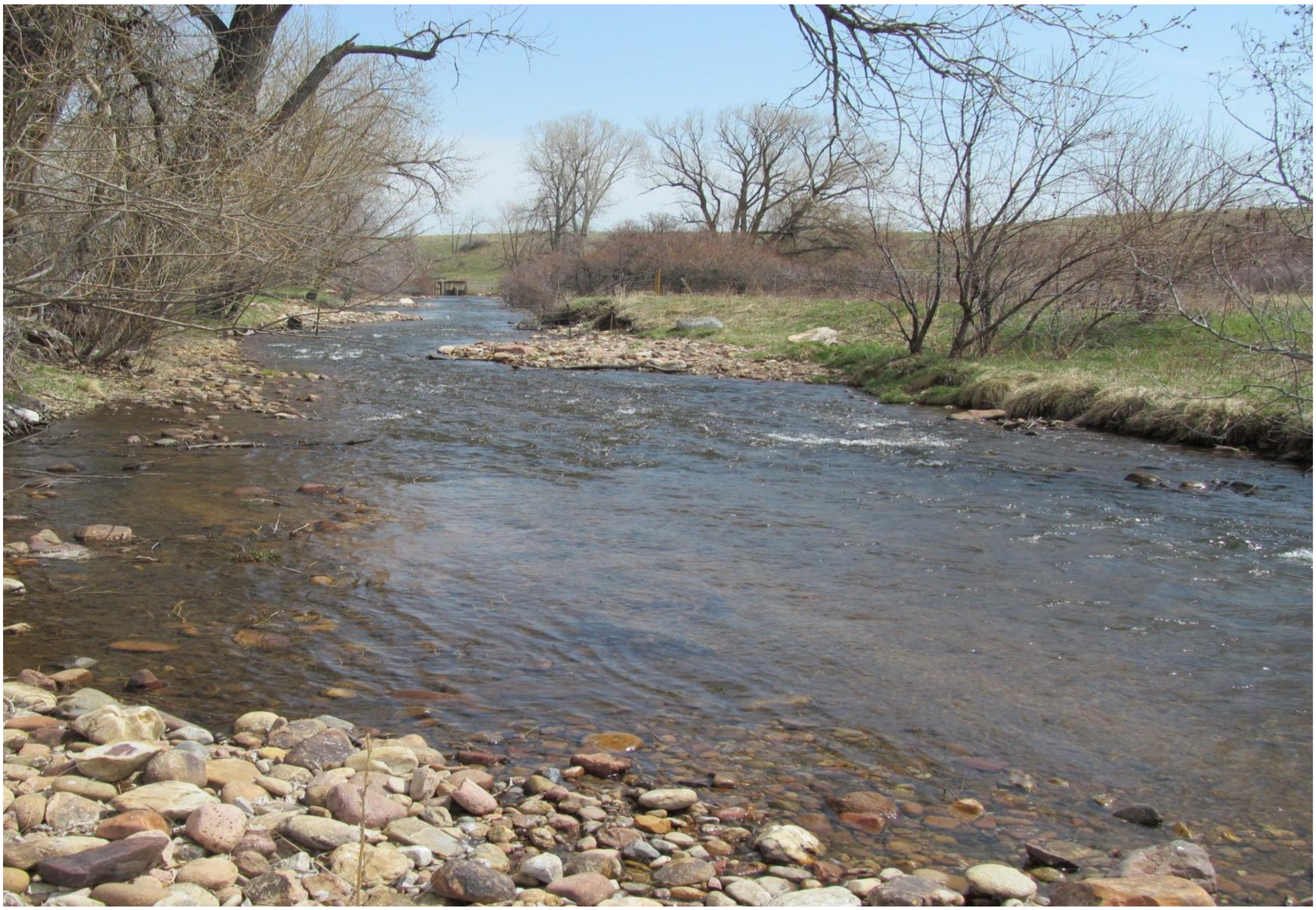
Macroinvertebrate Survey of South Boulder Creek, Boulder County, Colorado

Report to City of Boulder, Department of Open Space and Mountain Parks

August 2015



South Boulder Creek, upstream from U.S. 36

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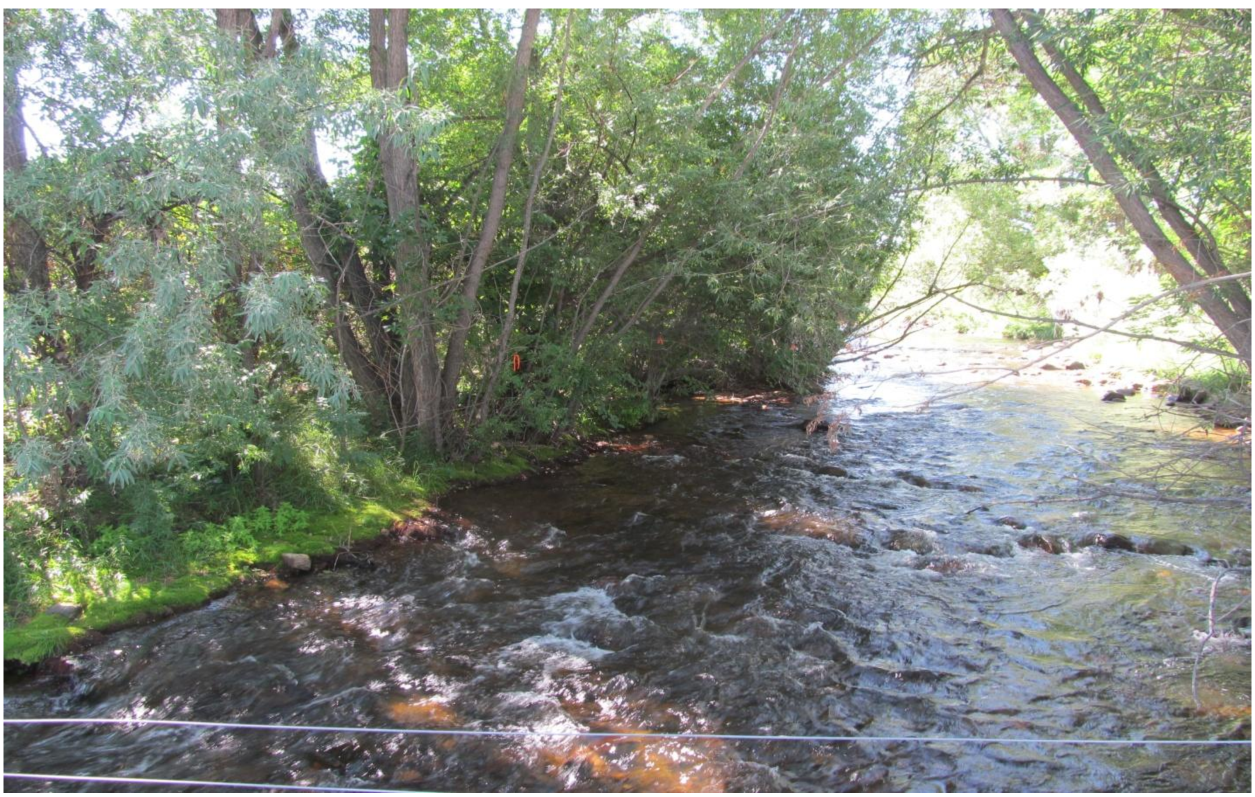
South Boulder Creek, with a 132-mi^2 drainage area constituting almost 30% of the Boulder Creek watershed, enters the Boulder Valley through Eldorado Canyon. From Eldorado Springs, the stream flows northeast 15 km to its confluence with Boulder Creek east of Boulder. Within the Boulder Valley, South Boulder Creek is a transition zone stream, characterized by cool to warm water temperatures, moderate gradients, and a mixture of substrates that includes sand, gravel, and cobble. Flows peak in late-April to early-July from snowmelt runoff. During the remainder of the year, flows are variable and frequently low, especially from November to March, when water is diverted for plains reservoir storage. The South Boulder Creek hydrograph has been modified by the effects of reservoirs and diversion dams. Gross Reservoir, 12 km west of Eldorado Springs, stores water transported from the Colorado River Basin. Water is diverted to the City of Denver and for irrigation. Below Eldorado Springs at least 12 diversion dams or other structures have obstructed the stream or diverted water for irrigation, storage, and power generation (Bestgen and Kondratieff 1996).

South Boulder Creek is biologically diverse and provides critical riparian habitat in the foothills of the Front Range, an area subject to increasing effects of urbanization. Two federally-listed threatened species occur in the floodplain of South Boulder Creek north and south of U.S. 36 - Ute ladies' tresses orchid (*Spiranthes diluvialis*) and Preble's meadow jumping mouse (*Zapus hudsonius preblei*). The northern leopard frog (*Rana pipiens*), a species of special concern (Colorado Division of Wildlife 2006), occurs in wetlands adjacent to South Boulder Creek (Germaine 2007, Joseph and Johnson 2012). Two native fish species proposed for listing in the revised State Wildlife Action Plan inhabit this reach of South Boulder Creek - plains topminnow (*Fundulus sciadicus*) and orangespotted sunfish (*Lepomis humilis*).

The macroinvertebrate fauna of South Boulder Creek has attracted the interest of biologists since the early 1900's. Several species of mayflies, including the widespread *Baetis tricaudatus*, were described from high-elevation areas of South Boulder Creek in Boulder County (Dodds 1923). Entomological interest at lower elevations has continued to the present. Research projects have addressed productivity of mayflies and stoneflies (Bjorklund 1970) and compared macroinvertebrate communities (Newell 1980). In 1995, a survey of fish and macroinvertebrates inventoried the stream from its confluence with Boulder Creek upstream to the Mesa Trailhead (Bestgen and Kondratieff 1996). A summary and compilation of recent collection records for Ephemeroptera, Plecoptera, and Trichoptera from the South Platte River Basin lists 28 species from South Boulder Creek below Gross Reservoir (Zuellig et al. 2012).

In 2010, the City of Boulder OSMP began restoration of a 3.2 km section of South Boulder Creek upstream from South Boulder Road. The project was a response to the degradation of aquatic habitat by water diversions, channel modifications, and grazing. This section of the creek lacked overwintering fish habitat during low-flow winter months. The City negotiated a minimum winter flow of seven cfs. Completed in 2012, aquatic habitat improvements included boulder clusters, low flow meander channels, side pools, meander cut offs, log pools, log wing deflectors, and woody debris clumps (Biohabitats 2013). Channel improvements for restoration of fish habitat also created habitat heterogeneity for aquatic macroinvertebrates, important elements of trophic structure in streams supporting trout and other cold-water fish.

Objectives of this study were (1) to collect macroinvertebrates within the restoration reach and at an upstream and downstream site, and (2) to compare the macroinvertebrate community with the 1995 survey (Bestgen and Kondratieff 1996). The initial study plan included two sampling periods: early to mid-summer and late fall. A new objective emerged after the record-setting rainfall and flood of September 9-13, 2013. South Boulder Creek (Fig.1) was severely affected by high streamflows, debris deposition, and overbank flooding, causing extensive channel scouring and damage to physical structures, including those installed in the restoration reach. These events occurred after the first sampling was completed. Documentation of the effects of flooding and channel scouring on macroinvertebrate abundance and diversity became an additional objective.



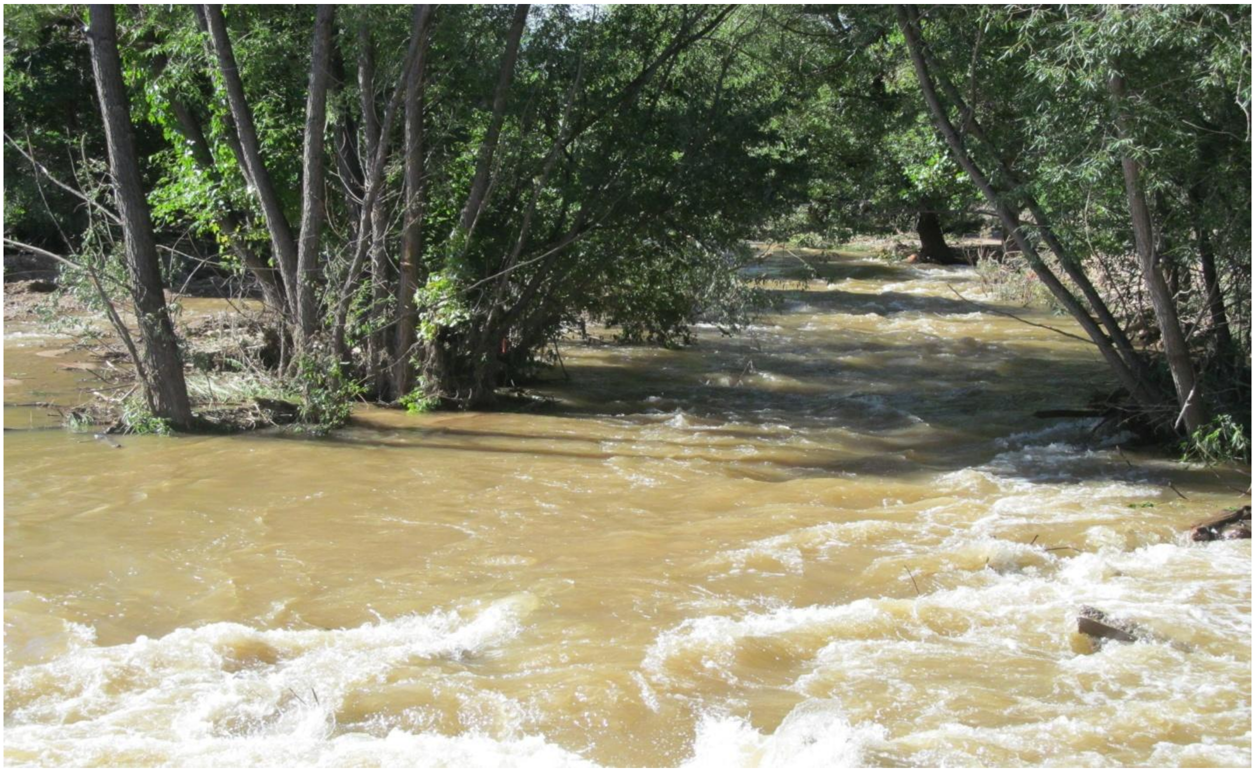


Figure 1. South Boulder Creek sampling site, 30 m upstream from South Boulder Road - 28 August 2013 (top), 18 September 2013 (bottom).

STUDY AREA

The study area encompasses 5 km of South Boulder Creek from the Lafayette Treatment Plant (about 0.8 km southwest of the bridge at South Broadway) downstream to South Boulder Road. Elevation is 1674 m at the upper end and 1638 m at South Boulder Road. Riparian vegetation is heterogeneous, with a canopy of large woody species (*Alnus incana, Populus deltoides, P. angustifolia, Salix fragilis*), interspersed with streamside stands of *Salix exigua* and open stream banks of grasses and sedges.

Six sampling sites were selected. Two sites from the 1995 survey (Bestgen and Kondratieff 1996) define the lower and upper boundaries of the study area. South Boulder Road site is immediately downstream of the restoration area and Lafayette Treatment Plant site is about 1.5 km upstream of the restoration area. Four new sites are within the restoration project, one in each designated stream reach of the design plan (Biohabitats 2010). General areas for sampling in the restoration area were identified in a preliminary reconnaissance (June 2013, D. D'Amico and M. Freehling). When water depth and velocity decreased to levels suitable for the Surber sampler (see Methods), four sites were selected on 20 August 2013. An important selection criterion was presence of a 10-m minimum length of riffle habitat for sampling. The six sites and their locations are listed from downstream to upstream:

- Site SB is 30 m upstream from South Boulder Road (39°59.136'N, 105°13.270'W);
- Site A (reach 1), is 180 m upstream from South Boulder Road (39°59.049'N, 105°13.262'W);
- Site B (reach 2) is 150 m downstream from the South Boulder Canyon Ditch diversion and fish ladder (39°58.434'N, 105°13.410'W);
- Site C (reach 3) is 210 m downstream from the Schearer Ditch headgate (39°58.183'N, 105°13.489'W);
- Site D (reach 4) is 45 m upstream from the Schearer Ditch headgate (39°58.029'N, 105°13.631'W);
- Site LT is 100 m southeast of the Lafayette Treatment Plant (39°57.394'N, 105°14.245'W).

METHODS

Stream macroinvertebrates were collected with a Surber square-foot (0.093 m^2) bottom sampler in late summer (23-29 August 2013) and late fall (8-12 November 2013). Water temperatures recorded at time of sampling were 14-15°C (August) and 4-7°C (November). On 30 October, velocity at the South Boulder Road stage had decreased to 50 cfs (Don D'Amico, pers. comm.), approaching the upper limit for the Surber sampler. Fall sampling was not possible until streamflow diminished in early November. Placement of the sampler is limited by stream depth (<30 cm), velocity, and substrate regularity. At each site, three Surber samples were taken in riffle areas, moving upstream from the first collecting location. The bottom frame was positioned over cobble and rubble substrate with the mouth of the net facing upstream. Invertebrates attached to large substrate particles (cobbles) were brushed into the frame and the substrate was stirred up with a small hand rake. Organisms within the frame were carried into the net by the current. Habitats unsuitable for the Surber sampler, e.g., pools or emergent vegetation, were sampled qualitatively with an aquatic D-net. An aerial net was used to sweep streamside vegetation for adult stages of aquatic taxa. In the field, each sample was transferred to a container of 80% ethyl alcohol.

Surber samples were washed through a 0.5 mm sieve and stored in 70% ethyl alcohol until sorted. Of three Surber samples collected at a site, two were randomly selected for sorting. The third was kept for reference. The sample was transferred to a subsampling frame (Moulton et al. 2000). The frame (30x20x3.8 cm) is constructed of plastic sides (1 cm thickness) and a bottom wire grid (2.5-cm squares) that supports a screen of Nitex™ mesh (0.1 mm opening). The bottom grid comprises 24 subsampling squares (5x5 cm). The frame was placed in a shallow tray containing 0.5 cm of water. The sample was distributed evenly on the mesh. The frame was lifted from the tray and set aside. A subsampling square was selected by random number table, its contents were transferred to a dish, and all macroinvertebrates were counted and sorted by family or order. Selection and removal of grid squares was repeated until 300 organisms were obtained. The entire sample was counted if it contained <300 macroinvertebrates. The sorted subsample was stored in 70% ethyl alcohol until subsequent taxonomic identification. Sample counts for each site were combined prior to data analysis. Qualitative samples were transferred to a tray of water and searched for additional taxa not detected in the Surber samples.

Aquatic insect taxa were identified to family and genus, using keys in Ward et al. (2002) and Merritt et al. (2008). Regional and specialized references were consulted for identification to species, when possible, for mayflies (Allen and Edmunds 1963, 1965; Allen and Chao 1978; Morihara and McCafferty 1979; Jacobus and McCafferty 2003), stoneflies (Szczytko and Stewart 1979, Stewart and Stark 2002), caddisflies (Alstad 1980, Flint 1984, Schefter and Wiggins 1986, Wiggins 1996), black flies (Peterson and Kondratieff 1994), and elmid beetles (Brown 1972, Brown and White 1978). Fourth-instar larvae of Chironomidae (midges) were mounted on glass slides in euparal mounting medium and identified to genus following keys and descriptions in Wiederholm (1983) and Ferrington et al. (2008). Most of the midge larvae were early instars and could not be reliably identified to genus. Summary data for chironomids includes presence-absence of late-instar taxa and counts of all midges in the subsamples (Appendix). Other macroinvertebrates were identified to genus or species for Amphipoda, Gastropoda, and Bivalvia and to class for Annelida, e.g., Oligochaeta. Nematodes (Nematoda) and water mites (Hydracarina) were not identified to a lower level. Identification and nomenclature follows Wu (1978), Pennak (1989), and Thorp and Covich (2001).

Metrics to describe macroinvertebrate composition in South Boulder Creek include richness (number of taxa), EPT richness (total Ephemeroptera, Plecoptera, and Trichoptera taxa), presence-absence, and percent occurrence of taxa in Surber samples. EPT richness, a commonly used indicator of pollution and water quality (Rosenberg et al. 2008), is also a useful index of trophic structure (Voshell 2002). EPT taxa, especially larvae, account for a high proportion in the diet of trout. EPT richness of 22-25 taxa is considered typical for Front Range streams (Bestgen and Kondratieff 1996). Taxa are designated as *abundant* (>10% relative abundance), *common* (1-10%), *uncommon* (0.1-0.9%), or *rare* (<0.1%) for descriptive purposes (Results and Discussion).

RESULTS AND DISCUSSION

The aquatic macroinvertebrate community comprised 54 taxa, including 48 insect taxa (Appendix). Total EPT richness was 24 species (Ephemeroptera, n=10; Plecoptera, n=6;

Trichoptera, n=8). Chironomidae accounted for >50% of the total macroinvertebrates in Surber samples, followed by Ephemeroptera (17%), Elmidae (11%), Trichoptera (7%), Simuliidae (3%), and Plecoptera (2%) (Table 1). Among EPT taxa, *Baetis tricaudatus* was the most abundant, occurring at all but one sampling site (Appendix). *Rhithrogena hageni* (Ephemeroptera: Heptageniidae), ephemerellid mayflies, *Triznaka signata* (a chloroperlid stonefly), and three caddisfly species (*Arctopsyche grandis, Brachycentrus americanus,* and *Hydropsyche oslari*) were common (Table 1). Elmids (riffle beetles) were the most abundant Coleoptera. *Optioservus* (Elmidae) accounted for almost 11% of total abundance (Table 1). Oligochaetes, nematodes, and water mites (Hydracarina) were the most abundant non-insect taxa (Appendix).

	Percent Occurrence			Taxa Richness					
				August		November		Aug + Nov	
	August	November	Aug + Nov	All	RR	All	RR	All	RR
EPT	12%	69%	26%	19	16	14	14	24	22
Ephemeroptera (mayflies)	8	44	17	10	8	4	4	10	9
Baetis tricaudatus	6	37	13	--	--	--	--	--	--
Rhithrogena hageni	<1	5	1	--	--	--	--	--	--
Ephemerellidae	2	1	2	5	4	1	1	5	5
Plecoptera (stoneflies)	1	7	2	3	2	5	5	6	5
Triznaka signata	<1	4	1	--	--	--	--	--	--
Isoperla fulva	0	2	<1	--	--	--	--	--	--
Trichoptera (caddisflies)	3	19	7	6	6	5	5	8	8
Brachycentrus americanus	<1	6	2	--	--	--	--	--	--
Glossosoma sp.	1	0	1	--	--	--	--	--	--
Hydropsychid caddisflies	1	12	4	1	1	3	3	1	3
Arctopsyche grandis	1	3	2	--	--	--	--	--	--
Hydropsyche oslari	0	8	2	--	--	--	--	--	--
Elmidae (riffle beetles)	13	7	11	4	4	3	3	4	3
Optioservus spp.	12	7	11	--	--	--	--	--	--
Chironomidae (midges)	70	15	56	5	5	2	2	7	6
Simuliidae (black flies)									
Simulium spp.	2	6	3	3	2	2	1	3	2
All taxa	--	--	--	43	34	29	27	54	47

Table 1. Percent occurrence and richness for selected taxa collected in Surber samples at South Boulder Creek, August and November 2013. "RR" denotes restoration reach sites (n = 4); "All" includes RR sites, SB site, and LT site. See Appendix for percent occurrence of all taxa.

August - November comparisons and flood effects

Two results of the macroinvertebrate community analysis were (1) a decrease in species number from August to November for all sites (43 vs. 29) and the restoration sites (34 vs. 27) (Table 1) and (2) a conspicuous decrease of total invertebrates in November Surber samples, in which none reached the maximum count of 300 organisms (Appendix). Taxa richness of Ephemeroptera declined in November (Table 1). Mayfly percent occurrence was higher in November, due to high numbers of *Baetis tricaudatus* and *Rhithrogena hageni*. With the exception of *Drunella grandis*, ephemerellid mayflies were collected only in August (Appendix). In November, taxa richness and percent occurrence of Plecoptera were higher, *Triznaka signata* being the most abundant species. Stoneflies were poorly represented in August samples, with three species present. Three stonefly species, including *Isoperla fulva*, were found only in November samples. Species richness of Trichoptera was similar in summer and fall; percent occurrence was higher in November. Of four common caddisflies, two showed distinct but opposite seasonal differences: *Hydropsyche oslari* occurred at all sites in November; *Glossosoma* was present in August only (Appendix). The elmid beetle *Optioservus* (larvae and adults) was abundant in August and common in November samples (Table 1). The preponderance of adult elmids occurred in August samples (Appendix). Chironomids accounted for 70% of macroinvertebrate abundance in August and 15% in November (Table 1). Five chironomid taxa were collected in August. Two additional taxa, *Diamesa* and *Tvetenia*, occurred only in November. Two common black fly species, *Simulium arcticum* and *S. tuberosum*, were present in August-November and August, respectively.

Floods result in a significant decrease in both numbers and species richness of stream invertebrates. Rapid post-flood recovery is a universal characteristic of stream communities (Resh et al. 1988), with recovery intervals after most floods being 2 to 4 months (Death 2008). A well-known example is that of a small stream in Pennsylvania (Hoopes 1974). After a short-term June flood, discharge increased 150-fold over several days, depositing rubble, gravel, and small boulders throughout the reach, with major portions of stream substrate scoured. By October, extensive faunal recovery had occurred.

A similar recovery was evident at South Boulder Creek, where a major effect of flooding on macroinvertebrate habitat was channel scouring and debris deposition. Cobble-boulder habitat remained (Fig. 2). Overbank flooding deposited sand and silt on terraces adjacent to the channel. The aquatic insect fauna in November reflects the alteration of stream habitat. A reduction in species richness and total abundance was obvious. Abundant or common post-flood taxa in this study are the same species found to be most common on bare upper surfaces of boulders in North Saint Vrain Creek: *Baetis*, *Brachycentrus americanus*, *Hydropsyche*, and *Simulium arcticum* (Ward 1975).

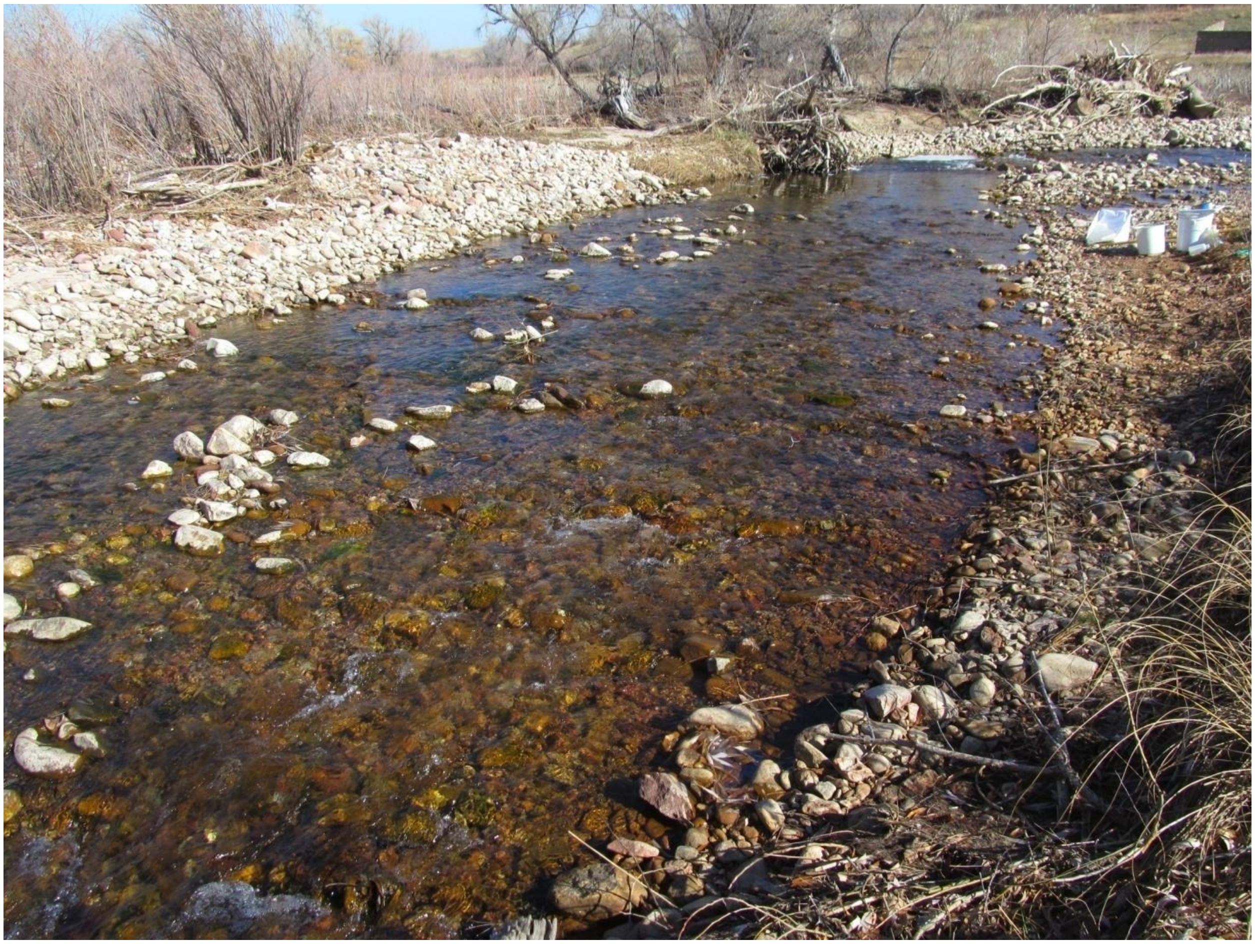


Figure 2. South Boulder Creek (sampling site C): scoured channel with boulder-cobble substrate (12 November 2013).

Baetid mayflies, hydropsychid caddisflies, and taxa with multivoltine life histories are frequently the dominant taxa at sites that exhibit rapid recovery after disturbance (Mackay 1992). In South Boulder Creek, Baetis tricaudatus and two hydropsychids, Arctopsyche grandis and Hydropsyche oslari, were more abundant in November. Baetis tricaudatus is bivoltine; larvae prefer rapids and are most often found clinging to stones (Morihara and McCafferty 1979). Another common mayfly, Rhithrogena hageni, increased in relative abundance and frequency at sampling sites in November. Rhithrogena nymphs are more abundant in deep, fast water; whereas Ephemerella larvae have an inverse relationship with depth and current (Ward 1992). Absence of Attenella margarita and Ephemerella species in November illustrates the effects of high velocity and water depth on ephemerellids. Cobble-boulder substrate sustains a high diversity of hydropsychid caddisflies. When gravel deposition fills interstitial spaces and reduces spatial heterogeneity of the substrate, Arctopsyche grandis disappears and overall caddisfly abundance declines. Relative abundance of hydropsychids increased (Alstad 1980). In

South Boulder Creek, *Arctopsyche grandis* was common before and after flooding, and *Hydropsyche oslari* was the most abundant caddisfly in November. Removal of smaller particles from the streambed would have enhanced habitat quality for hydropsychids. *Glossosoma*, a tortoiseshell-case caddisfly, was common in August samples, but was not found in November. *Glossosoma* larvae normally inhabit exposed microhabitats, e.g., upper surfaces of rocks submerged in current, but leave their cases to find sheltered locations as current velocity increases (Ward 1992). This behavior would explain their absence in November, exposing larvae to rapidly rising water before they could find refuge. In contrast, *Brachycentrus americanus* (Brachycentridae) larvae live in cases firmly attached to rocks and were a conspicuous and common post-flood species. The larvae either survived swift currents or rapidly colonized exposed surfaces as water levels and current velocity subsided.

The increase in November abundance of *Triznaka signata* (Plecoptera: Chloroperlidae) is noteworthy. Chloroperlid larvae inhabit the hyporheic zone (interstitial spaces between substrate particles), in gravel beneath the streambed (Ward et al. 2002). Ward (1975) reported *T. signata* to be absent or rare in all substrates except gravel in North Saint Vrain Creek. This species has a slow univoltine life cycle, in which early instar larvae develop in summer through fall and nymphal growth continues through winter until emergence in early spring (Hassage and Stewart 1990). These observations suggest that *T. signata* larvae can survive flooding and channel scouring in its hyporheic refuge. Larvae become susceptible to collection during Surber sampling when mineral deposits and gravel are overturned by raking.

Chironomids and simuliids (black flies) have short life cycles and are often dominant taxa during initial stages of recovery after a severe flood (Ward 1992). *Simulium arcticum* and the chironomid *Diamesa* showed this post-flood response. *Diamesa* larvae are adapted to swift water, fastening themselves to the substrate by posterior claws (Doughman 1983). They are more likely to persist during high flows or to colonize post-flood habitats earlier than other midge taxa. The reduction in numbers and loss of chironomid taxa in November samples (Appendix) emphasizes the deleterious effect of channel scouring on midge habitat, i.e., removal of sand and silt.

It should be emphasized that the storm and flooding of September 9-13, 2013 was a catastrophic and unusual event for South Boulder Creek. Three major floods have occurred there in the past 120 years (1969, 1938, and 1894), in contrast to 18 floods documented for Boulder Creek or its tributaries since 1875 (HDR Engineering 2007). Two 24-hour precipitation events on September 11 and 12 were nearly the equivalent of back-to-back 100-year recurrence interval storms (CH2M Hill 2015). Macroinvertebrate abundance and species richness were greatly reduced, but colonization and community recovery were evident after two months.

Comparison with 1995 survey

Thirty-eight aquatic insect taxa collected in this study (Appendix) were also found in 1995. Ten additional species were collected in 2013 - two dipteran species, five mayfly species, and three caddisfly species (Appendix). *Simulium tuberosum* is a widespread black fly in Colorado, including Boulder County (Peterson and Kondratieff 1994). *Clinocera* (Empididae), a predaceous dance fly, was rare in August samples. Larvae and adults inhabit exposed surfaces of rocks in rapid water (Egglishaw 1969, Harper 1980). The Ephemeroptera and Trichoptera taxa have been collected in or near Boulder on South Boulder Creek or Boulder Creek, as noted in the following records from Zuellig et al. (2012). Larvae of *Baetis flavistriga* (Baetidae) and *Attenella margarita* (Ephemerellidae) were collected at South Boulder Creek and Boulder Creek. *Ephemerella excrucians* (formerly *E. inermis*), *E. tibialis, and Serratella micheneri* are common ephemerellid mayflies in Colorado, occurring in mid- to low-elevation streams in Boulder County (also, McCafferty et al. 1993). *Serratella micheneri* larvae prefer cool-water streams with gravel substrate (Allen and Edmunds 1963). *Arctopsyche grandis* and *Hydropsyche cockerelli* are common, widespread caddisfly species in the South Platte River Basin. Larvae are known from Boulder Creek in Boulder. *Hydroptila* is a small caddisfly that has been collected from low-elevation streams in Boulder County. Their larvae and cases (<6 mm in length) are distinct from other genera of Hydroptilidae (Wiggins 1996).

Bestgen and Kondratieff (1996) collected macroinvertebrates on three dates (9 December 1994, 12 April and 4 October 1995) at four sites. Two of their collecting locations were used in the current study: Lafayette Treatment Plant (LT) and South Boulder Road (SB) (see Study Area). Total species richness was lower in this study (Table 2), which can be attributed to the sampling date (late August) and the effects of flooding after mid-September (see previous discussion). In August 2013, EPT richness for the two sites was 6 and 11 (Table 2). Late summer may not be optimal for sampling EPT larvae because of the potential loss of nymphs to adult emergence. Newell (1980) collected 20 EPT nymph taxa in mid-July at two sites on South Boulder Creek near Highway 93. In the present study, an early summer collection was not feasible because water depths and current velocities were unsuitable for the Surber sampler until late August.

	Total Richness		EPT Richness	
	LT	SB	LT	SB
December 1994	30	40	17	22
April 1995	31	35	17	19
October 1995	30	38	18	20
August 2013	20	20	11	6
November 2013	10	9	8	7

Table 2. Taxa richness at Lafayette Treatment Plant (LT) and South Boulder Road (SB) in 1995 and 2013.

In summary, lower species richness in 2013 is not surprising. Differences in sampling periods and effects of the flood make it difficult to compare macroinvertebrate composition to the earlier study. Explanations for the low richness values in this study include (1) absence of spring and early summer sampling, which excludes winter stonefly taxa, e.g., Capniidae, and other stoneflies that emerge by early summer, and (2) the consequences of September flooding and prolonged period of high runoff on late-fall or early-winter taxa that normally would have been present. The highest richness values occurred in December 1994 at the SB site (Table 2).

Ward (1975) compared the macroinvertebrate community of North Saint Vrain Creek (elevation 1677 m) to a study from 29 years earlier at the same site. He concluded that community composition had changed very little, despite an increase in riparian vegetation, differences in temperature and flow regimes, and construction of an upstream reservoir. In the 18 years between South Boulder Creek surveys, similar changes have either not occurred or evidence is incomplete. Dam construction at Gross Reservoir was completed and impoundment began 40 years before 1995. Flow data at Eldorado Springs (USGS gage 06729500) end in 1995, after which apparently no discharge or streamflow records are available. Native riparian trees have probably not increased since 1995. Absence of recent alluvial surfaces and young-age-class cottonwood-willow stands indicates that conditions for establishment and growth of woody riparian species are no longer present (D'Amico 1996). Prior descriptions of channel substrate and aquatic habitats in the study area (Bjorklund 1970, Bestgen and Kondratieff 1996) are similar to conditions in summer 2013. The preceding points and the absence of a major flood since 1969 (discussed previously) suggest the existence of a relatively stable stream habitat for macroinvertebrates from 1995 to August 2013. The overlap in taxa from both surveys and addition of relatively few new taxa in 2013 suggest that the macroinvertebrate fauna has not change appreciably. Recent stream restoration and increase in minimum flow created conditions for improving habitats for fish and invertebrates. Effects on aquatic invertebrates are not known, given the short time since inception and followed by flooding in 2013 that destroyed much of the restoration improvements.

Acknowledgments

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Literature Cited

Allen, R. K. and E. S. M. Chao. 1978. Mayflies of the Southwest: New species and records of Heptageniidae. Pan-Pacific Entomologist 54:311-315.

Allen, R. K. and G. E. Edmunds, Jr. 1963. A revision of the genus *Ephemerella* (Ephemeroptera: Ephemerellidae). VI. The subgenus *Serratella* in North America. Annals of the Entomological Society of America 5:583-600.

Allen, R. K. and G. E. Edmunds, Jr. 1965. A revision of the genus *Ephemerella* (Ephemeroptera: Ephemerellidae). VIII. The subgenus *Ephemerella* in North America. Miscellaneous Publications of the Entomological Society of America 4:243-282.

Alstad, D. N. 1980. Comparative biology of the common Utah Hydropsychidae (Trichoptera). American Midland Naturalist 103:167-174.

Bestgen, K. R. and B. Kondratieff. 1996. Fishes, macroinvertebrates, and habitat of South Boulder Creek, Colorado, within City of Boulder Open Space Property. Report to City of Boulder Open Space Department. 100p.

Biohabitats. 2010. South Boulder Creek aquatic habitat improvements design plan. Biohabitats, Inc., Denver.

Biohabitats. 2013. South Boulder Creek aquatic habitat improvements design-build. Biohabitats, Inc., Denver. (http://www.biohabitats.com/projects/south-boulder-creek-aquatic-habitat-improvements-design-build/).

Bjorklund, R.B. 1970. Interpreting relative productivity of South Boulder Creek by systematic stonefly (Plecoptera) and mayfly (Ephemeroptera) nymph counts. Report to City of Boulder Open Space Department. 12 p.

Brown, H. P. 1972. Aquatic dryopoid beetles (Coleoptera) of the United States. Biota of Freshwater Ecosystems Identification Manual No, 6. Water Pollution Control Research Series, U. S. Environmental Protection Agency, Washington, D.C.

Brown, H. P. and D. S. White. 1978. Notes on separation and identification of North American riffle beetles (Coleoptera: Dryopoidea: Elmidae). Entomological News 89:1-13.

CH2M Hill. 2015. South Boulder Creek major drainageway plan – alternatives analysis report. Prepared for City of Boulder, Urban Drainage and Flood Control District. CH2M Hill, Englewood, Colorado.

Colorado Division of Wildlife. 2006. Colorado's comprehensive wildlife conservation strategy and wildlife action plans. Colorado Division of Wildlife, Denver.

D'Amico, D. R. 1996. The riparian ecosystem of South Boulder Creek: Hydrology, vegetation and restoration opportunities. Report to City of Boulder Open Space Department. 39p.

Death, R. B. 2008. The effects of floods on aquatic invertebrate communities. Pp. 103-121, in Aquatic insects: Challenges to populations (Lancaster, J. and R. A. Briers, editors). CAB International, Cambridge, Massachusetts.

Dodds, G.S. 1923. Mayflies from Colorado: descriptions of certain species and notes on others. Transactions of the American Entomological Society 49:93–114.

Doughman, J. S. 1983. A guide to the larvae of the Nearctic Dimesinae (Diptera: Chironomidae). The genera *Boreoheptagyia, Protanypus, Diamesa, and Pseudokiefferiella*. U. S. Geological Survey, Water-Resources Investigations Report 83-4006.

Egglishaw, H. J. 1969. The distribution of benthic invertebrates on substrata in fast-flowing streams. Journal of Animal Ecology 38:19-33.

Ferrington, L. C., Jr., M. B. Berg, and W. P. Coffman. 2008. Chironomidae. Pp. 847-989, in An introduction to the aquatic insects of North America. 4th edition. (Merritt, R. W., K. W. Cummins, and M. B. Berg, editors). Kendall Hunt, Dubuque, Iowa.

Flint, O. S. 1984. The genus *Brachycentrus* in North America, with a proposed phylogeny of the genera of Brachycentridae (Trichoptera). Smithsonian Contributions to Zoology 398.

Germaine, S. 2007. Northern leopard frog inventory surveys. Report to City of Boulder Open Space and Mountain Parks. 12 p.

Harper, P. P. 1980. Phenology and distribution of aquatic dance flies (Diptera: Empididae) in a Laurentian watershed. American Midland Naturalist 104:110-117.

Hassage, R. L. and K. W. Stewart. 1990. Growth and voltinism of five stonefly species in a New Mexico mountain stream. Southwestern Naturalist 35:130-134.

HDR Engineering, Inc. 2007. South Boulder Creek climatology and hydrology report. City of Boulder and Urban Drainage and Flood Control District.

Hoopes, R. L. 1974. Flooding, as the result of Hurricane Agnes, and its effect on a macrobenthic community in an infertile headwater stream in central Pennsylvania. Limnology and Oceanography 19:853-857.

Jacobus, L. M. and W. P. McCafferty. 2003. Revisionary contributions to North American *Ephemerella* and *Serratella* (Ephemeroptera: Ephemerellidae). Journal of the New York Entomological Society 111:174-193.

Joseph, M. B. and P. T. J. Johnson. 2012. Habitat use of northern leopard frogs in the Front Range. Final Report. University of Colorado, Boulder, Department of Ecology and Evolutionary Biology. 27 p.

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

McCafferty, W. P., R. S. Durfee, and B. C. Kondratieff. 1993. Colorado mayflies (Ephemeroptera): An annotated inventory. Southwestern Naturalist 38:252-274.

Merritt, R. W., K. W. Cummins, and M. B. Berg (editors). 2008. An introduction to the aquatic insects of North America. 4th edition. Kendall Hunt, Dubuque, Iowa.

Morihara, D. K. and W. P. McCafferty. 1979. The *Baetis* larvae of North America (Ephemeroptera: Baetidae). Transactions of the American Entomological Society 105:139-220.

Moulton, S. R., J. L. Carter, S. A. Grotheer, T. F. Cuffney, and T. M. Short. 2000. Methods of analysis by the U. S. Geological Survey National Water Quality Laboratory – processing, taxonomy, and quality control of benthic macroinvertebrate samples. U. S. Geological Survey Open-File Report 00-212. Denver, Colorado.

Newell, R. L. 1980. Aquatic invertebrates of South Boulder Creek. Report to City of Boulder Open Space Department. 5p.

Pennak, R. W. 1989. Fresh-water invertebrates of the United States. 3rd edition. J. Wiley & Sons, New York.

Peterson, B. V. and B. C. Kondratieff. 1994. The black flies (Diptera: Simuliidae) of Colorado: An annotated list with keys, illustrations and descriptions of three species. Memoirs of the American Entomological Society no. 42:1-121.

Resh, V. H., A. V. Brown, A. P. Covich, M. E. Gurtz, H. W. Li, G. W. Minshall, S. R. Reice, A. L. Sheldon, J. B. Wallace, and R. C. Wissmar. 1988. The role of disturbance in stream ecology. Journal of the North American Benthological Society 7:433-455.

Rosenberg, D. M., V. H. Resh, and R. S. King. 2008. Use of aquatic insects in biomonitoring. Pp. 123-137, in An introduction to the aquatic insects of North America. 4th edition. (Merritt, R. W., K. W. Cummins, and M. B. Berg, editors). Kendall Hunt, Dubuque, Iowa.

Schefter, P. W. and G. B. Wiggins. 1986. A systematic study of the Nearctic larvae of the *Hydropsyche morosa* group (Trichoptera: Hydrosychidae). Life Sciences Miscellaneous Publication of the Royal Ontario Museum, Toronto.

Stewart, K. W. and B. P. Stark. 2002. Nymphs of North American stonefly genera (Plecoptera). 2nd edition. The Caddis Press, Columbus, Ohio.

Szczytko, S. W. and K. W. Stewart. 1979. The genus *Isoperla* (Plecoptera) of western North America: Holomorphology and systematics, and a new stonefly genus *Cascadoperla*. Memoirs of the American Entomological Society no. 32:1-120.

Thorp, J. H. and A. P. Covich, editors. 2001. Ecology and classification of North American freshwater invertebrates. 2nd edition. Academic Press, San Diego, California.

Voshell, J. R. 2002. A guide to common freshwater invertebrates of North America. McDonald & Woodward Publishing Company, Blacksburg, Virginia.

Ward, J. V. 1975. Bottom fauna-substrate relationships in a northern Colorado trout stream: 1945 and 1974. Ecology 56:1429-1434.

Ward, J. V. 1992. Aquatic insect ecology. 1. Biology and habitat. J. Wiley & Sons, New York.
Ward, J. V., B. C. Kondratieff, and R. E. Zuellig. 2002. An illustrated guide to the mountain stream insects of Colorado. 2nd ed. University Press of Colorado, Boulder.
Wiederholm, T. (editor). 1983. Chironomidae of the Holarctic region. Keys and diagnoses. Part 1. Larvae. Entomologica Scandinavica Supplement 19:1-457.
Wiggins, G. B. 1996. Larvae of the North American caddisfly genera. 2nd edition. University of Toronto Press, Toronto, Canada.
Wu, S.-K. 1978. The Bivalvia of Colorado. Part 1. The fingernail and pill clams (Family Sphaeriidae). Natural History Inventory of Colorado 2:1-39. University of Colorado Museum, Boulder.
Zuellig, R. E., B. D. Heinold, B. C. Kondratieff, and D. E. Ruiter. 2012. Diversity and distribution of mayflies (Ephemeroptera), stoneflies (Plecoptera), and caddisflies (Trichoptera) of the South Platte River Basin, Colorado, Nebraska, and Wyoming, 1873-2010. U. S. Geological Survey Data Series 606, 257 p.

Appendix. Numbers of aquatic macroinvertebrates collected from South Boulder Creek in August and November 2013. Data are combined counts for subsamples at six collecting sites: South Boulder Road (SB), Lafayette Treatment Plant (LT), and four Restoration Reach sites (A-D). "--" indicates that the taxon was not detected; "~" indicates a value <0.1%; for Chironomidae, "+" denotes presence of the taxon; "a" = adults.

	August						November						Aug + Nov	
		Restoration Reach						Restoration Reach						
	SB	A	B	C	D	LT	SB	A	B	C	D	LT	Total	%
EPHEMEROPTERA														
*Attenella margarita**	--	4	10	--	--	8	--	--	--	--	--	--	22	0.5
*Baetis flavistriga**	--	--	--	--	4	--	--	--	--	--	--	--	4	0.1
Baetis tricaudatus	--	6	40	30	65	50	94	72	35	55	70	105	622	13.3
Drunella grandis	--	--	--	--	--	2	2	--	--	3	3	2	12	0.3
*Ephemerella excrucians**	4	8	6	--	12	--	--	--	--	--	--	--	30	0.6
*Ephemerella tibialis**	--	--	--	6	--	--	--	--	--	--	--	--	6	0.1
Paraleptophlebia sp.	--	--	--	--	1	--	--	15	--	--	--	--	16	0.3
*Serratella micheneri**	--	8	--	--	--	--	--	--	--	--	--	--	8	0.2
Rhithrogena hageni	2	3	2	--	--	--	30	--	5	15	1	6	64	1.4
Tricorythodes explicatus	--	--	--	--	--	2	--	--	--	--	--	--	2	~
PLECOPTERA														
Claassenia sabulosa	--	--	--	--	--	--	--	6	--	--	--	--	6	0.1
Isoperla fulva	--	--	--	--	--	--	--	--	4	12	2	4	22	0.5
Malenka sp.	--	--	--	--	--	--	--	--	3	1	--	--	4	0.1
Pteronarcella badia	--	--	--	--	--	2	--	--	--	--	--	--	2	0.0
Skwala americana	1	--	--	3	5	3	--	2	--	--	--	--	14	0.3
Triznaka signata	--	--	2	--	3	5	--	8	5	22	7	6	58	1.2
TRICHOPTERA														
Agapetus sp.	--	--	2	--	--	--	--	--	--	--	--	--	2	~
*Arctopsyche grandis**	5	--	3	9	--	17	14	--	13	11	--	--	72	1.5
Brachycentrus americanus	10	--	--	4	--	--	22	11	7	15	10	5	84	1.8
Glossosoma sp.	2	--	--	4	10	28	--	--	--	--	--	--	44	0.9
*Hydropsyche cockerelli**	--	--	--	--	--	--	--	--	2	--	--	--	2	~
Hydropsyche oslari	--	--	--	--	--	--	35	3	26	22	10	2	98	2.1
Hydroptila sp.*	--	--	3	--	--	1	--	--	--	--	--	--	4	0.1
Lepidostoma sp.	--	--	--	--	12	4	1	--	--	--	5	4	26	0.6
HEMIPTERA														
Aquarius remigis	--	--	--	--	--	6	--	--	--	--	--	--	6	0.1
Rhagovelia sp.	--	--	--	--	--	--	--	--	2	--	--	--	2	~
COLEOPTERA														
Hydroporus sp.	--	--	--	--	4	2	--	--	--	--	--	--	6	0.1
Helophorus sp.	3	--	--	--	--	--	--	--	--	--	--	--	3	0.1
Hydrobius sp.	1	--	--	--	--	--	--	--	--	--	--	--	1	~
Tropisternus sp.	--	--	--	--	--	--	--	--	2	--	--	--	2	~
Elmidae														
Narpus concolor - a	--	--	--	--	2	--	--	--	--	--	--	--	2	~
Optioservus castanipennis - a	3	--	5	10	13	2	--	--	--	5	--	--	38	0.8
Optioservus divergens - a	2	--	4	14	12	--	--	1	--	6	3	--	42	0.9
Optioservus larvae	44	54	110	60	30	60	20	20	16	10	--	--	424	8.4
Zaitzevia parvula - a	--	--	4	6	2	--	--	--	--	4	--	--	16	0.3

Appendix (continued)

	August						November						Aug + Nov	
		Restoration Reach						Restoration Reach					Total	%
	SB	A	B	C	D	LT	SB	A	B	C	D	LT		
DIPTERA														
Atherix pachypus	--	--	--	--	--	--	--	--	--	2	2	--	4	0.1
Chelifera sp.	--	6	6	8	4	--	--	--	--	--	--	--	24	0.5
Clinocera sp.*	--	--	--	2	--	--	--	--	--	--	--	--	2	~
Hexatoma sp.	--	--	4	--	2	--	--	2	--	--	--	--	8	0.2
Chironomidae														
Cricotopus sp.	+	+	+	+	+	--	--	+	--	--	--	--		
Diamesa sp.	--	--	--	--	--	--	--	+	--	+	+	+		
Eukiefferiella sp.	+	+	+	--	+	+	--	--	--	--	--	--		
Pagastia sp.	+	+	+	+	+	+	--	--	--	--	--	--		
Tanytarsus sp.	--	--	+	--	+	--	--	--	--	--	--	--		
Thienemannimyia group	+	+	+	+	+	--	--	--	--	--	--	--		
Tvetenia sp.	--	--	--	--	--	--	--	--	--	--	--	+		
Chironomidae total	310	510	390	410	420	400	--	90	--	28	20	40	2,618	56.1
Simulium arcticum	16	2	--	2	--	4	22	--	6	8	2	--	62	1.3
*Simulium tuberosum**	10	--	11	29	--	2	--	--	--	--	--	--	52	1.1
Simulium vittatum	--	--	--	--	--	--	28	--	--	--	--	--	28	0.6
HYDRACARINA	2	2	--	--	10	--	--	14	--	--	2	--	30	0.6
AMPHIPODA														
Hyalella azteca	--	--	--	--	3	--	--	--	--	--	--	--	3	~
OLIGOCHAETA	4	2	--	2	4	6	--	--	2	--	--	--	20	0.4
NEMATODA	5	9	--	5	5	10	--	--	4	--	--	--	38	0.8
GASTROPODA														
Physella sp.	--	--	--	--	8	--	--	--	--	--	--	--	8	0.2
BIVALVIA														
Pisidium sp.*	--	--	--	--	6	--	--	--	--	--	--	--	6	0.1
Total	424	614	602	604	637	614	268	244	134	219	135	174	4,669	
Total taxa richness	20	15	19	18	26	20	9	13	14	15	13	10	54	
EPT richness	6	5	8	6	8	11	7	7	9	9	8	8	24	

* species not found in 1995 survey (Bestgen and Kondratieff 1996)