

runs along the Spring Creek (within 3 – 5 m from stream) under the highway bridge. This is a low-density residential area and the major land disturbance was located between two residences. This construction site had little or no buffer area. Silt fencing and a stormwater retention pond were used to retain sediment discharge. The upstream water sampler (40°50’33”N, 77°49’22”W) was located on the left bank 247 m upstream from the private bridge (Houser property) at 600 Rock Road. The downstream water sampler (40°50’44”N, 77°49’23”W) was located on the right bank 206 m downstream from the private bridge. The drainage area between the upstream and downstream areas was 16.33 ha, and 3.25 ha (19.9%) were disturbed by construction. The water level recorder was located near the left bank and is attached to the private bridge at 600 Rock Road (40°50’39”N, 77°49’21”W).

SEDIMENT LOADING

Stream discharge. -- Between December 1999 and March 2003, stream flows were measured along transects near the water level recorders at the Park Avenue and Rock Road study sites on Spring Creek. Transects were located in areas that had somewhat laminar flow, were free from obstructions, and were wadeable during high flow. Transects were perpendicular to stream flow, and the wetted width was divided into 12-15 equal segments. At each segment we measured depth and used a Marsh-McBirney Flo-Mate Model 2000 Portable Flowmeter to measure velocity. Stream stage was read from staff gauges located near the transects. We measured discharge on approximately 30 occasions spanning a wide range of stream flows. Rating curves for each site were constructed by plotting discharge against stage height. Stream discharge was highly correlated with stage height at both sites; therefore, we used these rating curves to convert stage data to discharge (Figure 2).

Stream stage was automatically measured at 30-minute intervals throughout the study with a WaterLog DH-21 pressure transducer. Data were downloaded at about monthly intervals and pressure readings were checked against the staff gauge to ensure that the instrument readings were accurate. When needed, the instrument was recalibrated. Stage readings were converted to discharge using the rating curve for that site.

Suspended sediment. – We used Sigma 800 SL automatic water samplers to obtain samples during storm events. The samplers were fitted with an in-stream actuator designed to start the sampler at the beginning of a storm event. We defined a storm event as a 5-cm increase in stream stage. Once started, the samplers pumped water samples every hour for 24 hours or until stream flow returned to base flow. Water samples were transported to the laboratory and processed within 24 hours.

We analyzed the water samples for turbidity in nephelometric turbidity units (NTU) using an Orbeco Hellige Digital Direct-Reading Turbidimeter (Model 965-10A). We recorded a high and low turbidity value for each sample and averaged the two values. The difference between the high and low values was typically less than 2 NTU's. A subsample of the water samples was analyzed for total suspended solids (TSS) with standard filtration procedures, drying, and weighing to the nearest milligram (APHA 1995; Method Number 2540 D). A quadratic regression was developed for each sampling site to estimate total suspended solids for samples when only turbidity was measured (Figure 3). This reduced the amount of laboratory time required to estimate TSS for all storm event samples.

During periods of low flow, field staff took weekly water samples at each of the four stations and measured turbidity levels. We extrapolated turbidity levels between grab samples to account for periods when no turbidity measurements were obtained.

Stream flow measurements and TSS values were multiplied by stream discharge to produce hourly sediment loads during storm events. The hourly sediment load values were added together to produce total sediment load for that storm event. During periods of low flow, total suspended sediment was multiplied by stream discharge to calculate daily sediment loads. The daily sediment loads and the hourly sediment loads were added together to determine the total sediment load for both the upstream and downstream stations of both study sites.

We analyzed TSS data with the Wilcoxon sign rank non-parametric test, because the data were not normally distributed. We compared hourly total suspended sediment levels from the upstream and downstream stations. We calculated the difference in TSS between the downstream and upstream stations and tested if the median of these hourly differences equaled zero using a significance value of $P = 0.05$.

SUBSTRATE COMPOSITION

We collected substrate samples from brown trout redds (spawning sites) in each year (1999-2002) in December. We collected up to 15 samples from redds found above the upstream sampling station and 15 samples directly below the downstream station at both the Park Avenue and Rock Road study sites. A 15-cm-diameter stovepipe sampler (McNeil and Ahnell 1964) was used to collect substrate samples from redds. The samples were then placed in buckets and taken to the laboratory for analysis. Samples were dried at 65^{o}C for 24-36 hours. The samples were sieved through a series of 10 screens with openings ranging in size from 0.0625 mm to 12.7 mm. The amount of substrate retained in each sieve was then weighed on an electronic scale to the nearest 0.1-gram. Percentage by weight of the material held by each sieve was calculated from the entire sample. The percentage by weight in each size class was used to calculate the fredle index of gravel quality (Lotspeich and Everest 1981). The fredle index (F_i) is the quotient of the geometric mean size (D_g) divided by the sorting coefficient (S_0). The geometric mean size is calculated by multiplying the midpoint diameter (D) of particles retained by a given sieve raised to the power of the decimal fraction by weight (w) of particles retained by that sieve for each of the 11 size classes.

$$D_g = (D_1^{w1} \times D_2^{w2} \times \ldots \times D_{10}^{w10})$$

The sorting coefficient was determined by taking the square root of grain size at the 75th percentile ($S_{0.75}$) divided by the grain size at the 25th percentile ($S_{0.25}$).

$$S_0 = (S_{0.75} / S_{0.25})^{0.5}$$

The percent by weight of sediment less than 1 mm in diameter was also calculated. A Mann-Whitney test was used to determine if differences between upstream and downstream sampling stations were statistically significant ($P = 0.05$).

MACROINVERTEBRATE COMMUNITIES

We collected macroinvertebrates using a 1-ft^2 Surber sampler in riffles every April and October starting in October 1999 and ending in April 2003. At each at the study sites, we collected 6 samples from a riffle above the upstream water monitoring sitation and 6 samples downstream of the downstream water-monitoring station. Samples were transferred from the net to labeled sample jars, preserved, and returned to the laboratory for processing. We placed samples in white porcelain pans and picked out all organisms that could be seen with the aid of a 2X magnifier. Organisms were separated by Order and then identified to several different levels, depending upon the Order. Ephemeroptera, Trichoptera, Plecoptera, Amphipoda, and Isopoda were identified to genus, while most other taxa were identified to family. After identification, specimens were stored in 80% methanol.

REDD SURVEYS

Unit personnel have determined locations and numbers of brown trout redds (spawning sites) in Spring Creek in, 1987,1988, 1997, and 1998. These surveys were conducted during the third week in November, which is after the peak spawning period. Spring Creek was divided into 16 sections, which are surveyed by two people walking upstream and counting redds. We used these same protocols from 1999 to 2002 to document density and distribution of brown trout redds.

RESULTS

Between November 1999 and May 2003, 118 storm events produced sufficient rainfall to increase stream flow and start the water samplers (Table 1). On several occasions automatic samplers failed to either initiate sampling at the start of the storm event or ceased sampling during the storm event. These failures were caused by several factors: clogged intake tube, frozen intake tube, jammed water level actuator, electric malfunction, and other mechanical problems. Ninety-five and 101 storm events were successfully sampled at the upstream and downstream sampling stations at the Park Avenue site and Rock Road site, respectively (Table 1). Storm events, where no corresponding upstream or downstream station samples were obtained, were excluded from the TSS analysis because no comparison of suspended solids between the upstream and downstream station was possible.

Turbidity values were positively correlated with TSS at both sites (Figure 3). Accordingly, we used these regressions to predict total suspended solids for the four stations throughout the study.

Typical storm events produced increased stream discharge and increased total suspended solids (Figure 4). The time of peak TSS at both the upstream and downstream stations were usually similar. Any variation in peak TSS between the upstream and downstream station arose from a different start time in the sampling program. Peak TSS lagged behind peak stream discharge probably because water continued to enter the stream after rainfall ceased. Once stream discharge returned to base flow, TSS also returned to pre-storm levels (Figure 4).

PARK AVENUE

During the first 20-months of the study, there were no consistent trends in TSS between the upstream and downstream stations at the Park Avenue site. We collected samples from both the upstream and downstream station for 53 storms (Table 2). The majority of the storms that we sampled showed no significant differences in TSS (Wilcoxon sign rank test, $P < 0.05$) between the upstream and downstream stations. During 16 storms TSS was significantly higher at the upstream station, than at the downstream station, and 12 were significantly higher at the downstream station, than at the upstream station (Table 2). Total sediment load, at the upstream station was 3.6% higher than the downstream station for the first 20-months . At this point in the study there was no indication that construction activities were contributing to increased sedimentation.

In July 2001, two concrete lined drainage channels were constructed between the upstream and downstream sampling stations at the Park Avenue site. Shortly after completion of these drainage channels, construction personnel built rock dams (rock sizes 3-30 cm) near the terminus of the drainage channels.

Presumably, these rock dams were intended to slow the progress of storm water before directly entering the stream, allowing time for sediment to settle and collect in the drainage channel. The rock dams were replaced sporadically and deposited sediment was removed throughout the study period. The upstream drainage channel was constructed approximately 10 m downstream of our upstream most sampling station. The downstream drainage channel (140 m upstream of the downstream sampling station) carried overflow from the stormwater retention pond and stormwater runoff that never passed through the pond. These drainage channels provided a direct path for sediment runoff to reach the stream. During the 23-months that followed the addition of the concrete drainage channels and additional land disturbance, we collected data from 42 more storm events. Of those storms, four showed a significantly ($P < 0.05$) higher TSS at the upstream station and 23 storms showed significantly ($P < 0.05$) higher TSS at the downstream station (Table 2). Total sediment load was 13.5% (344 metric tons) greater at the downstream station, than at the upstream station, for the 23-months after the drainage channel construction (Table 3).

ROCK ROAD

The Rock Road bridge construction area changed little over the 43-month study period. Of the 101 storms that were successfully sampled at both the upstream and downstream station, 66 of the storms had significantly higher ($P < 0.05$) TSS at the downstream station and 8 were significantly higher at the upstream station. Total sediment load increased by as much as 18.6 % in a single year and 13.6% (663 metric tons) for the entire study period below the construction activities (Table 4). The higher suspended solids at the Rock Road downstream station indicates a large increase in sediment discharged from the Rock Road construction site.

SUBSTRATE COMPOSITION

None of the three variables that we used to describe substrate composition (geometric mean particle size, median Fredle Index, median % < 1mm) of trout redds, showed any consistent trend when values at the upstream sampling locations were compared to those from the downstream locations (Table 5). We found eight instances in which there was a significant difference ($P < 0.05$) in one the variables at the upstream and downstream locations, and in 7 of 8 comparisons substrate quality was better at the downstream location than at the upstream location. These results provide rather conclusive evidence that sediment loading from the construction sites was not adversely affecting the quality of trout spawning habitat.

MACROINVERTEBRATE COMMUNITIES

Among the four sampling sites, total density of macroinvertebrates ranged widely, from about 100 to > 2000/ft^2 (Figure 6-7). *Chironomidae* larvae and *Gammaridae* were largely responsible for the highest densities of macroinvertebrates. The mean number of taxa from each set of samples ranged from about 9 to 15, which is typical of limestone valley streams. The mean Shannon-Weiner Diversity Index ranged from 1.3 to 1.8, though most samples had a low to modest diversity index. Tabulated raw data from all macroinvertebrate samples are included in the Final Report compact disk.

We employed an analysis of variance to test for differences in macroinvertebrate metrics by treating year, season, and location (upstream and downstream) as main effects including their interactions. At the Park Avenue site, there were no significant effects ($P > 0.05$) of year, season, or location on density, number of taxa, or diversity of macroinvertebrates. At the Rock Road site there was a significant effect ($P < 0.0004$) of year, season, and location on diversity, but diversity tended to be higher at the downstream station than at the upstream station. Thus, overall there was no indication that sediment loading from construction sites adversely affected benthic macroinvertebrate communities.

REDD SURVEYS

Among the sections that encompass the study sites, there has been an increase in the total number of trout redds from 1999 to 2003, which was also evident in other sections of Spring Creek. Total number of trout redds decreased slightly in 2001 but has not changed significantly since 1999. Thus, these data do not indicate any negative effects of construction activities on distribution or density of brown trout redds (Table 6).

DISCUSSION

Highway construction activities near Spring Creek from November 1999 to December 2002, led to an increased sediment load. Construction activities at the Rock Road bridge crossing produced consistent sediment increases throughout the study. Significant increases in TSS during storm events were observed in 65% of the storms successfully sampled. We found an average of 182 metric tons $\cdot$ year^{-1} (370 metric tons in 2002) of sediment attributable to construction activities. Theses results were similar to the 275 metric tons $\cdot$ year^{-1} observed by Hainly (1980), 653 metric tons $\cdot$ year^{-1} Downs Appel (1986), and 236 metric tons $\cdot$ year^{-1} Reed (1980). Differences in sediment load increases may be attributable to the differences in total area of land disturbances, sediment reduction measures taken, and yearly liquid precipitation during study periods. Attempts to reduce sediment at the Rock Road site (stormwater retention ponds, silt fencing) did help reduce sediment runoff during storm events. The lack of buffer area between disturbed areas and the stream contributed to sediment runoff from the site, even though a silt fence was installed along the stream. During periods of heavy rainfall, runoff was retarded by the silt fence, but eventually seeped underneath it.

The largest yearly increase in sediment load (18.6%) was observed in 2002, the period when construction was nearly complete and disturbed areas were beginning to become stabilized. It is likely that the sediment increase was attributable to increased liquid precipitation during the calendar year (Uri and Hedberg,1990). Liquid precipitation in 2002 was approximately 10% higher than yearly average for State College and 30% higher than in the initial two years of the study. The 20% below average liquid precipitation in the first two years of the study were timely and helped keep sediment loads lower than they would have been during years of average rainfall.

Storm events and total sediment load at the Park Avenue site from September 1999 to July 2001 showed little, if any, addition of sediment to the stream from construction activities. These findings were not surprising because there was little ground disturbance near the stream and most of the construction area was separated from the stream by a large grass-covered buffer zone.

Sediment load began to increase in early July 2001, when two concrete drainage channels, leading directly into Spring Creek, were constructed between the upper and lower sampling stations. Attempts to reduce sediment transport through these drainage channels by installing rock dams were largely unsuccessful. Reed (1978) found that lined drainage channels with rock dams trap a mere 5% of suspended sediment.

In 2001 before the concrete drainage channels were in place, the area received 23.8 in of liquid precipitation and total sediment load was 2.9% higher at the upper station than at the lower station. The higher sediment load at the upper station was likely due to construction activities and sediment drainage a few hundred meters above our upper sampler. These drainage areas were not in the original construction plans. During the final six-months of 2001 (after drainage channels were constructed), liquid precipitation was rather small (6.5 in), and total sediment load at the lower station was slightly greater (2.3%) than at the upper station. We did not record the intensity or duration of the storm events that we sampled. Therefore, it is impossible to know if the drainage channels were the sole reason for the increased sediment load after their construction in 2001. But, in 2002 when liquid precipitation increased, sediment load increased to an estimated 13.8% higher at the lower station. This increase, though much higher than previous year, may have been masked by sediment entering the stream above our upper most sampling station. Downs and Appel (1986) made similar observations; they concluded that sediment runoff was masked in a study stream by land disturbances upstream of a sampling site. Even with the potential masking of sediment increases, we still found significant TSS increases in 23 of 42 (55%) storms sampled after the installation of the drainage channels. Significant TSS increases were measured in 12 of the 53 (23%) storms sampled before the installation of the concrete drainage channels. If our study area truly extended above the upper most land disturbance as the initial construction plans suggested, we would have been able to have a better approximation of sediment loading at this site.

None of the other variables that we monitored, namely substrate composition, macroinvertebrate communities, and trout redds, seem to have been affected by the increased sediment loads during the road construction. We chose to monitor these variables, because many other studies have demonstrated that increased sediment loading will negatively affect substrate composition, salmonid reproduction, and macroinvertebrate communities. Apparently, the increased sediment loads that we observed, were not sufficiently large to induce such negative responses.

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REFERENCES

Acornley, R. M., Sear D. A., 1999. Sediment transport and siltation of brown trout (*Salmo trutta L*.) spawning gravels in chalk streams. Hydrological Processes 13, 447-458.

APHA(American Public Health Association), 1995. Standard methods for the examination of water and wastewater. American Water Works Association and Water Environment Federation. Washington, D.C. 19th edition, ed.

Barton, B., 1977. Short-term effects of highway construction on the limnology of a small stream in southern Ontario. Freshwater Biology 7, 99-108.

Carline, R. F., Beard T. D. Jr., Hollender B. A., 1991. Response of wild brown trout to elimination of stalking and no-harvest regulations without terminal tackle restrictions. North American Journal of Fisheries Management 11, 253-266.

Chisholm, J. L., Downs S. C., 1978. Stress and recovery of aquatic organisms as related to highway construction along Turtle Creek, Boone County, West Virginia. Geological survey paper 2055.

Cline, L. D., Short R. A., Ward J. V., 1982. The influence of highway construction on the macroinvertebrates and epilithic algae of a high mountain stream. Hydrobiologia 96, 149-159.

Downs, S. C., Appel D. H., 1986 (West Virginia Department of Highways Virginia Department of Natural Resources). Progress report on the effects of highway construction on suspended-sediment discharge in the Coal River and Trace Fork, West Virginia,1975-81. 84, 4275.

Hainly, R. A., 1980. The effects of highway construction on sediment discharge into Blockhouse Creek and Steam Valley Run, Pennsylvania. U.S. Geological Survey Water Resources Investigations 80-68.

Haynes, A., 1999. The long term effects of forest logging on the macroinvertebrates in a Fijian stream. Hydrobiologia 405, 79-87.

Lisle, T. E., 1989. Sediment transport and resulting deposition in spawning gravels, North Costal California. Water Resources Research 25(6), 1303-1319.

Lisle, T. E., Lewis J., 1992. Effects of sediment transport on survival of salmonid embryos in a natural stream: A simulation approach. Canadian Journal of Fisheries and Aquatic Science 49(11), 2337-2344.

Lotspeich, F. B., and Everest, F. H. 1981. A new method for reporting and interpreting textural composition of spawning gravel. U. S. Forest Service, Pacific Northwest Forest Range Experiment Station, Research Note PNW -369.

McNeil, W. J., and Ahnell, W. H. 1964..Success of pink salmon spawning relative to the size of spawning bed materials. U.S. Fish and Wildlife Service Special Scientific Report Fisheries No. 469. Washington, D. C.

Reed, L., 1978. Effectiveness of sediment-control techniques used during highway construction in central Pennsylvania. Geological survey water-supply paper 2054.

Reed, L., 1980. Suspended-sediment discharge in five streams near Harrisburg, Pennsylvania, before, during, and after highway construction. Geological Survey water-supply paper 2072.

Shaffer, E. L., Carline R. F., Guldin W., Cordell H. K., 1993. Economic amenity values of wildlife: six case studies in Pennsylvania. Environmental Management 19, 669-688.

Shaver, M. L., Shannon J. P., Wilson K. P., Benenati P. L., Blinn D. W., 1997. Effects of suspended sediment and desiccation on the benthic tailwater community in the Colorado River, USA. Hydrobiologia 357, 63-72.

Soulsby, C., Youngson A. F., Moir H. J., Malcolm I. A., 2001. Fine sediment influence on salmonid spawning habitat in a lowland agricultural stream: a preliminary assessment. The Science of the Total Environment 265, 295-307.

Taylor, B., Roff J. C., 1986. Long-term effects of highway construction on the ecology of a southern Ontario stream. Environmental Pollution 40, 317-344.

Uri, N. D., Hyberg B., 1990. Stream sediment loading and rainfall - A look at the issue. Water, Air, and Soil Pollution 51, 95-104.

Witzel, L. D., MacCrimmon H. R., 1983. Embryo survival and alevin emergence of brook charr, *Salvelinus fontinalis*, and brown trout, *Salmo trutta*, relative to redd gravel composition. Canadian Journal of Zoology 61, 1783-1792.

Table 1. Storm events sampled at the Park Avenue and Rock Road stations from November 1999 through May 2003. Storm start times rounded to nearest half hour. Successfully sampled storms denoted as yes (Y) or no (N).

		Start Time		Successfully Sampled			
				Park Avenue		Rock Road	
Date	Peak Discharge (m3/sec.)	Park Avenue	Rock Road	Upper	Lower	Upper	Lower
11/25/99	5.92	6:00	9:00	Y	Y	Y	Y
12/10/99	1.07	NA	10:00	N	N	Y	Y
12/13/99	1.19	10:00	10:30	Y	Y	Y	Y
12/20/99	3.31	16:00	10:00	Y	Y	Y	Y
1/10/00	1.94	13:00	15:00	Y	Y	Y	Y
2/14/00	3.97	2:30	5:00	Y	Y	Y	Y
2/27/00	4.46	14:30	19:00	N	Y	Y	Y
3/1/00	3.98	14:30	16:00	Y	Y	Y	Y
3/11/00	3.29	11:30	13:00	Y	Y	Y	Y
3/16/00	3.29	21:00	19:30	Y	Y	Y	Y
3/21/00	4.31	10:30	12:30	Y	Y	Y	Y
4/4/00	4.69	1:30	2:30	Y	Y	Y	Y
4/8/00	4.04	1:30	16:00	Y	Y	Y	Y
4/17/00	3.09	6:30	8:00	Y	Y	Y	Y
4/21/00	4.26	6:30	8:30	Y	Y	Y	Y
5/19/00	3.97	6:00	7:00	Y	N	Y	Y
5/22/00	5.06	8:00	10:30	Y	Y	Y	Y
5/23/00	4.89	17:00	16:00	Y	Y	Y	Y
5/24/00	4.78	0:00	20:00	Y	Y	Y	Y
5/27/00	2.30	5:00	4:00	N	Y	Y	N
6/6/00	3.15	22:30	0:30	Y	Y	Y	Y
6/13/00	3.50	17:30	20:30	Y	Y	N	Y
6/15/00	6.02	13:30	16:00	Y	Y	Y	Y
6/21/00	4.86	18:00	20:00	Y	Y	Y	Y
7/15/00	2.83	21:00	23:00	Y	Y	Y	Y
7/28/00	3.29	16:30	18:30	Y	Y	Y	Y
8/1/00	3.95	16:00	18:00	Y	Y	Y	Y
8/3/00	4.61	14:30	15:30	Y	Y	Y	Y
8/6/00	3.24	11:30	11:30	Y	Y	Y	Y
8/23/00	2.71	12:00	14:00	Y	Y	Y	Y
8/27/00	5.38	22:30	23:30	Y	Y	Y	Y
9/1/00	2.27	16:00	18:00	Y	Y	Y	Y
9/24/00	3.63	0:00	4:30	Y	Y	Y	Y
9/26/00	1.96	11:30	11:30	Y	Y	Y	Y
10/5/00	2.34	4:00	7:00	Y	Y	Y	Y
10/6/00	3.35	9:00	9:30	Y	Y	Y	Y
10/17/00	3.85	11:00	13:30	Y	N	Y	Y
11/10/00	3.62	2:30	4:00	Y	Y	Y	Y
11/26/00	1.73	1:00	3:00	Y	Y	Y	Y
11/29/00	1.31	20:00	22:00	N	Y	Y	N
12/12/00	1.23	3:00	5:30	Y	Y	Y	N
12/16/00	4.44	17:30	19:30	Y	N	Y	Y
1/19/01	1.32	7:30	NA	Y	Y	N	N
1/30/01	1.96	9:00	9:00	Y	Y	Y	Y
2/16/01	1.79	10:00	10:00	Y	Y	Y	Y
3/12/01	3.46	4:00	5:00	Y	Y	Y	Y
3/16/01	3.17	17:00	18:00	Y	Y	Y	N
3/21/01	5.35	9:00	11:30	Y	Y	Y	Y
3/29/01	4.78	14:30	15:00	Y	Y	Y	Y
4/6/01	4.45	8:00	9:00	Y	Y	Y	Y
4/9/01	3.96	19:00	20:30	Y	Y	Y	N
4/11/01	3.85	12:30	13:30	Y	Y	Y	Y
4/15/01	5.98	19:30	20:00	Y	Y	Y	N
5/25/01	1.75	7:00	13:00	N	Y	Y	N
5/27/01	1.39	13:00	13:00	Y	Y	Y	Y
6/1/01	2.96	15:00	18:30	Y	Y	Y	Y
6/3/01	2.89	0:30	1:30	Y	Y	Y	Y
6/16/01	9.05	10:00	10:00	Y	Y	Y	Y
6/20/01	2.01	13:00	13:00	Y	Y	Y	Y
6/22/01	3.04	12:30	12:30	Y	Y	Y	Y
6/30/01	1.85	11:30	11:30	Y	Y	Y	Y
7/5/01	3.23	16:00	17:30	N	Y	Y	Y
7/26/01	4.03	17:00	0:00	N	Y	Y	Y
8/4/01	1.89	17:00	17:00	N	Y	Y	Y
8/10/01	5.52	11:00	11:00	N	Y	Y	Y
8/16/01	2.25	17:30	20:00	N	Y	Y	Y
8/19/01	9.67	17:30	19:00	N	Y	Y	Y
8/31/01	2.73	NA	19:00	N	N	Y	Y
9/20/01	4.18	10:00	11:00	Y	Y	Y	Y
9/24/01	4.04	11:00	12:00	Y	Y	Y	Y
10/14/01	4.54	21:00	NA	N	Y	N	N
10/16/01	3.20	10:30	11:30	Y	Y	Y	Y
11/25/01	6.34	9:00	11:30	Y	Y	Y	N
11/30/01	4.94	11:00	11:00	Y	Y	Y	Y
12/17/01	2.11	1:00	15:30	Y	Y	Y	Y
2/10/02	4.50	15:30	17:30	Y	Y	N	Y
3/3/02	4.22	22:30	0:00	N	Y	Y	Y
3/9/02	4.05	15:30	16:00	Y	Y	Y	Y
3/16/02	4.10	0:00	3:30	Y	Y	Y	Y
3/20/02	4.42	4:00	6:00	Y	Y	Y	Y
3/26/02	5.60	9:00	8:30	Y	Y	Y	Y
4/8/02	4.29	18:00	19:30	Y	Y	Y	N
4/13/02	4.36	7:00	8:00	N	Y	Y	Y
4/28/02	4.49	7:30	9:00	Y	Y	Y	Y
5/1/02	4.46	15:30	15:00	Y	Y	Y	Y
5/9/02	4.60	0:00	1:30	Y	Y	Y	Y
5/12/02	4.60	7:30	9:30	Y	Y	Y	Y
5/28/02	4.46	17:00	18:30	Y	Y	Y	Y
5/30/02	4.60	18:00	19:30	Y	Y	Y	Y
6/4/02	5.94	21:00	20:00	Y	N	Y	N
6/5/02	4.91	13:00	15:00	Y	Y	Y	N
6/7/02	6.24	0:00	0:00	Y	N	Y	Y
6/14/02	5.09	11:00	11:00	Y	Y	Y	Y
6/27/02	5.56	15:30	16:00	Y	Y	Y	Y
7/19/02	4.35	14:00	14:00	Y	Y	Y	Y
7/23/02	4.01	12:00	18:00	Y	Y	Y	Y
8/23/02	4.01	20:00	22:30	Y	Y	Y	Y
9/15/02	3.93	13:00	15:30	Y	Y	Y	Y
9/22/02	4.67	18:00	20:30	Y	Y	Y	Y
9/26/02	4.42	15:30	18:00	Y	Y	Y	Y
10/15/02	3.95	3:00	9:00	Y	Y	Y	Y
10/25/02	4.27	21:00	23:00	Y	N	Y	Y
11/5/02	4.19	20:00	23:00	Y	Y	Y	Y
11/11/02	4.17	4:00	6:00	Y	Y	Y	Y
11/16/02	4.41	1:30	5:30	Y	Y	Y	Y
12/11/02	4.34	16:30	16:00	Y	N	Y	Y
12/14/02	4.45	0:30	6:00	Y	Y	Y	Y
12/21/02	4.48	NA	4:00	N	N	Y	Y
1/1/03	5.42	10:00	10:00	Y	Y	Y	Y
2/3/03	4.53	20:00	20:30	Y	Y	Y	Y
2/22/02	4.77	11:00	11:30	Y	Y	Y	Y
3/13/03	5.60	11:30	11:00	Y	Y	N	Y
3/20/03	5.82	11:30	15:30	Y	Y	Y	Y
4/5/03	4.85	0:30	0:00	Y	Y	Y	Y
4/11/03	4.84	6:00	7:30	Y	Y	Y	Y
5/5/03	4.25	10:30	12:00	Y	Y	Y	N
5/8/03	4.41	9:00	10:30	Y	Y	Y	Y
5/24/03	4.22	9:30	10:00	Y	Y	Y	Y

Table 2. Comparison of total suspended solids (TSS) during storm events, successfully sampled at upstream and downstream stations, at the Park Avenue site. P-values determined by Wilcoxon sign rank test. Asterisk denotes statistical significance where P < 0.05.

Date	Number of samples compared	Downstream TSS (mg/L)		Upstream TSS (mg/L)		Hourly Downstream		
		Median	Maximum	Median	Maximum	Median	P	
11/25/99	48	19.83	269.53	13.21	264.44	6.20	0.006	*
12/13/99	47	10.28	229.94	10.67	204.19	-1.90	0.021	**
12/20/99	24	7.25	108.27	5.89	127.65	1.31	0.002	*
1/10/00	24	5.45	17.69	3.57	21.45	0.44	0.338	
2/14/00	24	42.50	285.03	40.14	341.15	-0.54	0.616	
3/1/00	23	8.29	23.11	8.71	23.97	0.13	0.513	
3/11/00	24	8.54	58.50	9.63	51.46	-0.40	0.140	
3/16/00	24	5.21	52.45	6.39	60.55	-0.61	0.005	**
3/21/00	24	28.93	100.45	20.98	106.45	4.76	0.000	*
4/4/00	22	16.52	782.92	13.46	84.99	6.88	0.001	*
4/8/00	24	12.99	115.02	12.84	128.93	-0.78	0.009	**
4/17/00	48	8.66	37.07	10.47	31.87	-0.54	0.035	**
4/21/00	47	13.53	89.66	14.46	94.57	-0.41	0.332	
5/22/00	24	8.60	30.04	7.42	30.00	0.72	0.002	*
5/23/00	12	14.93	22.30	12.16	23.41	1.67	0.290	
5/24/00	24	15.05	131.26	15.13	116.27	1.42	0.000	*
6/6/00	24	4.40	33.95	3.98	35.04	0.54	0.036	*
6/13/00	24	11.24	123.18	9.59	111.87	2.31	0.000	*
6/15/00	24	40.47	620.09	42.65	352.50	-3.54	0.018	**
6/21/00	24	22.77	415.71	23.18	434.30	-0.27	0.484	
7/16/00	23	4.04	41.12	4.51	43.16	-0.86	0.000	**
7/28/00	24	9.34	110.10	9.32	102.84	-0.33	0.308	
8/1/00	24	23.41	165.62	24.52	205.18	0.15	0.679	
8/3/00	24	15.78	265.29	15.35	275.52	0.00	0.989	
8/6/00	24	12.63	38.27	12.75	39.62	-0.26	0.595	
8/23/00	24	7.07	49.54	7.38	59.67	-1.43	0.004	**
8/27/00	24	16.20	465.00	14.99	435.34	0.00	1.000	
9/1/00	24	8.85	36.19	7.61	39.67	0.21	0.679	
9/24/00	15	8.33	225.96	7.48	166.75	1.49	0.010	*
9/26/00	22	6.38	25.91	5.71	26.74	0.77	0.001	*
10/5/00	15	15.48	82.57	14.62	95.15	-1.23	0.410	
10/6/00	9	5.19	14.70	5.98	12.89	-0.42	0.636	
11/10/00	24	6.52	225.17	7.55	281.56	-3.08	0.015	**
11/26/00	23	4.17	54.55	8.02	77.52	-4.13	0.000	**
12/12/00	21	10.55	30.75	9.92	43.07	0.17	0.837	
1/19/01	24	10.59	21.03	13.70	29.60	-3.10	0.001	**
1/30/01	49	21.37	111.94	13.49	136.75	1.60	0.093	
2/16/01	24	9.81	13.74	11.38	14.58	-0.37	0.259	
3/12/01	24	26.04	200.39	18.19	166.75	4.85	0.000	*
3/16/01	24	19.16	32.19	19.87	30.13	-1.89	0.449	
3/21/01	48	23.56	201.15	23.39	202.67	1.41	0.082	
3/29/01	49	14.70	93.58	13.74	99.86	0.49	0.155	
4/6/01	24	15.17	112.74	16.37	132.76	-0.62	0.242	
4/9/01	24	6.90	17.61	9.47	44.69	-1.78	0.041	**
4/11/01	23	9.57	17.57	10.20	19.48	-0.19	0.132	
4/15/01	46	30.22	101.64	29.33	102.84	0.04	0.965	
5/27/01	23	10.59	17.73	11.78	20.57	-1.98	0.000	**
6/1/01	19	14.22	123.18	16.21	148.22	-2.66	0.004	**

Date	Number of samples compared	Downstream TSS (mg/L)		Upstream TSS (mg/L)		Hourly Downstream TSS		
		Median	Maximum	Median	Maximum	Median	P	
6/3/01	24	9.07	112.55	10.22	130.87	-2.44	0.000	**
6/16/01	36	25.24	1527.53	19.87	1217.34	4.36	0.001	*
6/20/01	14	11.62	20.52	16.95	27.44	-5.18	0.003	**
6/22/01	22	35.02	71.76	33.07	84.26	0.04	1.000	
6/30/01	21	7.48	10.47	7.52	12.29	-1.17	0.008	**
Drainage Ditches Construction Begins								
9/20/01	23	16.74	1113.92	19.52	261.91	-4.58	0.005	**
9/24/01	22	31.27	2067.86	31.55	187.69	-1.80	0.721	
10/16/01	20	11.60	92.42	10.08	65.54	0.69	0.533	
11/25/01	23	31.78	381.57	26.39	563.82	5.66	0.104	
11/30/01	24	32.57	202.67	32.60	237.98	-1.88	0.175	
12/17/01	24	18.13	55.51	19.52	66.38	-1.67	0.050	
2/10/02	23	56.31	185.48	53.45	212.64	-1.87	0.037	**
3/9/02	24	7.52	148.09	7.63	204.95	0.01	0.988	
3/16/02	24	13.82	67.86	12.77	15.03	2.51	0.247	
3/20/02	24	41.49	119.52	33.11	93.46	13.58	0.089	*
3/26/02	24	575.02	958.73	176.35	799.34	165.10	0.000	*
4/9/02	24	14.55	89.37	10.85	123.18	1.47	0.057	
4/28/02	24	34.45	1404.79	48.76	302.67	-9.87	0.100	
5/1/02	45	12.65	51.96	12.65	83.13	-1.14	0.254	
5/9/02	23	24.96	219.65	20.57	218.08	1.15	0.867	
5/12/02	48	48.53	1099.50	55.24	1052.09	-11.48	0.001	**
5/28/02	24	23.07	96.73	9.93	25.82	10.75	0.000	*
5/31/02	18	27.13	63.03	20.65	72.62	3.98	0.010	*
6/5/02	19	65.38	173.86	34.13	71.49	30.21	0.000	*
6/14/02	48	28.25	217.30	20.27	99.27	6.98	0.048	*
6/27/02	24	74.30	1946.32	39.89	613.99	28.11	0.000	*
7/19/02	24	19.67	188.42	13.43	168.16	6.81	0.000	*
7/23/02	22	24.61	259.39	15.39	103.14	15.85	0.000	*
8/23/02	24	38.65	453.25	28.12	58.86	12.13	0.008	*
9/15/02	24	5.53	32.14	7.02	17.44	-2.14	0.166	
9/22/02	24	35.78	593.45	23.26	378.62	14.80	0.000	*
9/26/02	46	34.13	166.96	23.45	113.78	13.22	0.000	*
10/15/02	24	21.85	79.34	27.74	101.88	-6.35	0.000	*
11/5/02	24	11.50	43.92	10.95	43.11	0.13	0.786	
11/11/02	24	19.96	244.49	12.87	104.04	11.63	0.000	*
11/16/02	23	19.48	34.18	12.33	26.95	7.01	0.000	*
12/14/02	20	30.53	214.97	16.95	36.37	15.99	0.000	*
1/1/03	47	82.68	796.59	40.04	198.13	23.94	0.000	*
2/3/03	19	42.16	207.24	27.09	227.55	3.65	0.073	
2/22/03	32	55.10	264.44	48.17	255.22	5.77	0.001	*
3/13/03	24	150.52	547.53	125.27	559.14	15.05	0.010	*
3/20/03	44	54.49	269.53	43.07	262.76	10.51	0.000	*
4/5/03	24	25.09	207.24	19.52	115.02	3.13	0.001	*
4/11/03	23	18.27	43.97	23.49	206.48	-8.53	0.018	**
5/5/03	23	13.94	37.81	15.84	47.83	-1.09	0.218	
5/8/03	46	17.16	207.01	15.27	99.98	2.56	0.031	*
5/24/03	11	9.57	18.93	12.53	18.48	-3.02	0.045	*

* Downstream site is significantly higher than upstream site
** Upstream site is significantly higher than downstream site

Table 3. Estimated sediment load (metric tons) at the upstream and downstream stations at the Park Avenue and Rock Road construction sites.

		Park Avenue		Rock Road	
Year	Rainfall * (in)	Sediment (t)	% difference	Sediment (t)	% difference
1999**	4.5				
Upstream		61	11.1	91	51.2
Downstream		68		188	
2000	31.4				
Upstream		380	-7.4	582	9.5
Downstream		354		644	
2001	30.3				
Upstream		798	0.1	969	8.9
Downstream		799		1063	
2002	42.5				
Upstream		1571	13.8	1618	18.6
Downstream		1823		1988	
2003***	15.7				
Upstream		526	13.5	926	4.2
Downstream		608		967	
TOTAL	124.5				
Upstream		3336	8.7	4186	13.7
Downstream		3653		4849	

* Total liquid precipitation for State College, PA as reported by The Pennsylvania State Climatologist.
** Partial year data, collection did not start until November 5, 1999
*** Partial year data, collection ended May 31, 2003

Table 4. Comparison of total suspended solids (TSS) during storm events, successfully sampled at upstream and downstream stations, at the Rock Road site. P-values determined by Wilcoxon sign rank test. Asterisk denotes statistical significance where $p < 0.05$.

Date	Number of samples compared	Downstream TSS (mg/L)		Upstream TSS (mg/L)		Hourly Downstream		
		Median	Maximum	Median	Maximum	Median	P	
11/25/99	48	20.39	943.66	17.86	266.93	66.45	0.000	*
12/10/99	24	5.48	8.85	4.84	14.01	0.39	0.204	
12/13/99	46	15.82	175.69	13.75	156.44	2.80	0.000	*
12/20/99	23	15.56	63.44	16.47	59.44	1.22	0.157	
1/10/00	22	10.59	22.63	8.34	17.76	1.68	0.001	*
2/14/00	24	64.45	163.54	62.11	136.70	9.50	0.000	*
2/27/00	24	58.14	168.54	43.10	133.90	7.48	0.000	*
3/1/00	23	19.55	38.38	15.50	31.30	2.53	0.000	*
3/11/00	23	18.15	37.66	17.05	31.17	2.09	0.000	*
3/16/00	11	11.69	29.87	11.69	26.08	3.13	0.029	*
3/21/00	23	35.69	104.79	31.83	77.21	5.39	0.000	*
4/4/00	24	32.58	327.47	27.45	271.46	-0.07	0.966	
4/8/00	24	22.70	74.52	22.14	65.45	1.64	0.003	*
4/17/00	47	19.64	47.95	16.34	39.04	3.20	0.000	*
4/21/00	24	25.95	58.84	50.50	464.08	-35.33	0.000	**
5/19/00	24	12.69	54.58	10.69	50.26	2.95	0.000	*
5/22/00	23	16.02	24.00	12.27	19.97	2.70	0.000	*
5/23/00	24	34.61	96.70	25.59	80.52	7.03	0.000	*
5/24/00	24	30.68	136.70	27.78	108.16	5.83	0.000	*
6/6/00	22	8.08	36.81	8.47	38.19	0.03	0.897	
6/15/00	24	72.30	408.39	99.88	373.10	-26.53	0.001	**
6/21/00	21	33.40	226.63	46.53	296.58	-16.19	0.000	**
7/15/00	45	8.02	24.65	16.08	58.77	-10.53	0.000	**
7/28/00	23	12.92	39.04	13.72	80.25	-0.90	0.140	
8/1/00	23	56.31	143.09	25.04	59.10	23.67	0.000	*
8/3/00	24	33.07	145.55	22.40	97.04	8.52	0.000	*
8/6/00	24	23.54	40.69	16.53	29.93	7.74	0.000	*
8/23/00	24	17.86	37.53	10.01	32.28	8.31	0.001	*
8/27/00	23	27.19	527.96	19.26	266.18	24.87	0.000	*
9/1/00	23	17.51	36.02	14.40	25.95	5.82	0.000	*
9/24/00	24	35.14	206.08	9.88	53.91	28.58	0.000	*
9/26/00	23	14.21	30.78	8.72	18.74	5.32	0.000	*
10/5/00	23	32.15	43.52	13.95	19.58	16.32	0.000	*
10/6/00	24	15.43	29.73	24.58	130.83	8.83	0.004	*
10/17/00	23	17.51	63.24	27.32	154.52	9.30	0.000	*
11/10/00	22	17.41	73.64	34.77	213.39	16.17	0.048	*
11/26/00	24	8.27	17.57	9.76	19.32	1.95	0.002	*
12/16/00	23	79.10	155.02	185.26	392.28	108.60	0.000	*
1/30/01	47	33.99	145.13	42.60	88.39	7.92	0.000	*
2/16/01	24	11.11	17.38	16.60	25.69	6.32	0.000	*
3/12/01	24	60.90	266.93	133.90	500.01	57.43	0.001	*
3/22/01	22	44.11	58.64	62.34	87.77	20.44	0.000	*
3/29/01	44	19.51	99.37	25.30	126.22	1.91	0.061	
4/6/01	8	53.25	84.25	69.94	104.99	19.01	0.014	*
4/11/01	15	22.57	26.93	24.19	29.41	-0.49	0.551	
5/27/01	23	17.05	28.30	19.71	28.23	1.98	0.061	
6/1/01	24	38.32	210.46	29.41	134.04	-5.70	0.100	
6/3/01	24	16.66	98.14	22.96	74.45	4.90	0.008	*
6/16/01	48	128.31	832.08	90.77	880.11	2.39	0.685	
6/20/01	16	14.01	49.67	21.92	51.13	7.72	0.059	
6/22/01	24	37.07	89.95	40.03	72.36	3.90	0.021	*
6/30/01	47	11.43	20.29	13.11	23.80	-2.93	0.060	
7/5/01	17	23.41	42.20	21.01	57.37	-0.58	0.813	
7/26/01	24	33.73	250.03	29.41	418.12	-7.07	0.041	**
8/4/01	18	13.04	25.56	16.21	34.84	5.48	0.001	*
8/10/01	24	68.67	342.30	84.58	423.00	11.65	0.031	*
8/16/01	24	28.69	58.17	26.93	53.91	-2.91	0.061	
8/19/01	21	354.09	910.26	335.26	1245.87	16.55	0.281	
8/31/01	23	26.05	113.40	27.52	116.71	2.15	0.011	*
9/20/01	23	45.30	336.04	28.75	254.15	-16.60	0.043	**
9/24/01	24	26.93	264.67	58.97	430.34	29.12	0.000	*
10/16/01	22	10.17	35.36	20.03	66.52	7.16	0.000	*
11/30/01	21	48.28	203.89	32.55	133.20	26.79	0.000	*
12/17/01	23	31.11	53.98	20.75	33.59	9.41	0.000	*
3/3/02	23	33.46	189.37	17.76	72.43	18.21	0.000	*
3/9/02	23	26.80	85.06	13.50	52.05	14.34	0.000	*
3/16/02	20	25.27	42.00	14.98	27.97	10.19	0.000	*
3/20/02	23	57.84	107.67	56.97	99.92	5.02	0.004	*
3/26/02	42	342.30	974.42	217.06	594.44	89.30	0.000	*
4/13/02	24	22.50	81.81	27.78	133.13	-6.70	0.310	
4/28/02	23	32.02	107.19	28.75	84.58	4.87	0.009	*
5/1/02	42	15.82	68.13	12.40	44.44	5.98	0.000	*
5/9/02	24	21.98	141.61	19.13	117.68	4.21	0.074	
5/12/02	38	46.89	856.00	43.98	779.18	12.55	0.000	*
5/28/02	23	7.57	38.52	15.43	29.67	-0.93	0.727	
5/30/200	36	88.86	205.35	73.03	184.32	9.34	0.000	*
6/7/02	21	104.37	357.25	98.34	392.28	2.96	0.889	
6/14/02	47	25.75	120.87	23.61	103.34	1.09	0.078	
6/27/02	22	69.72	436.88	57.90	431.15	9.26	0.000	*
7/19/02	23	24.65	64.98	16.66	39.70	4.86	0.005	*
7/23/02	16	22.89	37.07	13.43	20.81	9.61	0.000	*
8/23/02	24	18.93	27.38	23.48	99.51	-4.42	0.002	**
9/15/02	22	12.37	20.23	9.92	39.83	3.16	0.005	*
9/22/02	24	37.33	274.49	108.16	391.48	-60.94	0.000	**
9/26/02	44	45.04	125.11	28.04	102.52	14.57	0.000	*
10/15/02	19	43.59	90.84	32.48	64.98	9.80	0.000	*
10/25/02	24	19.90	79.24	17.70	69.34	1.96	0.021	*
11/5/02	24	15.56	50.33	13.69	36.09	5.48	0.000	*
11/11/02	24	23.67	40.09	22.24	30.65	2.01	0.023	*
11/16/02	22	22.96	52.52	21.07	49.80	1.73	0.069	
12/11/02	20	34.35	127.27	27.74	60.24	4.38	0.008	*
12/14/02	23	32.42	54.84	31.50	84.25	3.27	0.016	*
12/21/02	21	36.35	81.74	27.97	63.64	10.43	0.005	*
1/1/03	43	125.39	233.29	135.37	234.03	1.63	0.562	
2/3/03	19	24.00	125.53	31.89	118.72	-0.86	0.825	
2/22/03	38	59.64	155.02	65.12	120.52	8.96	0.000	*
3/20/03	42	141.96	272.98	131.10	238.56	2.46	0.183	
4/5/03	24	52.72	167.11	53.78	145.13	-1.31	0.484	
4/11/03	24	32.26	46.36	33.46	48.14	-1.04	0.484	
5/8/03	43	30.81	120.94	28.43	104.24	2.06	0.048	*
5/24/03	25	23.02	30.58	22.47	75.73	-0.62	0.830	

Table 5. Composition of substrates collected with stovepipe samplers from trout redds upstream and downstream of the construction sites at Park Avenue and Rock Road. Medians were compared using a Mann-Whitney test and P-values for each comparison are provided.

Year and variable	Sampling Locations							
	Park Avenue				Rock Road			
	Upper	Lower	P		Upper	Lower	P	
1999								
n	15	13			15	15		
Geometric Mean Particle Size	10.42	11.12	0.333		8.72	9.79	0.678	
Median Fredle Index	4.16	4.01	0.709		2.42	2.63	0.927	
Median % < 1 mm	7.92	9.18	0.507		15.64	13.57	0.461	
2000								
n	15	9			15	15		
Geometric Mean Particle Size	15.50	9.90	0.020	*	11.06	11.13	0.561	
Median Fredle Index	6.10	2.62	0.455		3.17	3.96	0.005	*
Median % < 1 mm	3.27	14.11	0.041	*	10.71	6.75	0.006	*
2001								
n	15	14			15	15		
Geometric Mean Particle Size	10.72	13.08	0.326		7.94	12.58	0.028	*
Median Fredle Index	3.43	5.46	0.003	*	1.99	4.35	0.214	
Median % < 1 mm	8.98	5.95	0.004	*	18.97	5.81	0.445	
2002								
n	15	12			15	15		
Geometric Mean Particle Size	11.09	12.62	0.188		7.92	9.01	0.942	
Median Fredle Index	4.02	4.33	0.097		2.23	2.73	0.294	
Median % < 1 mm	8.10	7.10	0.016	*	16.34	13.24	0.906	

* Significant at P < 0.05

Table 6. Numbers of brown trout redds counted during late November surveys of Spring Creek, 1997-2002. The Park Avenue site is located in section 7 and the Rock Road study site spanned the upstream boundary of section 9.

Section Number	Upstream boundary	Section Length (km)	Number of redds					
			1997	1998	1999	2000	2001	2002
6	HWY 26	1.34	17	14	30	36	47	46
7	Puddintown Rd.	2.31	47	32	36	38	45	75
8	Trout Rd.	2.33	19	35	15	42	38	116
9	Private bridge at 600 Rock Rd	2.99	128	156	143	193	138	259
10	Shiloh Rd	2.29	83	48	98	157	*	162

* Redd counts were not done at this site.

Figure 1. Map of Spring Creek with surrounding roads and our study site locations.

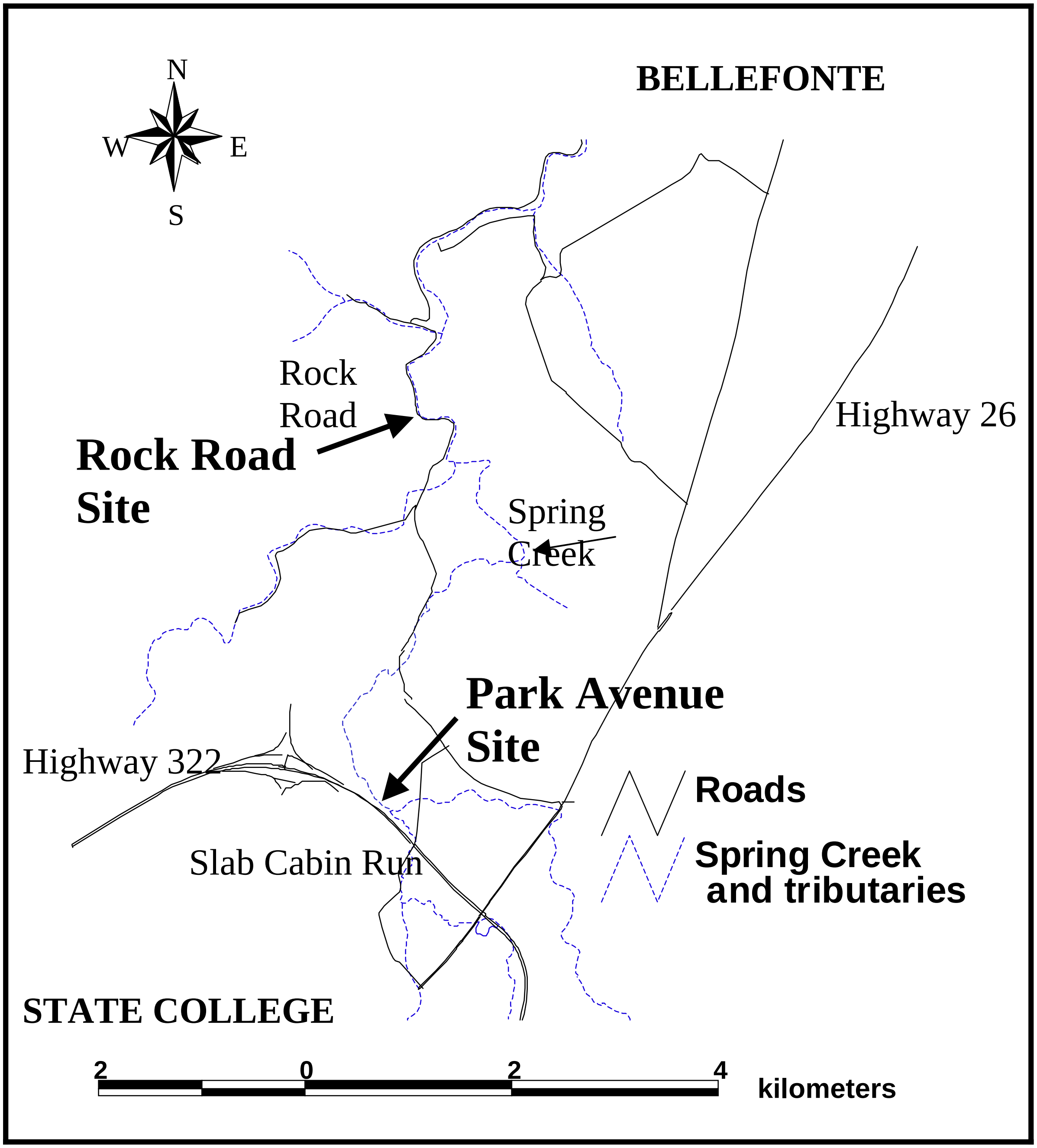
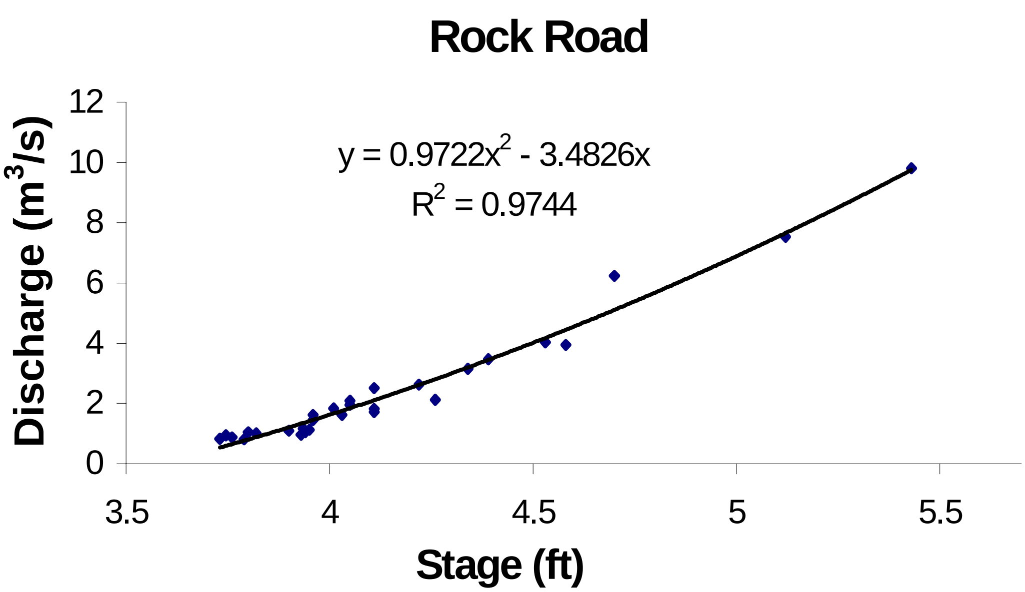


Figure 2. Rating curves of stream discharge versus stage height from flows taken at the Park Avenue and Rock Road sites.



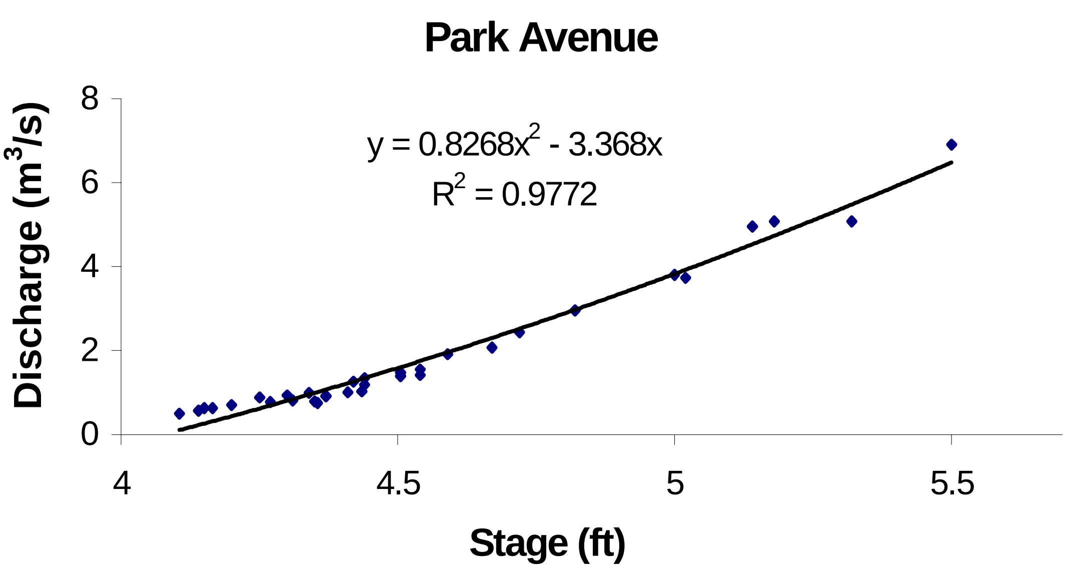
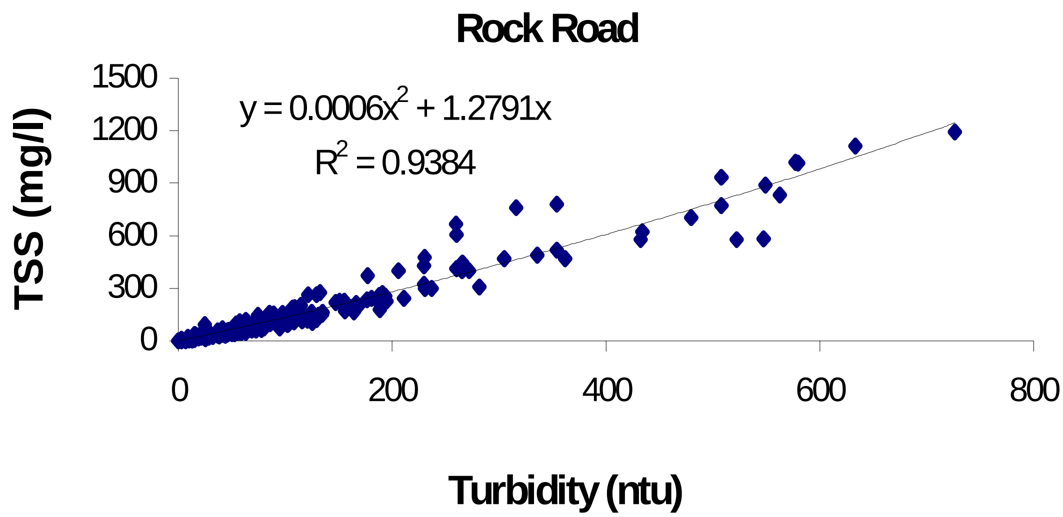


Figure 3. Relations between turbidity and total suspended solids (TSS) for the Park Avenue and Rock Road sites.



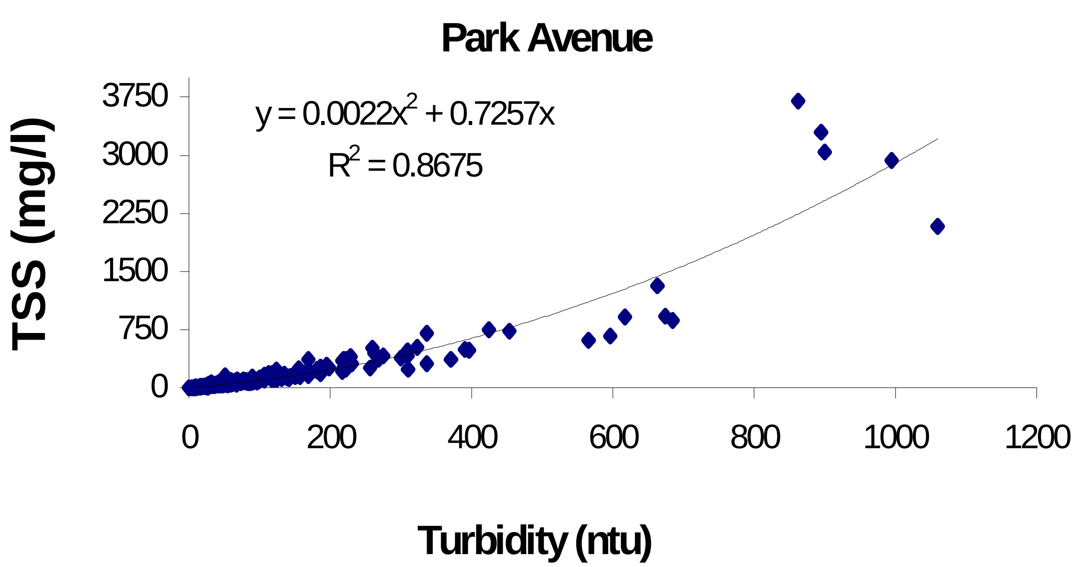


Figure 4. Hourly values for the May 19, 2000 storm event, showing the total suspended sediment at the Rock Road upper and lower stations with respect to stream discharge.

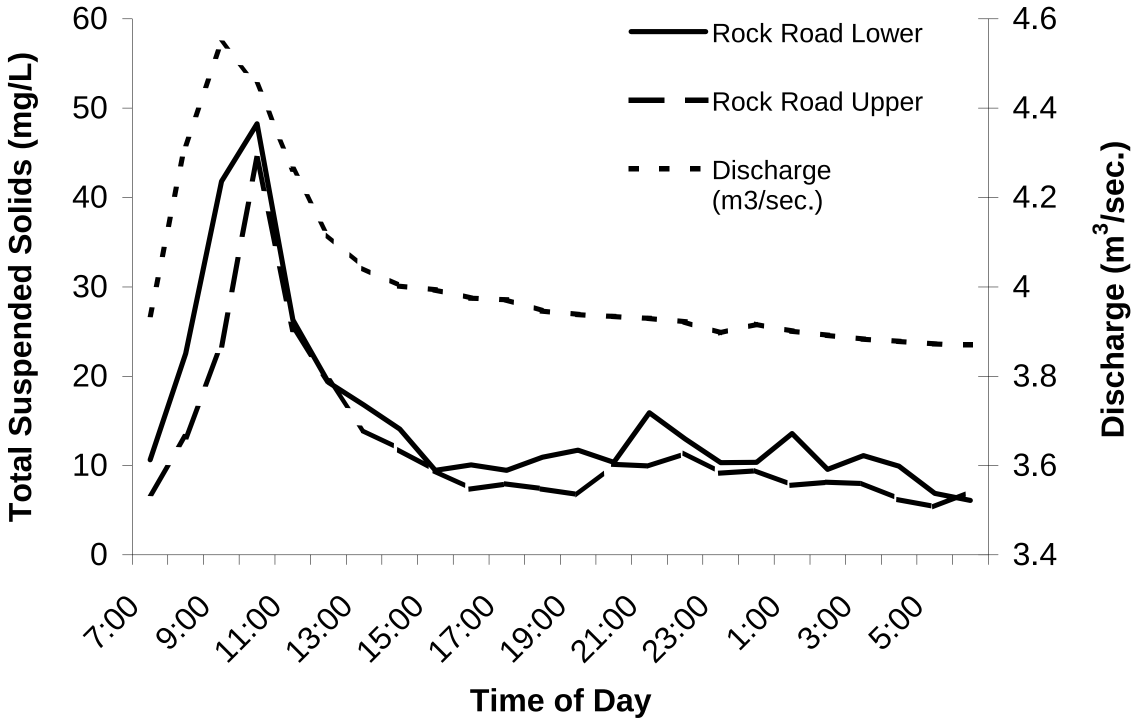
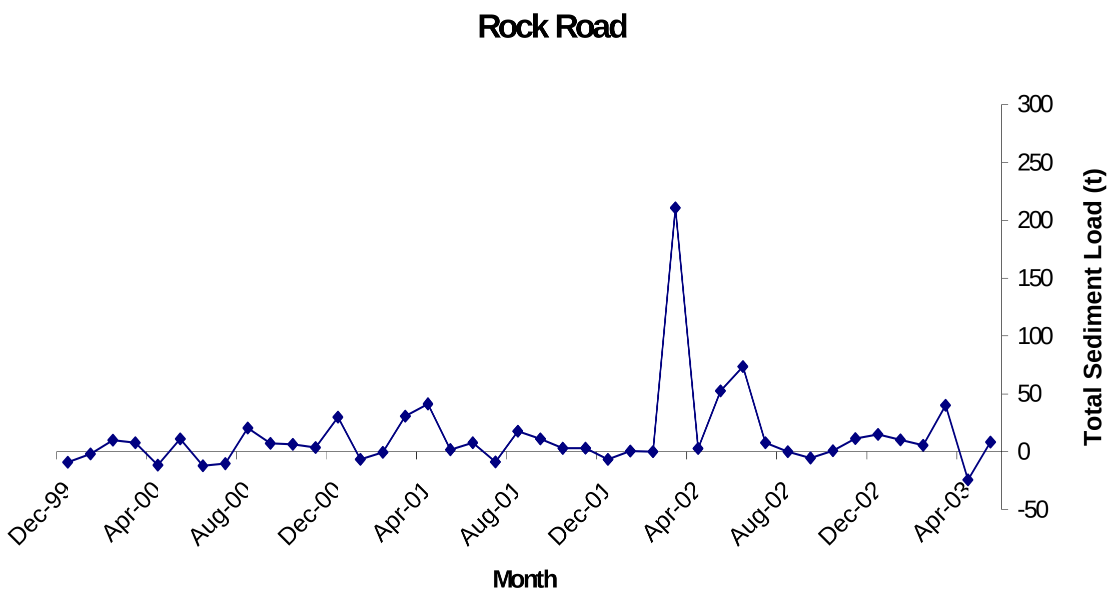


Figure 5. Monthly sediment load increase in metric tons (Downstream – Upstream) for the Park Avenue and Rock Road sites for the entire study.



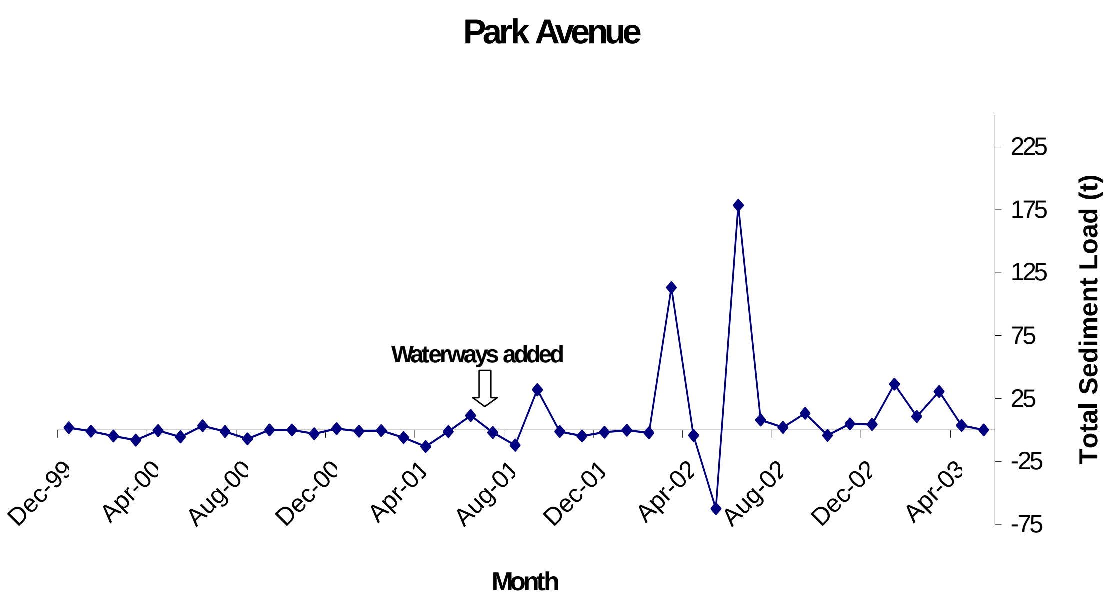


Figure 6. Median and interquartile range of density, number of taxa, and diversity index of macroinvertebrate communities at the upstream and downstream sampling sites in Spring Creek near the Park Avenue interchange and Rock Road bridge crossing, Fall 1999 through Spring 2003.