Volume 62 | Number 1 Article 7

2-19-2002

# Benthos recovery after an episodic sediment release into a Colorado Rocky Mountain river

Robert E. Zuellig
*Colorado State University, Fort Collins*

Boris C. Kondratieff
*Colorado State University, Fort Collins*

Howard A. Rhodes
*USDA Forest Service, Rocky Mountain Research Station, Laramie, Wyoming*

Western North American Naturalist 62(1), © 2002, pp. 59–72

# BENTHOS RECOVERY AFTER AN EPISODIC SEDIMENT RELEASE INTO A COLORADO ROCKY MOUNTAIN RIVER

Robert E. Zuellig[1,3], Boris C. Kondratieff[1], and Howard A. Rhodes[2]

ABSTRACT.—During late September 1996, approximately 7000 $m^3$ of clay- to gravel-sized sediment was flushed from Halligan Reservoir, Larimer County, Colorado, into the North Fork Cache la Poudre River during dam inspections. Approximately 9.6 km of this river was partially or completely affected by this episodic sediment release. Pools up to 3.2 km downstream from the dam lost 50% of their volume. Hess samples taken from October 1996 to September 1997, 100 m downstream from the dam (site 1) and 3.2 km downstream (site 2), revealed effects of sediment on recovery patterns of benthic communities. A 2-way ANOVA was used to determine significant interactions using site and date as main factors. Pairwise differences were then compared using least squares means to determine significant dates within and between sites. Ten days after the sediment release, both density and taxa richness at site 1 (55 organisms per $m^2$, 5 taxa) were significantly lower ($P < 0.05$) than site 2 (1156 organisms per $m^2$, 25 taxa). These differences remained until June when species richness and densities increased. Plecoptera and Trichoptera colonized from June to September after being eliminated at site 1 and reduced at site 2. No permanently flowing tributaries exist within the study area; therefore, passive downstream drift from such inputs apparently did not influence recovery. Increased densities of taxa such as Baetidae, Hydroptilidae, Hydropsychidae, Chironomidae, Simuliidae, and Oligochaeta occurred plausibly by rapid reproduction. Based on pre-event data, community function completely changed at site 2 from a scraper community to one dominated by collector-gatherers.

*Key words: sediment, recovery, benthic, macroinvertebrate, North Fork Cache la Poudre River, Colorado.*

Bed and suspended load sediments can affect stream ecosystems by increasing turbidity and filling streambed pools, which may reduce or eliminate benthic and fish productivity. Small amounts of sediment can reduce the density and diversity of benthic macroinvertebrates, and greater amounts of sediment can significantly alter benthic macroinvertebrate function and structure (Lenat et al. 1979). Episodic sediment transport events are considered temporary in duration. This type of sedimentary transport event can reduce densities of benthic macroinvertebrate communities up to 80% or even eliminate them completely (Waters 1995). Recovery from episodic releases of sediment is often rapid after the source input is ceased (Tsui and McCart 1981, Cline et al. 1982, DeWalt and Olive 1988). Knighton (1998) and Thorne et al. (1987) provide an extensive explanation of sediment transport in rivers, and Beschta et al. (1981) describe a sediment transport event during a controlled reservoir release. The length of time required for flushing large amounts of deposited sediment due to reservoir release and the temporal impact and recovery from those sediments on downstream macroinvertebrate-producing riffles have seldom been evaluated (Waters 1995).

During the last week of September 1996, Halligan Reservoir, a 150-ha agricultural water storage reservoir in northeastern Colorado, was drained for a dam inspection. Water released from the bottom of the dam transported approximately 7000 $m^3$ of clay- to gravel-sized sediment along 12 km of the North Fork Cache la Poudre River (Wohl and Cenderelli 2000). Approximately 2447 $m^3$ of silt and sand were deposited along the first 366 m of river below the dam. Most of the initial sediment deposition occurred in pools (Wohl and Cenderelli 2000). The first large pool downstream of the dam was completely filled by 3 vertical meters of silt and fine sediment. Pools up to 3.2 km downstream from the dam lost as much as 50% of their volume, and pools as far as 5 km downstream lost up to 30% of their volume (Wohl and Cenderelli 2000). Most of the suspended sediment load transport occurred

[1]Colorado State University, Department of Bioagricultural Sciences and Pest Management, Fort Collins, CO 80523.
[2]USDA Forest Service, Rocky Mountain Research Station, 222 South 22nd Street, Laramie, WY 82070.
[3]Present address: Colorado State University, Department of Fishery and Wilklife Biology, Fort Collins, CO 80523.

in April at both sites, whereas bedload sediment transport varied (see Wohl and Cenderelli 2000 for a detailed description of this episodic sediment transport event). Based on previous fish population studies (K.D. Fausch, Colorado State University, unpublished data), an estimated 4000 rainbow (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*) were killed by the sediment release.

This study describes the first year's temporal recovery of benthic macroinvertebrate communities along the North Fork Cache la Poudre River from Halligan Reservoir downstream 3.2 km. This episodic release of sediment provided a unique opportunity to follow the benthic macroinvertebrate recolonization of the riffle communities of this stream. Understanding temporal recovery patterns will aid managers in making better decisions about the timing of, and recovery from, future sediment releases. Limited pre-event data on benthic macroinvertebrate community structure and function were available, providing a comparison of pre- and post-event community dynamics.

## STUDY AREA

The North Fork basin drains 1500 km$^2$ with 110 km of stream including tributaries that drain into Halligan Reservoir (Black et al. 1959). This basin, underlain by Precambrian silver plume granite (Tweto 1979), has an average annual precipitation estimated at 40.6 cm and a mean elevation of 2374 m (Black et al. 1959). The dam at Halligan Reservoir was constructed in 1910 and is located on the North Fork of the Cache la Poudre River 14 km upstream from County Road 80c in the north central portion of Larimer County, Colorado (T11N R71W, sec34, NE1/4 of the SW1/4; Fig. 1). At full pool this reservoir covers 150 ha and has a storage capacity of 8 million m$^3$. The North Fork flows through a bedrock canyon below Halligan Reservoir, and no permanently flowing tributaries exist within the study area that could influence the recovery of benthic communities. Water release is controlled by the operation of Halligan Reservoir, which has a single outlet valve with the capacity of 3.93 m$^3 \cdot$ s$^{-1}$. Water spills over the dam when the outlet valve capacity is exceeded during each snowmelt season. Typically, the reservoir release hydrograph follows a snowmelt pattern, with peak flows in late May–early June followed by low late fall and winter base flows (Wohl and Cenderelli 2000).

## MATERIALS AND METHODS

Two sampling sites were established on the North Fork of the Cache la Poudre River below Halligan Reservoir. Site 1 was 100 m below Halligan Reservoir, and site 2 was 3.2 km downstream from the dam within The Nature Conservancy's Phantom Canyon Preserve. We took 3 subsamples twice per month from October 1996 to September 1997 at each site except in December, January, February, June, and September, when subsamples were taken monthly. High-water discharge during April prevented sampling, and samples taken on 31 January and 22 May 1997 were excluded from the analysis because of extreme low- and high-water conditions. We collected samples with a Hess bottom sampler with 500-µm mesh in riffle areas (Platts et al. 1983).

The structure and function of the benthic communities at both sites were evaluated using density (/m$^2$), total number of taxa (T), cumulative Ephemeroptera, Plecoptera, and Trichoptera taxa (EPT), Shannon's diversity (H) and Shannon's evenness (J) indices, and relative abundance of functional feeding guilds. The formulas presented by Washington (1984) were used to calculate H and J. Although ecological indices are controversial (Washington 1984), the Shannon diversity index has been widely applied and continues to be used as a data analysis tool (e.g., Reiners 1992). A sample was considered the combined total of 3 Hess subsamples taken at each site and date. T and EPT were calculated as the number of new taxa found in each subsample; H and J values were calculated using the combined total of each sample. Density values were calculated from the mean density of individuals /m$^2$ from the 3 Hess subsamples taken at each site and date. Using a balanced 2-way ANOVA, we compared density means with site and date as main factors. Pairwise differences were then calculated using least squares means to determine significance within and between sites. Density values were $\text{Log}_{10}$ +1 transformed before analysis (Norris and Georges 1993), which validated the assumptions of homogeneity of variances and normality. Statistical analysis was performed using a PC version of Statistical Analysis System (SAS® 1985). Following

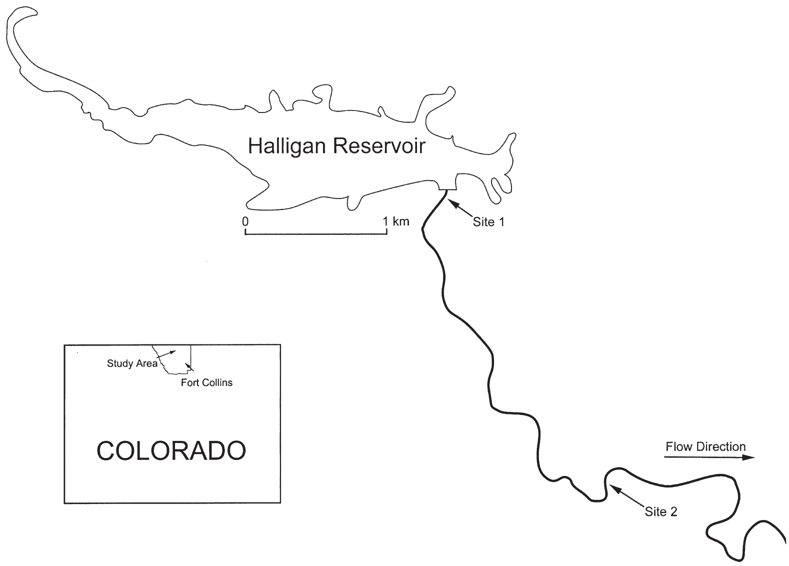


Fig. 1. Halligan Reservoir, the North Fork of the Cache la Poudre River, Larimer Co., Colorado, and study sites.

Merritt and Cummins (1996) and Thorp and Covich (1991), we assigned individuals to feeding guilds and then calculated the percentage of each guild in each sample. Community structure and feeding guild comparisons were made at site 2 with data collected at this same location by J.V. Ward and B.C. Kondratieff in 1990 in part of a report to The Nature Conservancy. These pre-event samples were represented by 3 Surber samples taken on 3 dates in 1990 (20 June, 19 July, 22 August) and were compared with our samples taken on similar dates in 1997 (28 June, 26 July, and 30 August).

## RESULTS

### Community Structure

H, J, T, EPT, density means, and $s_{\bar{x}}$ are summarized for sites 1 and 2 in Table 1. At site 1 the macroinvertebrate community from October 1996 to May 1997 was 91% Diptera, 1% each for Ephemeroptera and Plecoptera, and 7% remaining taxa which include the groups Oligochaeta, Nematoda, Gastropoda, Hydrocarina, and Turbellaria (Fig. 2). Ephemeroptera recolonized, making up 40% of the community from June to September, while Diptera continued to be abundant (55%) at site 1 (Fig. 2). Trichoptera increased to 2%, and remaining taxa decreased to 3%.

At site 2 community structure during the same time period was 56% Diptera, 4% Ephemeroptera, 14% Trichoptera, and 26% remaining taxa (Fig. 2). Ephemeroptera and Plecoptera began to increase in June 1997, Diptera and remaining taxa decreased, and the proportion of Trichoptera remained unchanged (17%; Fig. 2). The macroinvertebrate community for the entire sampling period at site 1 and site 2 primarily comprised Diptera and Ephemeroptera (Fig. 2). However, Diptera had a greater percentage representation at site 1, whereas Trichoptera and other remaining taxa were important at site 2 (Fig. 2).

### Total Number of Taxa (T) and Ephemeroptera, Plecoptera, Trichoptera Taxa (EPT)

Changes that occurred in T and EPT are described in Figure 3 using median, interquartile range, and extreme values. At site 1, T ranged from 4 in February to 33 in September. T began to increase substantially from the beginning of May to the end of June (Table 1). Only 2 EPT taxa were collected on any given date until May at site 1, and both of these were represented by only a few individuals. The number of EPT taxa increased in June and continued to increase throughout the remainder of the study period at both sites (Fig. 3). Four stonefly taxa at site 1, including early

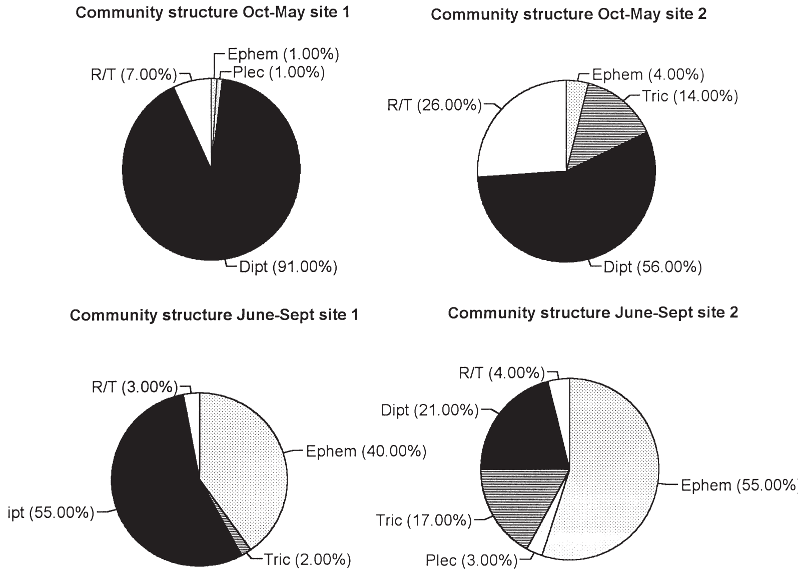


Fig. 2. Community structure data collected from the North Fork of the Cache la Poudre River from October 1996 to September 1997 after an episodic sediment release below Halligan Reservoir. Changes in community structure are shown as cumulative changes at sites 1 and 2 from October through May and from June through September. Ephem = Ephemeroptera, Plec = Plecoptera, Tric = Trichoptera, Dipt = Diptera, R/T = remaining taxa (Oligochaeta, Nematoda, Gastropoda, Hydracarina, and Turbellaria).

TABLE 1. Shannon diversity (H), Shannon evenness (J), total taxa (T), EPT taxa (EPT), and density values calculated for site 1 / site 2 data collected from the North Fork of the Cache la Poudre River below Halligan Reservoir, Larimer Co., Colorado. H and J indices were calculated from the cumulative number of individuals from each sample. T and EPT values were calculated from new taxa represented in $n = 3$ subsamples collected from October 1996 through September 1997. Estimated density values are reported means of $n = 3$ samples in individuals per $m^2 \pm s_{\bar{x}}$.

| Date | H | J | T | EPT | Density (/$m^2$) $\pm s_{\bar{x}}$ |
|---|---|---|---|---|---|
| 12-Oct-96 | 1.10 / 2.51 | 0.68 / 0.78 | 5 / 25 | 1 / 7 | 55 ± 17 / 1156 ± 138 |
| 28-Oct-96 | 0.54 / 2.54 | 0.28 / 0.73 | 7 / 33 | 1 / 14 | 794 ± 250 / 3446 ± 662 |
| 08-Nov-96 | 0.64 / 2.72 | 0.33 / 0.82 | 7 / 28 | 2 / 13 | 736 ± 327 / 1795 ± 114 |
| 20-Nov-96 | 1.11 / 2.59 | 0.50 / 0.76 | 9 / 31 | 2 / 10 | 518 ± 259 / 3391 ± 2095 |
| 13-Dec-96 | 0.98 / 2.68 | 0.47 / 0.91 | 8 / 19 | 1 / 7 | 805 ± 578 / 1389 ± 409 |
| 17-Feb-97 | 0.91 / 2.62 | 0.66 / 0.85 | 4 / 22 | 0 / 9 | 82 ± 31 / 529 ± 328 |
| 07-Mar-97 | 1.18 / 2.01 | 0.66 / 0.80 | 6 / 12 | 1 / 4 | 152 ± 20 / 276 ± 68 |
| 28-Mar-97 | 1.24 / 2.48 | 0.69 / 0.75 | 6 / 27 | 1 / 7 | 183 ± 96 / 1452 ± 232 |
| 02-May-97 | 1.10 / 2.37 | 0.50 / 0.74 | 9 / 25 | 2 / 7 | 1211 ± 292 / 2963 ± 462 |
| 28-Jun-97 | 2.02 / 2.46 | 0.63 / 0.63 | 25 / 38 | 11 / 19 | 8328 ± 4150 / 9219 ± 1499 |
| 09-Jul-97 | 1.79 / 2.35 | 0.61 / 0.65 | 19 / 37 | 9 / 18 | 8737 ± 1905 / 3730 ± 836 |
| 26-Jul-97 | 1.68 / 2.31 | 0.52 / 0.63 | 26 / 40 | 10 / 19 | 8277 ± 1020 / 3648 ± 821 |
| 09-Aug-97 | 2.17 / 2.57 | 0.69 / 0.71 | 23 / 36 | 11 / 16 | 5525 ± 766 / 2231 ± 644 |
| 30-Aug-97 | 2.50 / 2.76 | 0.74 / 0.77 | 30 / 36 | 12 / 17 | 3726 ± 411 / 1565 ± 495 |
| 26-Sept-97 | 2.47 / 2.80 | 0.71 / 0.70 | 33 / 55 | 15 / 25 | 5693 ± 1219 / 13,977 ± 2610 |

instars of Chloroperlidae, early instars of Perlodidae, *Isoperla quinquepunctata,* and *Triznaka signata,* and 4 caddisfly taxa, *Cheumatopsyche pettiti, Oecetis* sp., *Hydroptila* sp., and *Leucotrichia pictipes,* were represented in September samples. Only early size classes of semivoltine and univoltine Plecoptera were represented at site 1 a year later, suggesting that most stoneflies were eliminated by the initial sediment release. *Baetis tricaudatus, B. flavistriga, Serratella micheneri, Nixe criddlei, Paraleptophlebia* sp., and *Tricorythodes minutus*

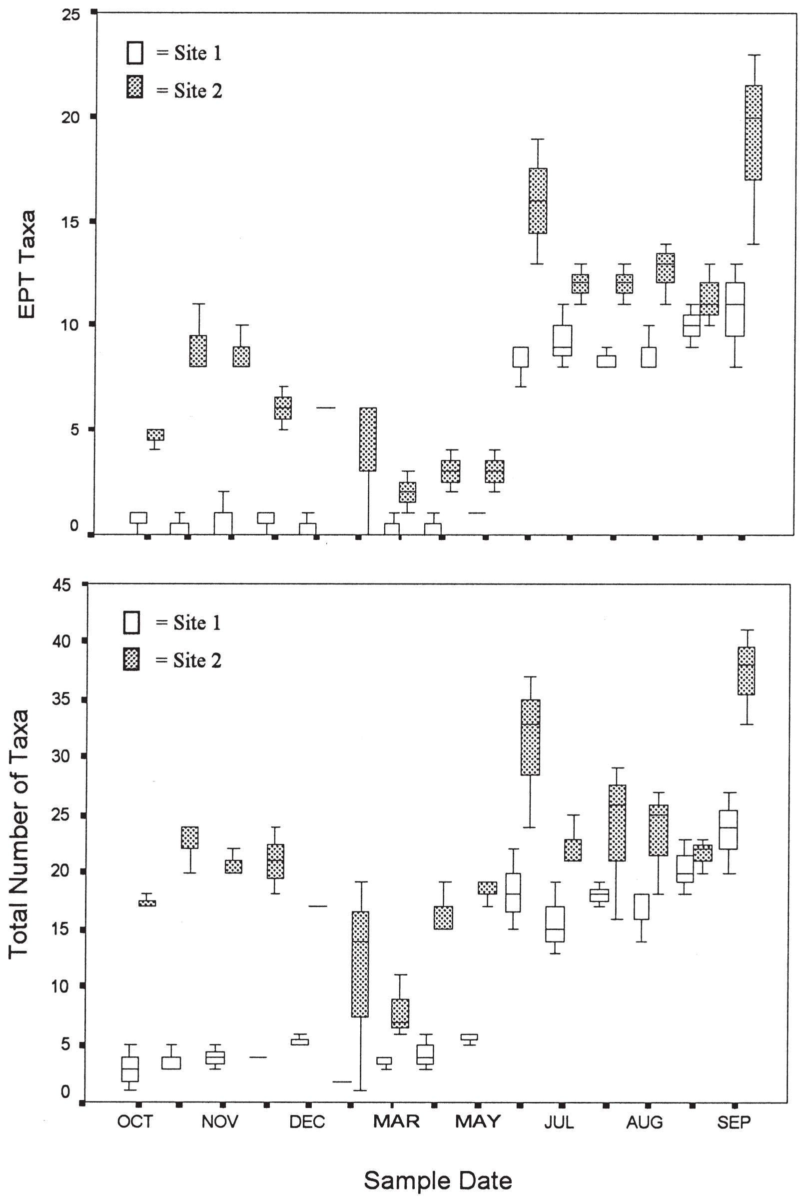


Fig. 3. EPT taxa (EPT) and total number of taxa (T) plotted using the median, interquartile range, and extreme values where $n = 3$ on all sample occasions. Data collected from the North Fork Cache la Poudre River downstream from Halligan Reservoir, Larimer Co., Colorado, at site 1 and site 2 from October 1996 through September 1997.

became common in samples from June through September at both sites.

At site 2, T ranged from 12 in March to 55 in September (Table 1). T increased by the end of October and remained relatively constant, decreased during the winter months, and then increased in early spring and early summer. A substantial increase occurred between August and September when T increased from 36 to 55. EPT taxa ranged from a low of 4 in March to 25 in September (Table 1). Mayflies and caddisflies were represented in all samples collected at site 2. Several stonefly taxa began to appear in June at site 2. Again, only early size classes of semivoltine and univoltine Plecoptera were represented. EPT and T showed similar increasing and decreasing patterns at both sites (Fig. 3).

TABLE 2. Pairwise differences using least means square calculated from estimated density $Log_{10}$ data where $n = 3$ on River after an episodic sediment transport event below Halligan Reservoir, Larimer Co., Colorado. Significant values

| | Sample period | | | | | | |
|---|---|---|---|---|---|---|---|
| | Oct | Oct | Nov | Nov | Dec | Feb | Mar |
| Within site 1 | — | **< 0.01** | 0.55 | 0.71 | 0.81 | **< 0.01** | 0.21 |
| Within site 2 | — | **0.07** | 0.29 | 0.65 | 0.39 | **< 0.01** | 0.81 |
| Between sites | **< 0.01** | **< 0.01** | **0.03** | **< 0.01** | 0.11 | **0.05** | 0.34 |

Shannon Diversity (H) and Shannon Evenness (J)

Macroinvertebrate communities of unpolluted waters typically exhibit H values above 3.0, whereas severely polluted streams have values less than 1.0 (Wilhm 1970). H values for Rocky Mountain streams generally approach or exceed 3.0 (Platts et al. 1983). At site 1, H values ranged from 0.54 to 2.50 but did not consistently exceed 1.00 until March and did not consistently exceed 2.0 until August (Table 1). J values at site 1 ranged from 0.28 to 0.74 (Table 1). They fluctuated at site 1 throughout the sampling period and yet stayed below the normal range (0.6–0.8) for unpolluted streams in the United States. In unpolluted streams in the United States, J values normally range from 0.6 to 0.8, whereas even mild levels of organic wastes generally depress values below 0.3. At site 2, H values ranged from 2.01 in March to 2.80 in September, approaching normal H values for Rocky Mountain streams (Table 1). J values fluctuated within the normal range for unpolluted streams in the United States throughout the sampling period at site 2.

Density

A balanced 2-way ANOVA revealed significant interactions between site and date ($P < 0.05$). We calculated least means squares values using $Log_{10} + 1$ density data; results are presented in Table 2 for sites 1 and 2 and describe significant interactions within and between sites. Significant density site and date interactions are shown using the median, interquartile range, and extreme values in Figure 4.

Estimated monthly taxa densities are presented in Appendix 1. Mean density at site 1 ranged from 55 ± 17 individuals per $m^2$ in early October to 8737 ± 1905 individuals per $m^2$ in July. The first significant increase in density occurred in early October from 55 ± 17 individuals per $m^2$ to 794 ± 250 individuals per $m^2$ in late October ($P < 0.05$). This increase was primarily made up of *Diamesa* spp. midges. Densities significantly increased again in March from 183 ± 96 individuals per $m^2$ to 1211 ± 292 individuals per $m^2$ in early May and then to 8328 ± 4150 individuals per $m^2$ in June ($P < 0.05$). *Diamesa* spp. and *Eukiefferiella* spp. midges represented the majority of this density increase. Significant decreases also occurred from December to February ($P < 0.05$; Table 1). Standard error of mean density ($s_{\bar{x}}$) expressed as a relative percentage of mean density ranged from 11% in August to 72% in December at site 1 (Table 1).

Mean density values at site 2 ranged from 529 ± 328 individuals per $m^2$ in February to 13,977 ± 2610 individuals per $m^2$ in September. The first significant increase began in early October from 1156 ± 138 individuals per $m^2$ to 3446 ± 662 individuals per $m^2$ at the end of October ($P < 0.05$). This increase was primarily made up of midges and oligochaetes. Density increased significantly again in March, from 1452 ± 232 individuals per $m^2$ to 2963 individuals per $m^2$ in early May and then to 9219 ± 462 individuals per $m^2$ in June ($P < 0.05$). *Diamesa* spp., *Eukiefferiella* spp., *Orthocladius* spp., and *Cricotopus* spp. midges made up the majority of this increase. Significant increases in density at site 2 also occurred between August (1565 ± 495 individuals per $m^2$) and September (13,977 ± 2610 individuals per $m^2$; $P < 0.05$). Most of this increase was represented by the mayflies *Acentrella insignificans,* early instars of *Baetis* spp., *Ephemerella infrequens,* and *Paraleptophlebia* sp.; the stonefly *Claassenia sabulosa;* the caddisflies *Ceratopsyche cockerelli, Hydropsyche* sp., and *L. pictipes;* and the midges *Diamesa* spp., *Eukiefferiella* spp., and *Orthocladius* spp. Significant decreases also occurred at site 2 from November to December and June to July ($P < 0.05$). Significant between-site differences almost continuously each sampling occasion. Data collected from October 1996 through September 1997 from the North Fork Cache la Poudre are in bold ($P \leq 0.05$).

| Sample period | | | | | | | |
|---|---|---|---|---|---|---|---|
| Mar | May | Jun | July | July | Aug | Aug | Sept |
| 0.92 | < 0.01 | < 0.01 | 0.66 | 0.98 | 0.47 | 0.52 | 0.50 |
| **< 0.01** | 0.22 | **< 0.01** | **0.02** | 0.95 | 0.35 | 0.53 | **< 0.01** |
| **< 0.01** | 0.11 | 0.19 | 0.15 | 0.14 | 0.09 | 0.09 | 0.12 |

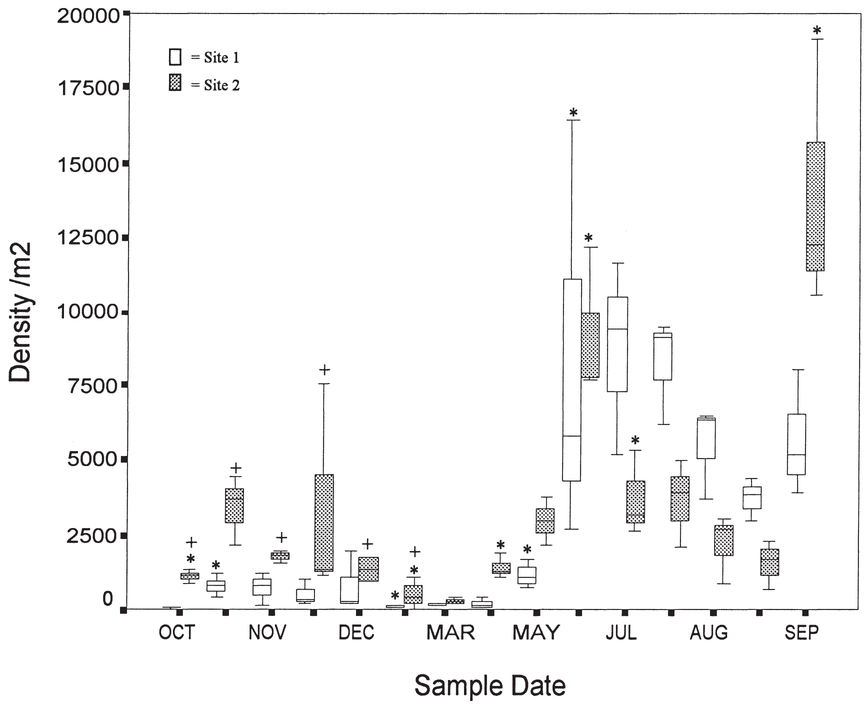


Fig. 4. Estimated density per m2 values plotted using the median, interquartile range, and extreme values where $n$ = 3 on all sampling occasions. Data collected from the North Fork of the Cache la Poudre River below Halligan Reservoir at site 1 and site 2 from October 1996 through September 1997. * indicates significance within a site and + indicates significance between sites ($P < 0.05$).

occurred from October through March ($P < 0.05$). Standard error of mean ($s_{\bar{x}}$) density expressed as a relative percentage of mean density ranged from 6% in early November to 62% in late November at site 2 (Table 2).

## Feeding Guilds

Feeding guild percentages for sites 1 and 2 are summarized in Table 3. At site 1 collector-gatherers (C/G) dominated all samples except those taken in July, when collector-filterers (C/F; *Simulium* sp.) dominated. C/G were represented in all samples where percentages ranged from 40% in June to 98% in October at site 1. C/F were represented in all samples except early October. C/F percentages ranged from 1% in late October to 54% in late July. Shredders (SH) were represented as small percentages in June, July, and September. Scrapers (SC) were represented in early October but did not reappear until June, when they were represented in the remainder of samples. SC percentages ranged from 1% in November, late June, and September to 14% in early August. Predators (PR) were represented by small percentages in all samples except early

TABLE 3. Feeding guild comparison calculated from samples for site 1 / site 2 data collected from the North Fork of the Cache la Poudre River below Halligan Reservoir, Larimer Co., Colorado, from October 1996 to September 1997. C/G = collector-gatherer, C/F = collector-filterer, SH = shredder, SC = scraper, PR = predator, P/H = piercer-herbivore, and Number sum = total number of individuals collected in a sample.

| Sample | C/G % | C/F % | SH % | SC % | PR % | P/H % | Number sum |
|---|---|---|---|---|---|---|---|
| 12-Oct-96 | 76 / 55 | 0 / 10 | 0 / 2 | 8 / 15 | 16 / 18 | 0 / 0 | 12 / 293 |
| 28-Oct-96 | 98 / 74 | 1 / 4 | 0 / 1 | 0 / 8 | 1 / 13 | 0 / 0 | 199 / 871 |
| 08-Nov-96 | 97 / 61 | 2 / 6 | 0 / 3 | 1 / 17 | 0 / 12 | 0 / 1 | 169 / 436 |
| 20-Nov-96 | 91 / 60 | 6 / 1 | 0 / 1 | 0 / 20 | 3 / 18 | 0 / 1 | 117 / 824 |
| 13-Dec-96 | 87 / 64 | 10 / 8 | 0 / 0 | 0 / 8 | 3 / 17 | 0 / 3 | 206 / 133 |
| 17-Feb-97 | 90 / 72 | 10 / 5 | 0 / 4 | 0 / 1 | 0 / 18 | 0 / 0 | 21 / 129 |
| 07-Mar-97 | 87 / 66 | 10 / 7 | 0 / 0 | 0 / 6 | 3 / 21 | 0 / 0 | 39 / 70 |
| 28-Mar-97 | 87 / 80 | 13 / 4 | 0 / 0 | 0 / 4 | 0 / 11 | 0 / 1 | 31 / 347 |
| 02-May-97 | 95 / 90 | 3 / 0 | 0 / 0 | 0 / 0 | 2 / 10 | 0 / 0 | 299 / 658 |
| 28-Jun-97 | 66 / 87 | 30 / 2 | 1 / 0 | 1 / 7 | 2 / 4 | 0 / 0 | 1876 / 2188 |
| 09-Jul-97 | 43 / 81 | 47 / 2 | 1 / 1 | 4 / 9 | 1 / 7 | 4 / 0 | 2122 / 857 |
| 26-Jul-97 | 40 / 78 | 54 / 7 | 0 / 0 | 4 / 4 | 1 / 11 | 1 / 0 | 2068 / 946 |
| 09-Aug-97 | 59 / 72 | 25 / 2 | 0 / 2 | 14 / 16 | 2 / 8 | 0 / 0 | 997 / 533 |
| 30-Aug-97 | 75 / 81 | 13 / 10 | 0 / 0 | 8 / 3 | 3 / 6 | 1 / 0 | 865 / 385 |
| 26-Sep-97 | 73 / 51 | 15 / 31 | 3 / 1 | 1 / 11 | 8 / 6 | 0 / 0 | 1398 / 3406 |

November, February, and late March by the deer fly *Chrysops* sp.; the midges *Thienemannimyia* group and *Cardiocladius* spp.; the dipteran *Atherix pachypus*; the stoneflies *T. signata, I. quinquepunctata,* early instars of Chloroperlidae, and early instars of Perlodidae; the dragonfly *Ophiogomphus severus;* and by water mites, flatworms, and nematodes. PR percentages ranged from 1% in late October and July to 8% in September. Piercer-herbivores (P/H) were represented in July and August by hydroptilid caddisflies. Percentages ranged from 1% in late July to 4% in August.

At site 2, C/G dominated all samples, with percentages ranging from 51% in September to 90% in early May. C/F, represented in all samples except in May, had percentages of 1% in November to 31% in late September. SH, represented by *Cricotopus* spp. and *Polypedilum* spp., appeared in about half the samples; SH percentages ranged from 1% to 4%. SC were represented in all samples except January and May; percentages ranged from 1% in February to 20% in November. PR were represented in all samples at site 2 and ranged from 4% in June to 21% in early March. P/H were represented only in November, December, and March samples and ranged from 1% to 3%. *Hydroptila* sp., *Agraylea multipunctata,* and *Sigara* sp. represented P/H taxa.

### Pre- and Post-disturbance at Site 2

Pre-event data are unfortunately limited, and therefore only qualitative comparisons of community structure and functional feeding guilds are made. A community structure comparison was made based on the data collected from July samples (Fig. 5). In 1990 Ephemeroptera made up 75% of the community, with 2% Plecoptera, 12% Trichoptera, 9% Diptera, and 2% remaining taxa groups. After the sediment transport event in 1997, Ephemeroptera decreased to 65%, Plecoptera were the same at 2%, Trichoptera decreased to 2%, and Diptera increased to 27%, while remaining taxa slightly increased to 3%. *Epeorus albertae, Choroterpes inornata, I. quinquepunctata, Suwallia* sp., *Helicopsyche borealis, Nectopsyche* sp., *Oecetis* sp., *Chimarra utahensis,* and *Lepidostoma* sp. were extirpated from post-disturbance samples (Appendix). *Nixe criddlei, Hesperoperla pacifica, T. signata, Perlesta decipiens,* and *Psychomyia flavida* invaded after the sediment release. A feeding guild comparison was based on data collected from July samples (Fig. 5). In 1990, SC made up 67% of the community, with 30% C/G, 2% PR, and 1% C/F. After the event in 1997, C/G increased to 78%, PR increased to 11%, C/F increased to 7%, and SC decreased to 4% of the community.

## DISCUSSION

Presumed effects of suspended load sediments on aquatic insects are loss of visual efficiency in feeding, interference in food gathering by filterers, abrasive action, and increased invertebrate drift (Waters 1995). Direct cause of increased invertebrate drift due to suspended

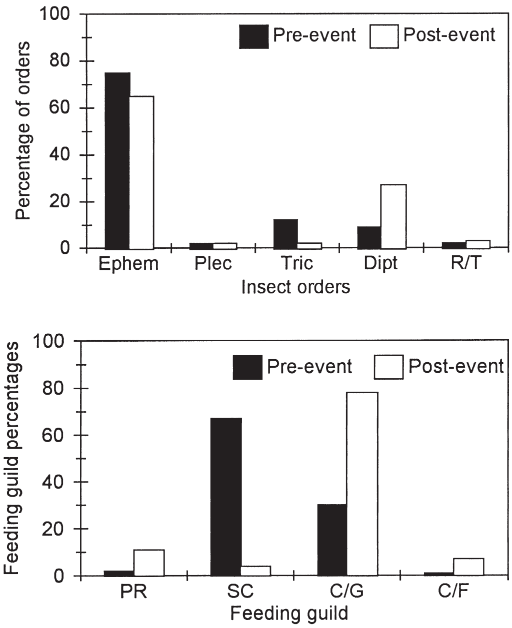


Fig. 5. EPT taxa, community structure, and feeding guild comparison of pre- and post-event data collected 3.2 km below Halligan Reservoir on the North Fork of the Cache la Poudre River at site 2. Pre-event data were collected in June, July, and August 1990. Post-event data were collected in June, July, and August 1997. Ephem = Ephemeroptera, Plec = Plecoptera, Tric = Trichoptera, Dipt = Diptera, R/T = remaining taxa (Oligochaeta, Nematoda, Gastropoda, Hydracarina, and Turbellaria), PR = predator, SC = scraper, C/G = collector gatherer, C/F = collector-filterer.

sediment is not known; however, White and Gammon (1977) and Rosenberg and Wiens (1978) found that suspended sediment indirectly increases drift by decreasing available light. Sediment transport can decrease primary productivity by reducing light and/or by abrading or suffocating periphyton and associated macrophytes (Waters 1995). The episodic sediment release from Halligan Reservoir during the last week of September 1996 eliminated the majority of the benthic macroinvertebrate community at site 1. Significant differences in density occurred between sites from October through March, suggesting that the benthic community closest to the sediment release (site 1) was most strongly affected. While Diptera dominated the community at both sites, rapid recolonization by Baetidae and Hydropsychidae began after flows increased during the snowmelt portion of the hydrograph (Wohl and Cenderelli 2000). Though the community showed high resilience at both sites, a complete alteration occurred in community function at site 2, changing from an SC-dominated community (heptageniid mayflies) to one dominated by C/G (midges and baetid mayflies). Hesse and Newcomb (1982) investigated a similar situation on the Niobrara River in Nebraska and found comparable intense short-term effects on the macroinvertebrate community. In our study the initial sediment deposition occurred in pools, creating storage sites that permitted continual sediment transport (Wohl and Cenderelli 2000), which may help explain decreases in density throughout the study period at site 2. On the other hand, these density differences may be attributed to life history traits of the taxa present. The function of the community may not return to pre-event conditions until the sediment stored in pools is moved through the system. Gradient, discharge, and current velocity control the rate of sediment removal, which can facilitate the rate of recolonization (Waters 1995). Higher-than-average spring–summer flows in 1997 recovered 50% of the original pool volumes (Wohl and Cenderelli 2000), which may have enhanced recolonization. Recolonization can occur laterally, from upstream or downstream, from within the substrate, or through oviposition (Williams and Hynes 1976). Rapid recolonization can also occur by passive downstream drift from unaffected upstream reaches (Barton 1977, Chrisholm and Downs 1978, Williams 1980, DeWalt and Olive 1988). However, no permanently flowing tributaries exist within the study reach; therefore, passive downstream drift from such inputs had apparently no influence on recovery. Additionally, the large reservoir probably prevented successful drift of rheophilic taxa from areas upstream of the reservoir. Recolonization can often be attributed to immigration from less disturbed areas such as hyporheic or upstream larvae movement (Plecoptera), egg laying by aerial-dispersing adults (midges, caddisflies), survival of more resistant stages (eggs and pupae), and rapid reproduction (Sheldon 1984). Macroinvertebrate stream communities most likely to recover quickly after disturbance are often dominated by baetid mayflies, taxa with multivoltine life histories, and filter-feeding hydropsychid caddisflies (Mackay 1992). Rapid recolonization occurred by Baetidae, Hydroptilidae and Hydropsychidae, Chironomidae, Simuliidae and Oligochaeta.

Additionally, this episodic event occurred late in the season, when many species of this geographic region are adapted to overwintering as early instars or eggs, which may help explain the differential recolonization of certain taxa.

Reference sites or streams were not available for comparison; therefore, natural variability of the structure and function of the benthic macroinvertebrate community may be incompletely known. However, this study clearly indicates rapid recolonization of certain taxa directly below Halligan Dam after the episodic sediment transport event. Sediment stored in the reservoir is periodically released during dam inspection procedures (Wohl and Cenderelli 2000). We suggest that these releases occur either in late fall or early spring if adequate flushing flows are available. An episodic event of this magnitude may have greater long-term effects on the benthic community during late spring or summer because of regional species biologies (Ward and Kondratieff 1992). Additionally, we suggest releasing sediment at more frequent intervals to reduce the magnitude of sediment entering the North Fork downstream of Halligan Reservoir during sediment flushing operations.

## ACKNOWLEDGMENTS

Special thanks to Rich Durfee for providing chironomid identification. We thank Drs. LeRoy Poff, Colorado State University; Russell Rader, Brigham Young University; Lawrence E. Stevens, consulting ecologist; and 2 anonymous reviewers for improving earlier versions of this paper. The Nature Conservancy and North Poudre Irrigation Company provided access. Heather Knight, The Nature Conservancy, provided field assistance early in the project, and Scott Fitzgerald, Oregon State University, prepared samples for identification. We thank Dr. Ellen Wohl and Sara Rathburn, Colorado State University, for providing sediment movement information. Steve Puttmann, Colorado Division of Wildlife, arranged partial funding for this project.

## LITERATURE CITED

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

BESCHTA, R.L., W.L. JACKSON, AND K.D. KNOOP. 1981. Sediment transport during a controlled reservoir release. Water Resources Bulletin 17:635–641.

BLACK, P.E., E.C. FRANK, R.H. HAWKINS, R.C. MALONEY, AND J.R. MEIMAN. 1959. Watershed analysis of the North Fork of the Cache la Poudre River, Larimer County, Colorado, and Albany County, Wyoming. Cooperative Watershed Management Unit, College of Forestry and Range Management, Colorado State University, Fort Collins. 121 pp.

CHRISHOLM, J.L., AND S.C. DOWNS. 1978. Stress and recovery of aquatic organisms as related to highway construction along Turtle Creek, Boone County, West Virginia. U.S. Geological Survey Water Supply Paper 2055. Washington, DC.

CLINE, L.D., R.A. SHORT, AND J.V. WARD. 1982. The influence of highway construction on the macroinvertebrates and epilithic algae of a high mountain stream. Hydrobiologia 96:149–159.

DEWALT, R.E., AND J.H. OLIVE. 1988. Effects of eroding glacial silt on benthic insects of Silver Creek, Portage County, Ohio. Ohio Journal of Science 88:154–159.

HESSE, L.W., AND B.A. NEWCOMB. 1982. Effects of flushing Spencer Hydro on water quality, fish and insect fauna of the Niobrara River, Nebraska. North American Journal of Fisheries Management 2:45–52.

KNIGHTON, D. 1998. Fluvial forms and processes: a new perspective. Arnold, London. 383 pp.

LENAT, D.R., D.L. PENROSE, AND K.W. EAGLESON. 1979. Biological evaluation of non-point source pollutants in North Carolina streams and rivers. Biological Series 102, North Carolina Department of Natural Resources and Community Development, Raleigh.

MACKAY, R.J. 1992. Colonization by lotic macroinvertebrates: a review of processes and patterns. Canadian Journal of Fisheries and Aquatic Sciences 49: 617–628.

MERRITT, R.W., AND K.W. CUMMINS. 1996. An introduction to the aquatic insects of North America. 3rd edition. Kendall/Hunt Publishing Company, Dubuque, IA. 862 pp.

NORRIS, R.H., AND A. GEORGES. 1993. Analysis and interpretation of benthic macroinvertebrate surveys. Pages 234–286 *in* D.M. Rosenberg and V.H. Resh, editors, Freshwater biomonitoring and benthic macroinvertebrates. Chapman and Hall, New York and London.

PLATTS, W.S., W.F. MEGAHAN, AND G.W. MINSHALL. 1983. Methods for evaluating stream, riparian, and biotic conditions. General Technical Report INT-138, U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT.

REINERS, W.A. 1992. Twenty years of ecosystem reorganization following experimental deforestation and regrowth suppression. Ecological Monographs 62:503–523.

ROSENBERG, D.M., AND A.P. WIENS. 1978. Effects of sediment addition on macrobenthic invertebrates in a northern Canadian river. Water Research 12:753–763.

SAS INSTITUTE. 1985. SAS® user's guide: statistics. Version 5 edition. Cary, NC.

SHELDON, A.L. 1984. Colonization dynamics of aquatic insects. Pages 401–429 *in* V.H. Resh and D.M. Rosenberg, editors, The ecology of aquatic insects. Praeger, New York.

THORNE, C.R., J.C. BATHURST, AND R.D. HEY. 1987. Sediment transport in gravel-bed rivers. John Wiley and Sons Ltd., New York. 995 pp.

THORP, J.H., AND A.P. COVICH. 1991. Ecology and classification of North American freshwater invertebrates. Academic Press, San Diego, CA.

TSUI, P.T.P., AND P.J. MCCART. 1981. Effects of stream-crossing by a pipeline on the benthic macroinvertebrate communities of a small mountain stream. Hydrobiologia 79:271–276.

TWETO, O. 1979. Geologic map of Colorado, 1:500,000. United States Geologic Survey.

WARD, J.V., AND B.C. KONDRATIEFF. 1992. An illustrated guide to the mountain stream insects of Colorado. University Press of Colorado, Niowot. 191 pp.

WASHINGTON, H.G. 1984. Diversity, biotic, and similarity indices, a review with special reference to aquatic ecosystems. Water Research 18:653–694.

WATERS, T.F. 1995. Sediment in streams: sources, biological effects and control. American Fisheries Society Monograph 7. 249 pp.

WHITE, D.S., AND J.R. GAMMON. 1977. The effect of suspended solids on macroinvertebrate drift in an Indiana creek. Proceedings of the Indiana Academy of Science 86:182–188.

WILHM, J.L. 1970. Range of diversity index in benthic macroinvertebrate populations. Journal of the Water Pollution Control Federation 42:R221–R224.

WILLIAMS, D.D. 1980. Temporal patterns in recolonization of stream benthos. Archiv fur hydrobiologie 90:56–74.

WILLIAMS, D.D., AND H.B.N. HYNES. 1976. The recolonization mechanisms of stream benthos. Oikos 27: 265–272.

WOHL, E.E., AND D.A.CENDERELLI. 2000. Sediment and transport patterns following a reservoir sediment release. Water Resources Research 36:319–334.

*Received 7 February 2000*
*Accepted 9 October 2000*

The appendix follows on the next three pages.

APPENDIX. Estimated monthly taxa density collected from the North Fork of the Cache la Poudre River below Halligan Reservoir 100 m downstream from the dam (site 1) and 3.2 km downstream from the dam (site 2) after an episodic sediment release and at site 2 in 1990 before the release. Data represent average density /m$^2$ per month and are reported as site 1 (1996–97) / site 2 (1996–97) and / site 2 (1990). $N$ = the number of samples taken per month at a given site. Solid lines indicate that the taxon was not detected. + denotes taxa that were identified at different taxonomic resolutions for post-event samples.

| Sample date | Oct-96 / 96 | Nov-96 / 96 | Dec-96 / 96 | Jan-97 / 97 | Feb-97 / 97 | Mar-97 / 97 | May-97 / 97 | Jun-97 / 97 / 90 | Jul-97 / 97 / 90 | Aug-97 / 97 / 90 | Sep-97 / 97 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Site sampled | Site 1 / 2 | Site 1 / 2 | Site 1 / 2 | Site 1 / 2 | Site 1 / 2 | Site 1 / 2 | Site 1 / 2 | Site 1 / 2 / 2 | Site 1 / 2 / 2 | Site 1 / 2 / 2 | Site 1 / 2 |
| Number of samples per site | $n$ = 6 / 6 | $n$ = 6 / 6 | $n$ = 3 / 3 | $n$ = 3 / 3 | $n$ = 3 / 3 | $n$ = 6 / 6 | $n$ = 3 / 3 | $n$ = 6 / 6 / 3 | $n$ = 6 / 6 / 3 | $n$ = 6 / 6 / 3 | $n$ = 3 / 3 |
| Taxa list | | | | | | | | | | | |
| **EPHEMEROPTERA** | | | | | | | | | | | |
| *Baetis* sp. | 2 / 0 | — | 8 / 0 | — | — | — | 9 / 0 | 241 / 1382 / 643 | 12 / 92 / 183 | 146 / 79 / 854 | 712 / 2095 |
| *B. flavistriga* | — | — | — | — | — | — | 0 / 2 | 1273 / 1791 / + | 327 / 316 / + | 443 / 57 / + | 39 / 20 |
| *B. tricaudatus* | 0 / 2 | 0 / 28 | — | 0 / 4 | — | 0 / 9 | 0 / 30 | 214 / 1168 / + | 3 / 179 / + | 54 / 48 / + | 674 / 973 |
| *Acentrella insignificans* | — | — | — | — | — | — | — | 0 / 175 / 0 | 0 / 61 / 0 | 2 / 52 / 0 | 0 / 352 |
| *Ephemerella infrequens* | 0 / 4 | 2 / 2 | 0 / 23 | 0 / 4 | 0 / 4 | — | 0 / 2 | 0 / 19 / 65 | 0 / 14 / 0 | 0 / 2 / 0 | 0 / 613 |
| *Serratella micheneri* | 0 / 5 | — | — | — | — | — | — | 128 / 1090 / 0 | 216 / 604 / 25 | 191 / 137 / 4 | 23 / 20 |
| *Epeorus albertae* | — | — | — | — | — | — | — | 0 / 0 / 223 | 0 / 0 / 25 | 0 / 0 / 39 | — |
| *Heptagenia* sp. | — | 0 / 1 | — | — | — | — | — | 23 / 202 / 14 | 10 / 9 / 1332 | 16 / 4 / 50 | 0 / 12 |
| *Nixe criddlei* | — | — | — | — | — | — | — | 47 / 105 / 0 | 66 / 62 / 0 | 176 / 12 / 0 | 8 |
| *Paraleptophlebia* sp. | 0 / 16 | 0 / 20 | 0 / 12 | — | 0 / 27 | 0 / 3 | 0 / 1 | 167 / 51 / 32 | 28 / 5 / 104 | 88 / 15 / 4 | 144 / 383 |
| *Choroterpes* sp. | — | — | — | — | — | — | — | — | 0 / 0 / 11 | 0 / 0 / 118 | — |
| *Tricorythodes minutus* | 0 / 9 | 1 / 5 | — | 0 / 4 | — | — | 0 / 1 | 35 / 19 / 0 | 134 / 28 / 251 | 135 / 95 / 18 | 234 / 75 |
| *Caenis* sp. | — | — | — | — | — | — | — | — | — | 0 / 1 / 0 | 0 / 4 |
| **PLECOPTERA** | | | | | | | | | | | |
| Chloroperlidae | — | — | — | — | — | — | — | 0 / 4 / 0 | — | — | 8 / 0 |
| *Suwallia* sp. | — | — | — | — | — | — | — | 0 / 0 / 4 | — | — | — |
| *Triznaka signata* | 0 / 1 | 0 / 1 | 0 / 12 | — | 0 / 4 | — | 7 / 0 | 0 / 12 / 0 | 0 / 5 / 0 | 0 / 3 / 0 | 4 / 32 |
| *Skwala americana* | — | — | — | — | — | — | — | 0 / 12 / 0 | 0 / 32 / 22 | 0 / 6 / 61 | 0 / 24 |
| Perlodidae | — | — | — | — | — | — | — | 0 / 4 / 0 | — | — | 8 / 28 |
| *Isoperla quinquepunctata* | — | — | — | — | — | — | 0 / 10 | 0 / 0 / 18 | — | 4 / 0 / 0 | 4 / 8 |
| *Claassenia sabulosa* | 0 / 3 | 0 / 3 | — | — | 0 / 8 | — | — | — | 0 / 6 / 0 | 0 / 21 / 4 | 0 / 178 |
| *Perlesta decepiens* | — | — | — | — | — | — | — | 0 / 4 / 0 | 0 / 55 / 0 | 0 / 9 / 0 | 0 / 4 |
| *Hesperoperla pacifica* | 0 / 1 | — | — | — | — | — | — | — | 0 / 3 / 0 | — | — |
| **TRICHOPTERA** | | | | | | | | | | | |
| *Brachycentrus americanus* | 0 / 3 | — | — | — | — | 6 / 0 | — | — | — | — | — |
| *Helicopsyche borealis* | 0 / 3 | 0 / 1 | — | — | — | 0 / 4 | — | 0 / 0 / 29 | 0 / 0 / 4 | — | 0 / 4 |
| *Agapetus boulderensis* | 0 / 2 | 0 / 5 | — | — | — | — | — | — | — | — | — |
| *Hydropsyche* sp. | 0 / 52 | 1 / 18 | 0 / 16 | — | 0 / 8 | 6 / 0 | — | 0 / 12 / 22 | 2 / 9 / 11 | 12 / 25 / 510 | 160 / 2234 |
| *Ceratopsyche cockerelli* | 0 / 6 | 0 / 14 | 0 / 23 | 0 / 4 | 0 / 12 | 0 / 5 | 0 / 1 | 0 / 4 / 0 | 0 / 5 / 0 | — | 0 / 1301 |
| *Cheumatopsyche pettiti* | — | — | — | — | — | — | — | — | — | 0 / 3 / 0 | 12 / 32 |
| *Chimarra* sp. | — | — | — | — | — | — | — | — | — | 0 / 0 / 7 | — |
| *Hydroptila* sp. | — | 0 / 3 | 0 / 16 | — | — | 0 / 2 | 1 / 0 | 23 / 8 / 0 | 18 / 0 / 0 | 2 / 2 / 0 | — |
| *Agraylea multipunctata* | — | — | — | — | — | — | — | 8 / 0 / 0 | 0 / 1 / 0 | — | — |
| *Leucotrichia pictipes* | 1 / 105 | 1 / 228 | 0 / 39 | — | 0 / 4 | 0 / 12 | — | — | 0 / 10 / 0 | 3 / 9 / 4 | 12 / 1419 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Ochrotrichia* sp. | 0 / 1 | — | — | — | — | — | — | — | — | — | — |
| *Dolophilodes aequalis* | — | — | — | — | — | — | — | 4 / 0 / 0 | — | — | — |
| *Lepidostoma* sp. | 0 / 5 | 0 / 25 | — | 0 / 4 | 0 / 12 | — | — | 0 / 0 / 25 | — | — | 0 / 67 |
| *Nectopsyche* sp. | — | — | — | — | — | — | — | 0 / 0 / 4 | — | — | — |
| *Oecetis* sp. | — | 0 / 1 | — | — | — | — | — | 0 / 0 / 18 | 0 / 0 / 4 | — | 4 / 24 |
| *Psychomyia flavida* | 0 / 1 | — | — | — | 0 / 4 | 0 / 3 | 0 / 1 | 0 / 31 / 0 | 0 / 8 / 0 | 0 / 10 / 0 | 0 / 297 |
| **COLEOPTERA** | | | | | | | | | | | |
| *Agabus* sp. | — | — | — | — | — | — | — | 0 / 8 / 0 | — | — | — |
| Elimdae | — | — | — | — | — | — | — | + / + / 4 | + / + / 7 | + / + / 36 | — |
| *Heterlimnius corpulentus* | 1 / 8 | 2 / 6 | — | — | — | 6 / 0 | — | 0 / 4 / + | 0 / 3 / + | 0 / 6 / + | 47 / 32 |
| *Optiservus* sp. | 0 / 247 | 0 / 169 | 0 / 90 | — | 0 / 74 | 0 / 50 | 0 / 18 | 0 / 19 / + | 0 / 21 / + | 0 / 17 / + | 0 / 316 |
| *Zaitzevia parvula* | 0 / 32 | 0 / 24 | 0 / 27 | — | 0 / 16 | 0 / 3 | 0 / 1 | — | 0 / 3 / + | 0 / 2 / + | 0 / 28 |
| *Narpus* sp. | — | — | — | — | — | — | — | — | — | 0 / 1 / + | 0 / 4 |
| **ODONATA** | | | | | | | | | | | |
| Zygoptera | — | — | — | — | — | — | — | — | 0 / 0 / 4 | — | — |
| *Ophiogomphus severus* | — | — | — | — | — | — | — | — | — | 2 / 1 / 0 | — |
| **LEPIDOPTERA** | | | | | | | | | | | |
| *Petrophilia avernalis* | 0 / 1 | 0 / 1 | — | — | — | 0 / 1 | — | — | — | 1 / 0 / 0 | 16 / 4 |
| **HEMIPTERA** | | | | | | | | | | | |
| *Aquarius remigis* | 0 / 1 | — | — | — | — | — | — | — | — | — | — |
| **COLLEMBOLA** | | | | | | | | | | | |
| Collembola | — | — | — | — | — | — | 2 / 0 | — | — | — | — |
| **DIPTERA** | | | | | | | | | | | |
| Dolichopodidae | — | — | — | — | — | — | — | — | — | — | 0 / 4 |
| *Atherix pachypus* | 1 / 115 | 1 / 137 | 0 / 66 | — | 0 / 74 | 0 / 37 | 0 / 28 | 0 / 8 / 0 | 0 / 16 / 0 | 0 / 13 / 183 | 4 / 253 |
| Tipulidae | — | — | — | — | — | — | — | + / + / 39 | + / + / 7 | + / + / 72 | — |
| *Antocha* sp. | 0 / 4 | 0 / 1 | — | — | — | — | — | + | 0 / 6 / + | 0 / 2 / + | 0 / 162 |
| *Dicranota* sp. | — | 1 / 0 | — | — | — | — | — | + | + | + | — |
| *Hexatoma* sp. | — | — | — | — | — | — | — | + | 0 / 1 / + | 0 / 1 / + | 4 / 8 |
| *Tipula* sp. | — | 0 / 1 | — | — | — | — | — | + | + | + | 0 / 8 |
| *Simulium* sp. | 2 / 0 | 9 / 0 | 78 / 0 | — | 8 / 8 | 41 / 14 | 8 / 0 | 2172 / 144 / 11 | 1085 / 65 / 18 | 339 / 19 / 72 | 1398 / 573 |
| *Simulium* pupae | — | — | — | — | — | — | — | 300 / 12 / — | 45 / 1 / — | 16 / 1 / — | 0 / 12 |
| Ceratopogonidae | 1 / 0 | — | — | — | — | — | — | — | — | — | — |
| Empididae | — | — | 16 / 0 | — | — | — | — | 0 / 0 / 4 | — | — | — |
| *Clinocera* sp. | — | — | — | — | — | — | — | — | — | 0 / 1 / 0 | 0 / 146 |
| *Maruina pennaki* | — | — | — | — | — | — | — | — | — | — | 0 / 4 |
| *Deuterophlebia coloradensis* | — | — | — | — | — | — | — | 0 / 179 / 11 | 0 / 26 / 0 | 0 / 1 / 0 | — |
| *D. coloradoensis* pupae | — | — | — | — | — | — | — | 0 / 93 / 0 | 0 / 10 / 0 | 0 / 2 / 0 | — |
| *Chrysops* sp. | — | — | — | — | — | — | 1 / 0 | — | — | — | — |
| Chironomidae | — | — | — | — | — | — | — | + / + / 11 | + / + / 11 | + / + / 68 | — |
| Chironomidae pupa | 7 / 4 | 35 / 42 | 16 / 66 | 8 / 0 | — | 0 / 6 | 24 / 0 | 666 / 639 / — | 3 / 2 / — | 9 / 18 / — | 183 / 217 |

APPENDIX 1. Continued.

| Sample date | Oct-96 / 96 | Nov-96 / 96 | Dec-96 / 96 | Jan-97 / 97 | Feb-97 / 97 | Mar-97 / 97 | May-97 / 97 | Jun-97 / 97 / 90 | Jul-97 / 97 / 90 | Aug-97 / 97 / 90 | Sep-97 / 97 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Site sampled | Site 1 / 2 | Site 1 / 2 | Site 1 / 2 | Site 1 / 2 | Site 1 / 2 | Site 1 / 2 | Site 1 / 2 | Site 1 / 2 / 2 | Site 1 / 2 / 2 | Site 1 / 2 / 2 | Site 1 / 2 |
| Number of samples per site | *n* = 6 / 6 | *n* = 6 / 6 | *n* = 3 / 3 | *n* = 3 / 3 | *n* = 3 / 3 | *n* = 6 / 6 | *n* = 3 / 3 | *n* = 6 / 6 / 3 | *n* = 6 / 6 / 3 | *n* = 6 / 6 / 3 | *n* = 3 / 3 |
| Taxa list | | | | | | | | | | | |
| **DIPTERA** (continued) | | | | | | | | | | | |
| *Nilotanypus* sp. | — | — | — | — | — | — | — | + | 1 / 0 / + | 1 / 0 / + | — |
| *Thienemannimyia group* | 0 / 6 | 0 / 4 | 4 / 0 | — | — | 0 / 8 | 0 / 15 | 101 / 8 / + | 0 / 1 / + | 3 / 10 / + | 4 / 0 |
| *Diamesa* sp. | 175 / 6 | 242 / 53 | 592 / 90 | 4 / 16 | 8 / 55 | 175 / 82 | 113 / 0 | 0 / 580 / + | 18 / 0 / + | + | — |
| *Pseudodiamesa* sp. | 1 / 2 | — | — | — | — | 0 / 1 | — | + | + | + | — |
| *Pagastia* sp. | — | — | — | — | — | — | — | + | 0 / 1 / + | + | — |
| *Potthastia* sp. | — | — | 0 / 8 | — | 0 / 8 | 0 / 4 | 0 / 14 | + | 1 / 0 / + | + | — |
| Orthocladinae | 0 / 17 | 0 / 10 | — | — | — | 0 / 5 | 0 / 50 | + | + | + | — |
| *Brillia* sp. | — | — | — | — | — | — | — | + | + | + | 0 / 12 |
| *Cardiocladius* sp. | 0 / 3 | 0 / 11 | 0 / 12 | — | 0 / 4 | 0 / 5 | 0 / 9 | 0 / 152 / + | 0 / 8 / + | 3 / 0 / + | 4 / 0 |
| *Cricotopus* sp. | 0 / 2 | — | — | — | — | — | — | + | + | + | 136 / 0 |
| *Ortho/Cricotopus* sp. | 0 / 220 | 0 / 52 | — | — | — | 0 / 5 | 0 / 193 | 179 / 1036 / + | 1 / 12 / + | 31 / 78 / + | 409 / 727 |
| *Eukiefferiella* sp. | 0 / 70 | 0 / 161 | 0 / 51 | 0 / 82 | 58 / 47 | 164 / 89 | 270 / 99 | 2515 / 0 / + | 34 / 7 / + | 22 / 42 / + | 685 / 747 |
| *Lopescladius* sp. | — | — | — | — | — | 0 / 2 | — | + | + | 0 / 2 / + | 4 / 0 |
| *Nanocladius* sp. | — | — | — | — | — | — | — | + | + | 2 / 0 / + | 0 / 12 |
| *Parametriocnemus* sp. | 0 / 12 | 0 / 10 | 0 / 8 | — | 0 / 16 | 0 / 1 | 0 / 18 | + | + | 0 / 2 / + | — |
| *Synorthocladius* sp. | — | 0 / 2 | — | — | — | — | 0 / 13 | + | 2 / 2 / + | 31 / 1 / + | 121 / 12 |
| *Tvetenia* sp. | 0 / 11 | 0 / 110 | 0 / 12 | 0 / 12 | 0 / 19 | 0 / 28 | — | + | + | + | — |
| *Chironomus* sp. | — | — | — | — | — | — | — | 4 / 0 / + | + | + | — |
| *Demicryptochironomus* sp. | — | — | — | — | — | — | — | 0 / 4 / + | + | + | — |
| *Microtendipes* sp. | — | — | — | — | — | — | — | + | + | + | 0 / 4 |
| *Parachironomus* sp. | 0 / 2 | — | — | — | — | — | 0 / 3 | + | 5 / 1 / + | 9 / 0 / + | 308 / 0 |
| *Phaenopsectra* sp. | — | — | — | — | — | — | — | + | 2 / 0 / + | 0 / 1 / + | — |
| *Polypedilum* sp. | 0 / 6 | — | — | — | 0 / 8 | — | — | 55 / 0 / + | 1 / 7 / + | 2 / 12 / + | 0 / 24 |
| *Tribelos* sp. | — | — | — | — | — | — | — | + | + | 8 / 0 / + | — |
| Tanytarsini | — | — | — | — | — | — | — | + | 0 / 4 / + | + | — |
| *Micropsectra* sp. | — | — | — | — | — | — | — | 4 / 0 / + | 0 / 2 / + | + | 0 / 4 |
| *Zavrelia* sp. | — | — | — | — | — | — | — | — | + | + | 0 / 1 |
| **REMAINING TAXA** | | | | | | | | | | | |
| Oligochaeta | 19 / 125 | 18 / 63 | 97 / 16 | — | 8 / 93 | 6 / 35 | 11 / 53 | 82 / 58 / 29 | 0 / 21 / 18 | 47 / 26 / 4 | 206 / 67 |
| Nematoda | — | 1 / 0 | 8 / 0 | — | — | 0 / 2 | 0 / 9 | 19 / 117 / 0 | 0 / 29 / 0 | 24 / 0 / 0 | 0 / 59 |
| Gastropoda | — | — | — | — | — | — | — | + / + / 4 | + / + / 4 | + / + / 4 | — |
| *Physella* sp. | — | 0 / 1 | — | — | — | 0 / 1 | 1 / 1 | + | + | 11 / 0 / + | 27 / 0 |
| *Ferrissia* sp. | — | 0 / 1 | — | — | — | — | — | + | + | + | 0 / 12 |
| Hydrocarina | 1 / 24 | 0 / 34 | — | — | — | 6 / 0 | — | 0 / 19 / — | 0 / 4 / — | 1 / 0 / — | 8 / 36 |
| *Dugesia dorotocephala* | 0 / 2 | — | — | — | — | — | 2 / 0 | 4 / 4 / — | — | — | 23 / 12 |