Fishes, Macroinvertebrates, and Habitat of South Boulder Creek, Colorado, Within City of Boulder Open Space

Fishes, Macroinvertebrates, and Habitat of South Boulder Creek, Colorado, within City of Boulder Open Space Property

A Final Report

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EXECUTIVE SUMMARY

South Boulder Creek on City of Boulder Open Space property was surveyed in 1994-1995 to determine composition and patterns of distribution and abundance of fish and macroinvertebrate assemblages. Stream discharge, water temperatures, and habitat were characterized at streamwide and site specific scales to identify factors limiting those biotic assemblages.

A total of nine native and seven non-native fish species was collected in 25 samples at 15 sites. Native species, mostly minnows and suckers, were widespread and numerically dominant. Non-native species, mostly trout and sunfishes, were generally sporadic in occurrence and relatively uncommon. Effects of non-native species on native forms was not studied. The fish community is dynamic, as non-native species continue to be introduced, or disperse from reservoirs, into South Boulder Creek.

Analysis of historic records indicated that at least three and perhaps as many as nine native fishes have been extirpated from South Boulder Creek. Most extirpated fishes are habitat specialists and require cool, clear water and sand and gravel substrate for reproduction. Remaining fish species are mostly habitat generalists and relatively tolerant of degradation.

A total of 96 macroinvertebrate taxa were identified from 40 samples collected in South Boulder Creek in winter 1994, spring 1995, and late-summer 1995 at six different localities. The most diverse macroinvertebrate communities were found upstream of South Boulder Road. Siltation (sediment), low flows, and perhaps higher temperatures limited species richness of the macroinvertebrate community downstream of there. High flows in spring and summer 1995 removed silt from the reach between South Boulder and Baseline roads and may have been responsible for the partial recovery of the invertebrate community there in fall 1995.

A number of interacting factors including channelization, reduced stream discharge, and siltation affect the distribution and abundance of fishes and aquatic macroinvertebrates in South Boulder Creek. Reduced streamflows and previous channelization limit habitat to wide, shallow runs and riffles throughout South Boulder Creek, but especially upstream of South Boulder Road. Deep pools and large woody debris necessary to support fishes species with large adult body size are few or lacking and may exacerbate effects of low flows, especially in winter. Although streamflows are low, physical habitat improves slightly in a short reach downstream of South Boulder Road to Baseline Road, but higher silt deposition is evident.

Diversion dams near South Boulder Road may block upstream dispersal of several fish species in South Boulder Creek because species richness of the fish community declines abruptly just upstream of there. The upstream distribution of those warmwater fish species may also be limited by cooler water temperatures and poor habitat. Species richness of the macroinvertebrate community declines sharply downstream of South Boulder Road and may be limited by siltation.

Continued monitoring of fish and macroinvertebrate communities of South Boulder Creek is recommended in order to better define community dynamics and factors affecting those biota. Design and implementation of such monitoring programs are discussed. Recommendations for future research are also given.

INTRODUCTION

The organisms that occupy a particular environment are often good indicators of the relative health of that ecosystem and reflect the chemical, physical, and biological conditions in which they evolved. Biological community changes, and therefore biological evaluation, reflect many environmental conditions and anthropogenic impacts. The presence of species that are intolerant of pollutants or habitat perturbations or communities that are dominated by native taxa are generally thought to indicate something positive about the relative health of that environment. Absence of sensitive forms, dominance by tolerant species, or lack of organisms at all may indicate a less than pristine situation and ecosystem stress. Collections of biota at survey sites can, if continued over time or if matched to historical records or unimpacted areas, aid in determining trends in the ecological integrity of an ecosystem. Unfortunately, relatively little is known about native fishes and aquatic macroinvertebrates in plains streams in Colorado such as South Boulder Creek because basic survey data, especially historical data, are lacking.

Stresses to aquatic ecosystems include natural environmental fluctuations as well as anthropogenic disturbances. Karr et al. (1986) defined five classes of environmental factors that affect aquatic ecosystems: energy source, water quality, habitat quality, flow regime, and biotic interactions (Table 1). They stress that these classes are interrelated and the biological community may be altered by changes in any one of the factors. Therefore, the components and structure of the biological community reflect many environmental factors, making biological monitoring a powerful tool. Additionally, the integration of many environmental factors suggests that approaches to water resource management problems be broad-based.

Table 1.--Environmental factors that affect aquatic biota (modified from Karr et al. 1986).

Food (Energy) Source

- type, amount, and particle size of organic material entering a stream from the riparian zone versus primary production in the stream
- seasonal pattern of available energy

Water Quality

- temperature
- turbidity
- dissolved oxygen
- nutrients (primarily nitrogen and phosphorus)
- organic and inorganic chemicals, natural and synthetic
- heavy metals and toxic substances
- pH

Habitat Structure

- substrate type
- water depth and current velocity
- spawning, nursery, and hiding places
- diversity (pools, riffles, woody debris)
- basin size and shape

Flow Regime

- water volume
- temporal distribution of floods and low flows

Biotic Interactions

- competition
- predation
- disease
- parasitism

Solutions that consider many aspects of the watershed, and manage the ultimate cause of a problem, are likely to be more effective and more economical than solutions which only consider proximate causes (Karr et al. 1986, Ohio Environmental Protection Agency 1988).

Because environmental fluctuations and anthropogenic disturbances often interact to affect stream biota in complex ways, chemical and physical measurements (e.g., water quality standards) can provide only indirect measures of the health of an aquatic ecosystem (Karr and Dudley 1981). Direct measurement of the health or ecological integrity of aquatic communities provides a better assessment of environmental degradation (Karr et al. 1986, Karr 1991).

Baseline survey data that describe distribution and relative abundance of aquatic biota and habitat conditions are necessary to assess the current status and health of an ecosystem. Fishes and benthic macroinvertebrates are thought to be good indicators of the relative health of an aquatic ecosystem (Karr et al. 1986, Resch and Rosenburg 1993). These taxa integrate effects of both site and watershed conditions and the magnitude of detrimental impacts may be manifest in the composition and abundance of these taxa. Assessments of these are important for defining potential impacts to existing biota and to evaluate restoration potential of the South Boulder Creek ecosystem. Therefore, our objectives were to:

1) Characterize species composition, distribution, and relative abundance of fish and aquatic macroinvertebrates from fall 1994 through summer 1995 in South Boulder Creek, on City of Boulder Open Space property;
2) Conduct a habitat survey of South Boulder Creek;
3) Collect cursory water chemistry data; and
4) Prepare a report summarizing results of surveys and comparison with historical data if available.

Also included is a discussion of possible factors affecting the distribution and abundance of fishes and macroinvertebrates within the South Boulder Creek aquatic ecosystem and historical changes in the fish community based on a survey of available literature and records. This report further discusses ways to monitor and improve aquatic communities in South Boulder Creek.

METHODS

Fish sampling and data analysis.--Fish collection sites were geographically widespread and spaced to narrowly define distributional patterns of fishes, especially as related to distribution of diversion dams. Specific efforts were also made to locate and sample other unique sites such as off-channel ponds because of potential for rare species in such habitats. Four sites (site 1, South Mesa Trailhead; site 2, LaFayette Water Treatment Plant; site 8, just downstream of South Boulder Road; and site 10, just upstream of Baseline Road) were chosen for multiple occasion fish sampling in order to detect species that may be variably abundant in different seasons. The lowermost two sites, while geographically close, were of interest because each locality represented the upstream extent of several fish species in South Boulder Creek, and site 10 was sampled in historic collections.

Because the primary focus of this study was to survey taxa that existed within a reach, a variety of gear including seines, dipnets, and a backpack electrofisher (Coffelt BP-4) was used to collect fishes in stream habitat. A variety of gear types is generally considered more efficient than a single gear type at documenting species composition of a fish community. Length of site varied directly with habitat complexity and was equivalent to 10 to 20 stream widths, which is generally adequate to document species composition and relative abundance of fish taxa in small streams. An effort was made to sample in all habitat types at each site including riffles, runs, pools, and backwaters. Substrate in riffles and runs was disturbed during sampling to dislodge benthic fishes. During electrofishing, voltage was typically set at 125-200 volts which produced 0.1-0.3 amperes which allowed for efficient capture of specimens without visibly injuring them. Electrofishing time and station length were recorded.

Standing water habitats such as off-channel pools and gravel-pit ponds were sampled primarily with seines (3 to 6 mm mesh). Seines hauls were made along shoreline areas in water up to 1.2 m deep.

Fish collected in samples were typically counted, a subsample occasionally measured to the nearest mm total length (TL), and fish were returned to the stream. A few difficult to identify juvenile sunfish specimens and some larvae were preserved and returned to the lab for identification.

Invertebrate sampling and data analysis.--Invertebrate samples were collected in three different seasons (fall 1994, and spring and late-summer 1995) at Sites 1, 2, and 10. Quantitative collections were also made near site 8 but just upstream instead of downstream of South Boulder Road because better habitat was available there and because sampling below site 8 diversion dams, which were important in limiting upstream distribution of fishes, was not important for macroinvertebrates with aerial adult life stages. Qualitative collections were occasionally made at these sites and at sites 11 and 15.

A Surber square-foot bottom sampler (Fig. 1) was used to obtain quantitative samples in South Boulder Creek. The 0.093 m^2 metal frame was placed over suitable cobble and rubble and the substrate particles brushed and disturbed until all animals are washed downstream into the net. Three replicate samples were collected at each of the four permanent sites in each of the three seasons.

Qualitative benthic samples were taken with a standard D-frame kick net. The major objective was to obtain specimens from the many microhabitats of South Boulder Creek that was not sampled with the quantitative device. Selected specimens were returned alive for

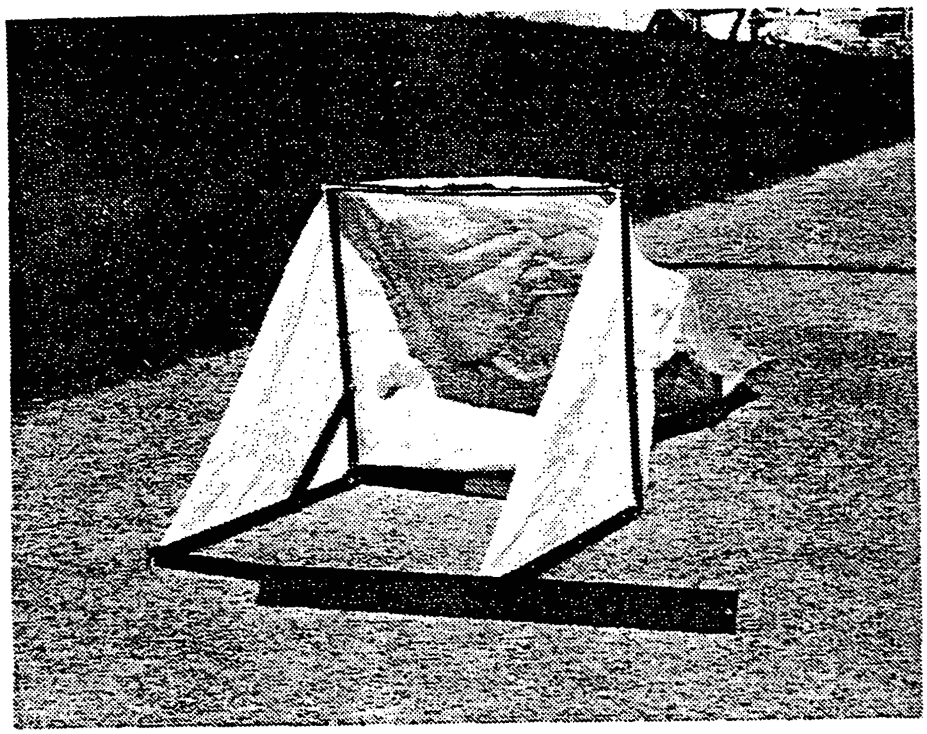

Fig. 1. Quantitative Surber sampler used to collect stream macroinvertebrates.

rearing to adult stage for positive species identification. Additionally, emergent adult insects were obtained with an aerial net by sweeping riparian vegetation or capturing flying insects. Others were collected by carefully examining exposed debris and rocks.

Samples were placed into a labeled plastic bags and preserved by adding formaldehyde to a concentration of approximately 5%. Macroinvertebrates were enumerated, and identified to the lowest practical taxonomic level. Final storage of samples was in 80% ethanol. Samples were preserved and identified in the lab.

An invertebrate sample was defined as the mean number of organisms of each taxon found in the three Surber replicate samples at each site and date. Data from the macroinvertebrate samplers were analyzed to obtain basic benthic aquatic community data including taxa richness and density of macroinvertebrates.

Biotic indices applied to invertebrate communities are an extension of the use of indicator organisms to a community (Washington 1984). These indices assign a value related to pollution or disturbance tolerance to each taxon, and through a mathematical formula calculate a score. The index may or may not account for absolute or relative abundances of organisms (Hellawell 1986). Like the indicator species concept, the effectiveness of a biotic index is considered limited to certain types of pollution or disturbance and to specific geographical areas (Washington 1984).

The measurement of diversity has two components: taxa richness and relative abundance. Richness is simply a count of the number of taxa (i.e. species) present. A modified species richness index is the EPT index, which was calculated by summing the number of taxa in orders Ephemeroptera, Plecoptera, and Trichoptera represented in a sample.

Many species in these three orders are considered pollution-sensitive (Hawkes 1979, Resch and Rosenburg 1993). Relative abundance, or evenness, is a description of how the number of organisms in a community are distributed among the taxa. In this study we are using two measures of diversity to describe the benthic communities of South Boulder Creek streams: taxa richness, Shannon (or Shannon-Wiener) and diversity index. One of the simplest and most basic measures used in aquatic ecology is taxa richness, which is simply the number of different taxa found in a given space and time. The Shannon diversity index (Shannon and Weaver 1949) utilize both of the components of diversity and is based on the proportional abundance of species. A recent review of the use and meaning of ecological diversity may be found in Magurran (1988). Washington (1984) reviewed the ecological application of diversity indices along with biotic and similarity indices.

The Shannon diversity index is based on information theory and relates to the uncertainty of the identity of an individual chosen at random (Washington 1984, Magurran 1988). Shannon's index was calculated as:

$$H' = -\sum p_i \ln p_i$$

where p_i is the proportion of individuals in taxon i, or more specifically, $p_i = n_i/N$ where n_i is the number of individuals in the ith taxon and N is the total number of individuals in the sample. The Shannon index is sometimes calculated with $\log_2$ or $\log_{10}$ rather than the natural log, and the values obtained would differ by a constant (Brower and Zar 1977, Magurran 1988). This index is one of the most widely reported in ecological literature (Washington 1984, Resch and Rosenburg 1993).

All indices must be interpreted with caution because they do not consider qualitative species composition, because moderate disturbance may increase diversity, and because many communities have naturally low diversity.

Preserved fish specimens were deposited at the Larval Fish Laboratory, Colorado State University, and a voucher collection of selected invertebrate species listed in Appendix A has been deposited in the C. P. Gillette Museum of Arthropod Diversity, Colorado State University, Fort Collins.

Habitat sampling and data analysis.--General notes on habitat conditions and streamflows were made during each fish collection. More comprehensive habitat data was collected at the four permanent sites (1, 2, 8, 10) as follows. Several measurements were made of stream width within the site in order to determine approximate mean stream width. A first transect was placed transverse to streamflow beginning at a random point near the downstream end of the site; nine subsequent transects were placed upstream of each other at intervals corresponding to two mean stream widths. At sites 1 and 8, where diversion dams existed within the reach, transects were made only up and downstream of the obvious influence of the diversion dam and upstream pool. At each transect, stream width, depth, velocity (estimated by eye), and substrate was measured at five equidistant points along the transect in the wetted channel. If the stream was not zero depth at either or both banks due to undercutting, point data were also collected there. Placement of transects at those intervals ensured that most of the typical collection site was covered and five points along the transect was considered adequate to estimate depth, velocity, and substrate characteristics. The qualitative velocity measurement used here was accurate to within 15 % (KRB, unpublished data), and was useful to obtain estimates of variation in water velocity across the stream channel and within the reach. Macrohabitat type (riffle, run, pool, or combinations of these) of the transect locality was recorded in order to estimate the relative amounts of each type in the reach. Maximum depth in the reach was also measured. Means and coefficients of variation (CV; = standard deviation/mean x 100) for measured habitat variables were calculated in order to compare habitat conditions at different sites and their potential effects on fish species abundance and fish size distributions. The mean described the *average* habitat conditions at a site while CV was a unitless measure of variation that allowed comparisons of habitat *variability* among sites.

STUDY AREA

South Boulder Creek emerged from a mountain canyon near Eldorado Springs, Colorado, and then flowed northeast, mostly on or adjacent to City of Boulder Open Space property. From the upstream South Mesa Trailhead (site 1) downstream for 13 km to its confluence with Boulder Creek (Fig. 2), this stream can be described as a Colorado transition zone stream. Transition zones of streams are geographically and physically intermediate between cold, high-gradient, rubble- and cobble-bottomed mountain streams and warmer, low gradient, sandy-bottomed plains streams. Thus, transition zone stream habitats typically occur in the foothills area and have water temperatures that are cool-warm, moderate gradients, and a mixture of substrate types including sand, gravel and cobble.

The riparian zone of South Boulder Creek was mixed, sometimes having a reasonably dense canopy of large woody vegetation including cottonwood *Populus spp.*, alder *Alnus sp.*, and willow *Salix spp.* Primary streamside vegetation in open places was grasses and sedges.

The South Boulder Creek hydrograph was highly modified and dominated by the effects of reservoirs and diversion dams, although the degree of modification was not evident from available gauge data. Gross Reservoir, which was about 12 km west of Eldorado Springs, stores water diverted from the Colorado River basin on the west slope of Colorado via the Moffat Tunnel and has partially regulated South Boulder Creek flows since 1956 (U. S. Geological Survey published annually). Mean monthly discharge measured at the U.S. Geological Survey gauge just upstream of Eldorado Springs prior to (1913-1955) and after

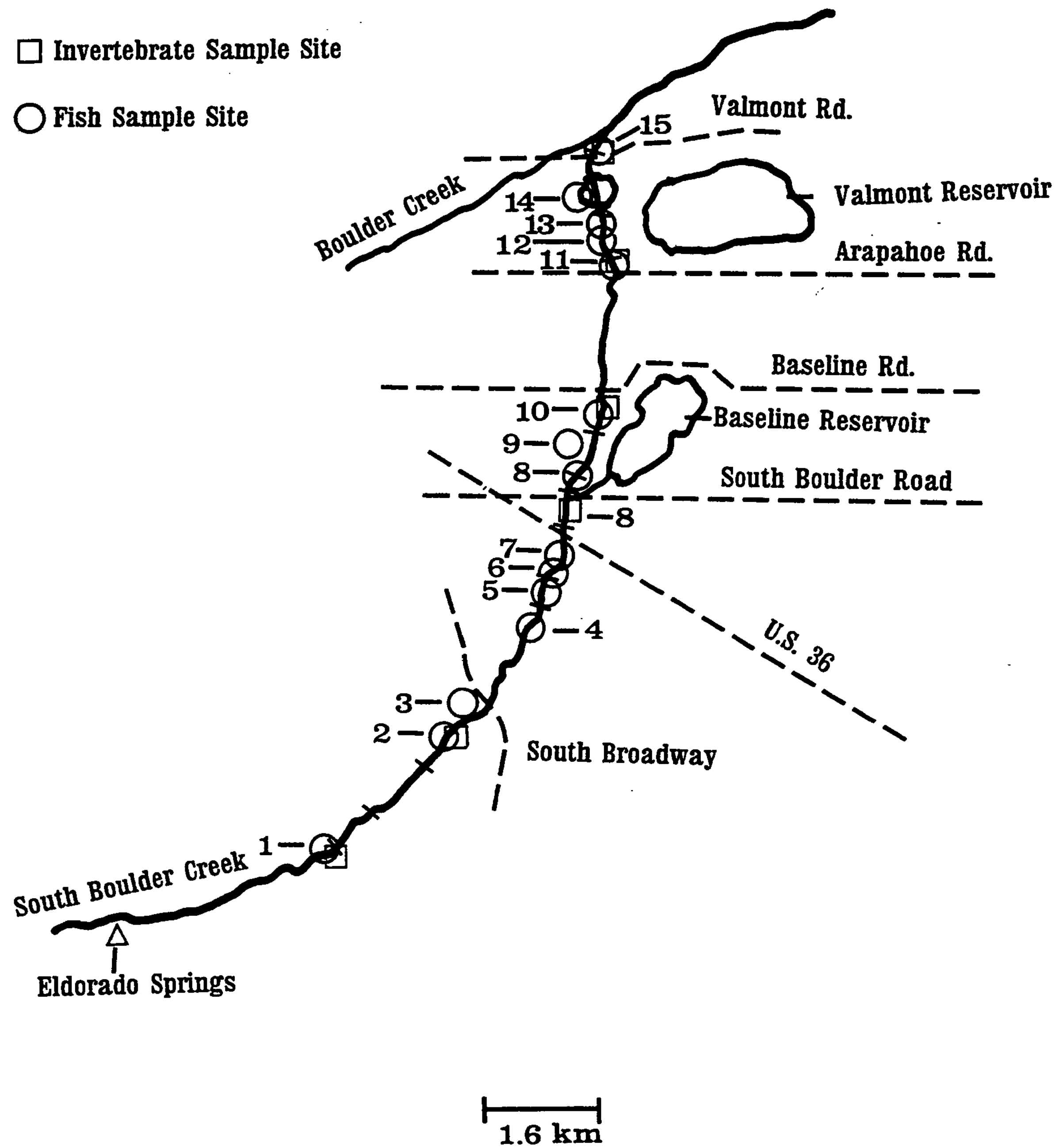

Figure 2.--The South Boulder Creek study area. Numbered open circles represent fish sampling localities, open squares represent localities where fish and macroinvertebrates were sampled. Solid bars across the stream represent diversion dams or other obstructions to fish dispersal.

(1956-1993) impoundment of Gross Reservoir were lower only for the period April-July (Fig 3), presumably because snowmelt flows were stored.

Diversions for the City of Denver and for irrigation occurred upstream of Eldorado Springs and the U.S. Geological Survey gauge (# 06729500). Downstream of Eldorado Springs, no less than 12 diversion dams or other structures divert water or obstruct the stream. These dams divert water for irrigation of pasture or hay fields or to fill storage reservoirs.

Although flows in South Boulder Creek show a traditional late April-early July peak due to snowmelt runoff and discharge at the gauge is reasonably similar to historic levels during that season, flows during the remainder of the year are highly variable and often quite low, especially from November to March when flows are diverted for plains reservoir storage. It is important to remember that the monthly flows depicted (Fig. 3) are upstream of many diversions and downstream flows are progressively lower and often near zero for many weeks in winter. Flows were especially low downstream of the diversion just north of South Boulder Road. Except in flood (e.g., spring-early summer 1995), the whole of South Boulder Creek just downstream of Arapahoe Road flowed into a complex of reservoirs used for cooling water which will be collectively referred to as Valmont Reservoir. Downstream of there, flows in the South Boulder Creek "floodway" to KOA Reservoir were only from diversion dam leakage or groundwater seeps and were typically very low. South Boulder Creek flows downstream of KOA Reservoir were likewise extremely low.

Water was typically quite clear especially at low flows and visibility often exceeded 1 m. Water clarity was reduced to < 0.2 m during high flows caused by runoff. Water conductivity ranged from 50-140 microsiemens/cm^2, but was doubtless higher during lower

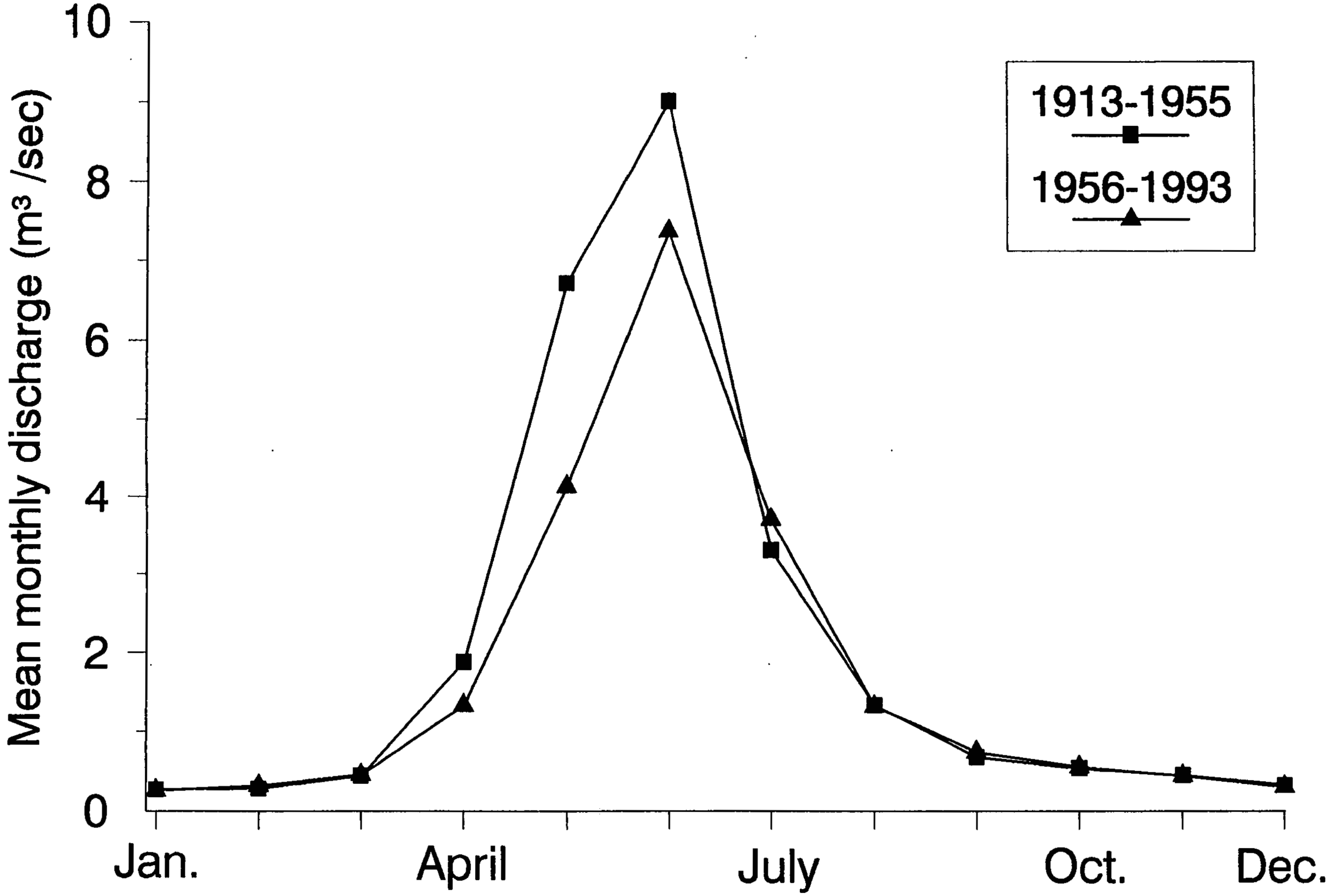

Figure 3.--Mean monthly stream discharge records for South Boulder Creek, near Eldorado Springs (gauge # 06729500) for pre-impoundment (1913-1955) and post-impoundment (1956-1993) periods. Numerous diversions dramatically affect stream flow downstream of this gauge, especially in winter months.

flows, and pH ranged from 7.8 to 8.9, values which are well within the tolerance limits for fishes in South Boulder Creek. Water temperatures are discussed in a separate section.

The channel of much of South Boulder Creek was straight, generally incised, and habitat at base flow consisted of relatively homogeneous and shallow riffle-run habitat. Substrate in reaches upstream of South Boulder Road was predominantly cobble, gravel, and rubble, downstream of South Boulder Road to the Valmont Reservoir diversion it was cobble, gravel, rubble, and sand, and downstream of there to Boulder Creek it was sand and silt. Much of the silt in South Boulder likely derived from the canal that entered the west side South Boulder Creek just downstream of South Boulder Road, and from surrounding pasture. Silt deposition was especially heavy when flows were low. High flows in spring and summer 1995 removed much of the silt from South Boulder Creek between South Boulder Road and Baseline Road.

Much of South Boulder Creek appeared to have been channelized in the past, perhaps as long as 40-50 years ago or more, based on the size of some riparian trees in affected reaches. Channelization associated with older riparian growth was commonplace throughout the stream but especially evident upstream of South Boulder Road. The channel of South Boulder Creek seemed slightly less modified downstream of South Boulder Road to Baseline Road, as it had a few meanders, the channel was still relatively narrow, and pools created by scour under riparian vegetation were more numerous. The channel downstream of the Valmont Reservoir diversion was initially difficult to detect because it was so highly modified, small, and bore little resemblance to a natural system.

RESULTS

The South Boulder Creek Fish Community

Species composition and abundance.--A total of 2,850 fish specimens and nine native and seven non-native species were collected in 25 samples at 15 sites during 1994-95 sampling of South Boulder Creek (tables 2 and 3). Results of sampling at each sample site are presented in Appendix I. Among the native fishes, longnose sucker and longnose dace were the most frequently collected, widespread, and abundant species in South Boulder Creek, whereas the fathead minnow, plains topminnow, creek chub, stoneroller, and white sucker were abundant, but restricted in distribution. Green sunfish and orangespotted sunfish were rare, with only a single specimen of the latter species collected at site 10.

Among the non-native species, rainbow trout was the most frequently collected taxa, and was relatively widespread and common upstream of site 8. All other non-native taxa were restricted in distribution and abundance and, with the exception of largemouth bass, were rare. Largemouth bass was common in standing water habitat or in South Boulder Creek adjacent to KOA or other reservoirs (sites 11-15), but was otherwise uncommon.

Longitudinal zonation.--Fish communities in transition zone streams typically exhibit a distinct longitudinal pattern, where a few cold and coolwater species predominate in upstream areas, and diversity and abundance of warmwater species increases *gradually* in a downstream direction. The result is highest species richness in the lowermost reaches of the stream, presumably because habitat there is the largest and most variable (Kuehne 1962, Propst 1982).

Table 2.--List of fish species collected during the 1994-95 survey of South Boulder Creek, Colorado, on City of Boulder Open Space property, their status (N = native, I = introduced), frequency of occurrence at sites (N = 15 possible), and in collections (N = 25 possible), and percent abundance in all samples (% of 2850 total specimens collected); + indicates more specimens observed but not captured at some sites.

			Occurrence		Percent
Common Name	Scientific Name	Status	Sites	Collections	Abundance
rainbow trout	*Oncorhynchus mykiss*	I	7	9	10.3
brown trout	*Salmo trutta*	I	4	5	0.8
central stoneroller	*Campostoma anomalum*	N	2	4	5.8
common carp	*Cyprinus carpio*	I	2	2	+
fathead minnow	*Pimephales promelas*	N	6	10	23.5
longnose dace	*Rhinichthys cataractae*	N	8	12	7.8
creek chub	*Semotilus atromaculatus*	N	5	9	9.4
longnose sucker	*Catostomus catostomus*	N	8	14	23.5
white sucker	*Catostomus commersoni*	N	5	8	2.7
plains topminnow	*Fundulus sciadicus*	N	6	9	8.4 +
western mosquitofish	*Gambusia affinis*	I	1	2	0.6 +
green sunfish	*Lepomis cyanellus*	N	5	8	1.2
pumpkinseed	*Lepomis gibbosus*	I	2	5	0.6
orangespotted sunfish	*Lepomis humilis*	N	1	1	< 0.1
bluegill	*Lepomis macrochirus*	I	3	4	0.1 +
largemouth bass	*Micropterus salmoides*	I	5	6	5.3 +
black crappie	*Pomoxis nigromaculatus*	I	1	1	< 0.1

In South Boulder Creek, cold and coolwater species such as trout, longnose dace, and longnose suckers comprised the relatively depauperate fauna in the upstream reach from site 1 downstream to the South Boulder ditch diversion; between there and the diversion downstream of South Boulder Road only fathead minnow was added. Plains topminnow was present at site 3, an upstream off-channel pond, but that population is not considered in the longitudinal zonation discussion because it was not influenced by the stream.

Table 3.--Sites where fish species were captured in South Boulder Creek, Colorado, on City of Boulder Open Space property, 1994-1995. Sites correspond to localities on Fig. 1.

Common Name	Scientific Name	Sites where collected
rainbow trout	*Oncorhynchus mykiss*	1, 2, 5, 6, 7, 8, 10
brown trout	*Salmo trutta*	1, 8, 10, 11
central stoneroller	*Campostoma anomalum*	10, 12
common carp	*Cyprinus carpio*	13, 14
fathead minnow	*Pimephales promelas*	6, 7, 8, 10, 13, 15
longnose dace	*Rhinichthys cataractae*	1, 2, 4, 5, 6, 7, 8, 10
creek chub	*Semotilus atromaculatus*	8, 10, 11, 12, 15
longnose sucker	*Catostomus catostomus*	1, 2, 4, 5, 6, 7, 8, 10
white sucker	*Catostomus commersoni*	8, 10, 11, 12, 15
plains topminnow	*Fundulus sciadicus*	3, 8, 9, 12, 13, 14
western mosquitofish	*Gambusia affinis*	15
green sunfish	*Lepomis cyanellus*	3, 8, 10, 11, 15
pumpkinseed	*Lepomis gibbosus*	8, 10
orangespotted sunfish	*Lepomis humilis*	10
bluegill	*Lepomis macrochirus*	8, 10, 14, 15
largemouth bass	*Micropterus salmoides*	8, 11, 12, 14, 15
black crappie	*Pomoxis nigromaculatus*	10

Immediately downstream of the South Boulder Road diversion at site 8 native species composition changes *abruptly*, because creek chub, white sucker, plains topminnow, and green sunfish were first sampled and were present in relatively large numbers. At site 10, which is < 1.5 km downstream of site 8, the most upstream occurrence of central stoneroller and the only occurrence of orangespotted sunfish was noted. In addition, non-native pumpkinseed, bluegill, and black crappie sampled in this middle reach represented the most upstream distributions of these taxa. Presence of the former species in multiple collections at site 8 suggested a resident stream population, but the latter two taxa were probably represented by individuals dispersing from Baseline Reservoir upstream through canals.

The lowermost portion of South Boulder Creek from the Valmont Reservoir diversion downstream to Boulder Creek was highly modified and the native fish community was neither diverse nor were fish abundant. Six native species occurred in that reach but all except plains topminnow were rare and comprised a small portion of individuals found there. Plains topminnow was found in large numbers in shallow, vegetated portions of KOA Reservoir, but was not found downstream of there. Non-natives largemouth bass and western mosquitofish (only downstream of KOA Reservoir) predominated in that reach.

Thus, the fish community of South Boulder Creek can be divided into three distinct longitudinal zones. The most upstream community from site 1 downstream to site 7 was depauperate and composed exclusively of cold or coolwater tolerant species, most of which were native taxa. The short 3.5 km-long middle portion of South Boulder Creek from the South Boulder Road diversion downstream to Arapahoe Road (site 8-11) supported all the native taxa presently known to exist in the stream and had the highest species richness of any of the three zones. The lowermost portion of South Boulder Creek supported only taxa that can persist in standing water, but habitat was so poor and predaceous largemouth bass so common there, that most of these may disappear without recruitment of individuals from the middle portion of South Boulder Creek.

Comparisons with historic collections.--It is possible that as many as 18 fish species were native to South Boulder Creek, but only nine were detected in 1994-95 (Table 4). Past collection records, though scant, indicated that native species common shiner *Luxilus cornutus* (Museum of Southwestern Biology (MSB) catalog # 1425, N = 16) and bigmouth shiner *Notropis dorsalis* (Hendricks 1950, MSB 1419, N = 49)) and johnny darter *Etheostoma nigrum*

Table 4.--Comparison of fishes collected South Boulder Creek by Hendricks (1950), Li (1968), Propst (1982), and this study. Fishes found just downstream in Boulder Creek are presented for comparison and data are from the above mentioned sources as well as from Juday (1904) and Ellis (1914). A single species list was derived from the different studies regardless of the number of collections made (one or many) but were usually only from one or two localities.

Taxa	Hendricks	Li	Propst	Present	Boulder Creek native taxa
cutthroat trout[a]					X
rainbow trout		X	X	X	
brown trout				X	
central stoneroller	X		X	X	X
lake chub[a]					X
common carp				X	
common shiner	X				X
hornyhead chub[a]					X
bigmouth shiner	X				X
blacknose shiner[a]					X
northern redbelly dace[a]					X
fathead minnow			X	X	X
longnose dace	X	X	X	X	X
creek chub	X	X	X	X	X
longnose sucker	X	X	X	X	X
white sucker	X		X	X	X
plains topminnow			X	X	X
western mosquitofish				X	
green sunfish			X	X	X
pumpkinseed				X	
orangespotted sunfish				X	X
bluegill			X	X	
largemouth bass			X	X	
black crappie				X	
Iowa darter[a]					X
johnny darter			X		X
Number of taxa	7	4	12	16	

[a] Species not collected in South Boulder Creek but hypothesized as a historic resident based on collections of these species in Boulder Creek just downstream, likely historic similarities in habitat between the two streams, and habitat preferences of the species involved.

(Propst 1982, N = 4) were present in South Boulder Creek, the latter as recently as 1979, but none of these were collected during 1994-95. Although exact collection localities for Hendricks (1950) were difficult to determine, it appears that most of these extirpated taxa were present in the middle portion of South Boulder Creek from Arapahoe Road upstream to South Boulder Road.

Other species likely once native to South Boulder Creek were greenback cutthroat trout *Salmo clarki stomias*, lake chub *Couesius plumbeus*, hornyhead chub *Nocomis bigutattus*, northern redbelly dace *Phoxinus eos*, Iowa darter *Etheostoma exile*, and possibly, blacknose shiner *Notropis heterolepis*. Native status of these species in South Boulder Creek is based on their presence in historic collections from Boulder Creek just downstream, on the likely historic similarities in habitat between the two systems, and the habitat preferences of the species involved. That early collections did not document resident status of those presumed native species in South Boulder Creek was likely due to relatively late first collections in South Boulder Creek (post-1949), which were well after extensive water diversion, changes in land-use patterns which degraded streams, channelization, and pollutants had impacted local streams (Ellis 1914).

While it is possible that some presumed extirpated taxa may still occur in South Boulder Creek, most are habitat specialists and likely do not. Nearly all of the species extirpated from South Boulder Creek require clear, cool water and clean gravel substrate upon which to spawn and are sensitive to increased turbidity and siltation, and all are presently rare in Colorado in their historic Front Range stream habitat. Cutthroat trout and lake chub are cold water species that may have been rare in the South Boulder Creek study area but were likely more common upstream (Bestgen et al. 1991, Behnke 1992). Native cutthroat trout were eliminated from most of their native Colorado range by hybridization with non-native rainbow trout, competition with other non-native salmonids, and habitat destruction (Behnke 1992). Lake chub may never have been common in Colorado.

Reductions in populations of gravel-spawning common shiner and hornyhead chub in Colorado were likely due to increased siltation (Propst and Carlson 1986). Northern redbelly dace, which live in Colorado only in transition zone streams in off-channel marshes or ponds (Bestgen 1989), and blacknose shiner and Iowa darter which prefer clear ponds or slow streams with vegetation (Becker 1983), were likely eliminated by widespread channelization in South Boulder Creek. Lack of extensive sandy substrate and limited distribution be may reasons for disappearance of bigmouth shiner and johnny darter from South Boulder Creek; each of these species remain relatively common elsewhere in the South Platte River drainage (Propst and Carlson 1986) and are tolerant of silty conditions in other Colorado streams (pers. obs.). The demise of these otherwise tolerant species perhaps speaks to the extent of habitat modifications in South Boulder Creek.

Absence of certain common fish species in historic collections compared to the current study (Table 4) likely represented lack of collecting effort then rather than historic absence of those taxa. Likewise, increased diversity of non-native taxa during 1994-95 compared to historic collections likely represented more intensive collecting in this study and may also reflect continued introduction of more game species into reservoirs that subsequently disperse into South Boulder Creek via canals.

The South Boulder Creek Macroinvertebrate Community

Over the three sampling dates, 96 macroinvertebrate taxa were identified from the qualitative samples and quantitative benthic samples (Appendix III). The Baseline Road site consistently had the lowest number of total taxa, averaging 23 over the three dates (Table 5). Species richness at the other three sites was considered typical for a Front Range Rocky Mountain stream (Ward and Kondratieff 1992). Baseline Road site had the lowest number of EPT taxa (10) while South Mesa Trailhead, Lafayette Water Treatment Plant, and South Boulder Road site EPT values were moderate, with averages ranging from 17 to 21 taxa (Table 6). An average of 22-25 EPT taxa is typical for Front Range streams (B. C. Kondratieff, personal observation).

Mean density estimates over the sampling period were 1950 individuals/m^2 at South Mesa Trailhead, 1876 individuals/m^2 at Lafayette Water Treatment Plant, 4072 individuals/m^2 at South Boulder Road, and 1809 individuals/m^2 at Baseline Road (Table 7). The highest densities were recorded in December 1994.

Over the sampling period species of Ephemeroptera and Trichoptera were usually the most abundant groups (Tables 8-11). At the South Mesa Trailhead site the EPT orders comprised two-thirds of the benthic community (Table 8). At Lafayette Water Treatment Plant and South Boulder Roads sites, there was a typical representation of the major aquatic insect orders (tables 9 and 10; Ward and Kondratieff 1992). At the Baseline Road site, Oligochaeta (segmented worms) were abundant, and the Plecoptera (stoneflies) were rare or absent (Table 11). The absence of Plecoptera indicated this site was impacted by dewatering and

Table 5.--Total number of macroinvertebrate taxa found on each sampling date, South Boulder Creek, Boulder County, Colorado. Collection sites are ME = South Mesa Trailhead; LF = Lafayette Water Treatment Plant; SB = South Boulder Road; BL = Baseline Road.

Date	ME	LF	SB	BL
9 Dec 1994	39	30	40	21
12 April 1995	31	31	35	21
4 Oct 1995	30	30	38	27
Mean	33	30	38	23

Table 6.-- Total number and macroinvertebrate taxa in each of three orders Ephemeroptera, Plecoptera, and Trichoptera (EPT) found on each sampling date, South Boulder Creek, Boulder County, Colorado. Collection sites are ME = South Mesa Trailhead; LF = Lafayette Water Treatment Plant; SB = South Boulder Road; BL = Baseline Road.

Date	ME	LF	SB	BL
9 Dec 1994	25	17	22	10
12 April 1995	19	18	19	8
4 Oct 1995	20	17	20	13
Mean	21	17	20	10

Table 7.--Macroinvertebrate density expressed as individuals/m^2, South Boulder Creek, Boulder County, Colorado. Collection sites are ME = South Mesa Trailhead; LF = Lafayette Water Treatment Plant; SB = South Boulder Road; BL = Baseline Road.

Date	ME	LF	SB	BL
9 Dec 1994	3530	1916	6437	1266
12 April 1995	1260	2683	3100	3260
13 Oct 1995	1060	1030	2680	900
Mean	1950	1876	4072	1809

Table 8.--Macroinvertebrate relative abundance, expressed as percent of individuals, by taxonomic group for South Mesa Trailhead site, by date, and mean for sampling period, South Boulder Creek, Boulder County, Colorado. Rounded percentages < 1 are not presented.

	Mean	December	April	October
Ephemeroptera	36	15	34	61
Plecoptera	12	9	13	15
Trichoptera	31	57	28	9
Coleoptera	7	11	5	4
Diptera	12	8	19	8
Turbellaria	0	0	0	0
Oligochaeta	1	0	0	2
Amphipoda	0	0	0	0
Isopoda	0	0	0	0

Table 9.--Macroinvertebrate relative abundance, expressed as percent of individuals, by taxonomic group for Lafayette Water Treatment Plant site, by date, and mean for sampling period, South Boulder Creek, Boulder County, Colorado. Rounded percentages < 1 are not presented.

	Mean	December	April	October
Ephemeroptera	15	5	6	34
Plecoptera	14	11	20	11
Trichoptera	23	33	27	9
Coleoptera	35	47	26	32
Diptera	5	2	4	10
Turbellaria	6	2	15	1
Oligochaeta	1	0	0	2
Amphipoda	0	0	0	0
Isopoda	1	0	0	2
Gastropoda	1	0	2	0

Table 10.--Macroinvertebrate relative abundance, expressed as percent of individuals, by taxonomic group for South Boulder Road site, by date, and mean for sampling period, South Boulder Creek, Boulder County, Colorado. Rounded percentages < 1 are not presented.

	Mean	December	April	October
Ephemeroptera	13	5	3	30
Plecoptera	11	18	11	5
Trichoptera	32	33	44	18
Coleoptera	24	31	27	13
Diptera	13	31	27	13
Turbellaria	5	3	9	2
Oligochaeta	3	6	2	0
Amphipoda	0	0	0	0
Isopoda	0	0	0	0
Gastropoda	0	0	0	0

Table 11.--Macroinvertebrate relative abundance, expressed as percent of individuals, by taxonomic group for Baseline Road site, by date, and mean for sampling period, South Boulder Creek, Boulder County, Colorado. Rounded percentages < 1 are not presented.

	Mean	December	April	October
Ephemeroptera	25	19	38	17
Plecoptera	1	1	0	1
Trichoptera	24	21	35	17
Coleoptera	4	2	5	6
Diptera	17	8	10	32
Turbellaria	2	2	2	2
Oligochaeta	19	34	6	18
Amphipoda	1	0	0	2
Isopoda	4	10	0	3
Gastropoda	1	2	2	0

increased siltation. Plecoptera are very sensitive to almost all types of pollutants and decreases in flows (Baumann 1979).

The Oligochaeta are well-known components in streams that experience siltation and reduced flows (Thorp and Covich 1991). Additionally, the higher percentages of Amphipoda (scuds), Isopoda (aquatic sowbugs) and Gastropoda (snails) at the Baseline Road site indicated siltation and organic enrichment. These tolerant taxa were the predominant ones found in qualititative samples collected at sites 11 and 15 and are generally common only in degraded Rocky Mountain streams.

The Shannon diversity index scores were similar at the four sites (Table 12). The highest diversity values were recorded from South Mesa Trailhead site, the most pristine site sampled. Macroinvertebrate communities of unpolluted waters exhibit Shannon diversity index values between 3.0 and 4.0, whereas values from polluted streams are generally less than 1.0 (Wilhm 1970). Platts et al. (1983) indicated that Rocky Mountain streams generally approach or exceed 3.0. No comparable data are available from other Colorado Foothill or Front Range streams.

Table 12.--Macroinvertebrate Shannon Diversity (H') by site and date. South Boulder Creek, Boulder County, Colorado. Collection sites are ME = South Mesa Trailhead; LF = Lafayette Water Treatment Plant; SB = South Boulder Road; BL = Baseline Road.

Date	ME	LF	SB	BL
9 Dec. 1994	2.6	2.3	2.5	2.1
12 April 1995	2.9	2.4	2.4	2.0
13 Oct. 1995	2.2	2.6	2.7	2.6

Habitat

Habitat at sample sites.--Site 1 was the most upstream site and was sampled several times during the course of the study for fish and macroinvertebrates and once for habitat in fall 1995. Fish and habitat data were collected beginning about 15 m upstream of the foot bridge upstream over a diversion dam to a large pool formed by an instream boulder, a reach of about 160 m. Macroinvertebrates were collected in a riffle and run just downstream of the large upstream pool. As with all sites, flow varied markedly by season and was very high in spring 1995 such that the parking area adjacent the site was closed and the stream could not be sampled. The downstream half of the site was mostly riffle and run habitat with cobble and rubble substrate and had about 50% canopy cover while the upper half was mostly open. On 18 October 1995 when flows were estimated to be about 0.43 m^3/sec, the channel was relatively wide, had variable depths and water velocities and substrate was mostly cobble and gravel (Table 13). Maximum depth at this site was 0.90 m. This site had the largest population of adult salmonids found in the South Boulder Creek study area. Adult rainbow and brown trout resided in the large upstream pool, while juvenile rainbow trout and longnose suckers were common throughout the reach. Only a single longnose dace was captured.

Site 2 was adjacent the LaFayette Water Treatment Plant and was sampled several times during the course of the study for fish and macroinvertebrates and once for habitat in fall 1995. This site typified habitat in this reach, as the channel was wide and straight, water depth slightly shallower and depths and water velocities were less variable than at site 1, and substrate was cobble and rubble. Habitat was mostly shallow riffles and runs < 0.2 m deep and little complex habitat or pools were present at low flow. Maximum depth at this site was

Table 13.--Summary of habitat measurements made at South Mesa Trailhead (Mesa), LaFayette Water Treatment Plant (LaFayette), South Boulder Road (South Boulder), and Baseline Road (Baseline) sites in South Boulder Creek; Fig. 2 presents site localities. Habitat variables stream width (m), depth (m), velocity (m/s) (those as mean, range, coefficient of variation [CV]), substrate (% composition within site), maximum depth (m), and dominant macrohabitat type (riffle-run (RiRu), run (Ru)) were summarized from data collected at ten transects within the site. Transects were spaced at upstream intervals corresponding to two stream widths; habitat data were collected at five to seven points along each transect. Percent substrate composition at sites was determined by classifying dominant or co-dominant substrate particle size in a circle within a 10 cm radius around the habitat point as follows; silt = 0.004 to 0.064 mm, sand = > 0.064 to 2 mm, gravel = > 2 to 64 mm, cobble = > 64 to 127 mm, rubble = > 127 to 256 mm, boulder = > 256 mm.

Site[a]	Stream width	Depth	Velocity	Maximum depth	Habitat type	Substrate composition					
						Silt	Sand	Gravel	Cobble	Rubble	Boulder
Mesa	8.72	0.26	0.19	0.90	RiRu	0.0	2.9	30.8	37.5	22.1	6.7
	4.27-11.9	0.01-0.58	0.00-0.60								
	24.0	55.3	84.2								
LaFayette	7.56	0.25	0.19	0.52	RiRu	0.0	9.4	17.0	35.8	32.1	5.7
	4.27-12.5	0.02-0.50	0.00-0.60								
	38.2	48.0	72.9								
South Boulder	4.75	0.25	0.15	0.75	Ru	2.5	11.0	15.3	48.3	20.3	2.5
	3.66-6.55	0.08-0.72	0.00-0.40								
	20.3	48.1	71.6								
Baseline	5.03	0.22	0.13	0.80	Ru	5.8	12.5	29.8	36.5	11.5	3.8
	3.35-8.53	0.04-0.52	0.00-0.40								
	27.9	49.0	83.0								

[a] Stream discharge was estimated to be 0.43 m^3/s at Mesa and LaFayette, but lower (0.20 m^3/sec) at South Boulder and Baseline sites during habitat measurements due to water diversion.

0.50 m. The canopy was mostly open and streamside vegetation was dominated by short willows and grasses. Juvenile rainbow trout and longnose suckers dominated at this site and a small number of longnose dace were present. Shallow water during winter resulted in poor fish habitat and we observed many benthic macroinvertebrates frozen in the ice.

Site 3 was a small gravel pit pond just west of Boulder Open Space Maintenance buildings, just south of Broadway Avenue and at the West Trailhead. The pond was about 25 x 40 m and mostly surrounded by cattails *Typha* sp. and sedges *Scirpus* sp. Substrate was cobble overlain with silt in the shallow nearshore area. Seining yielded plains topminnow and green sunfish on two separate occasions. Male plains topminnows were in breeding color on 19 May 1995 when water temperatures exceeded 20°C.

Site 4 was upstream of the Shearer headgate for about 200 m and was sampled only once. The stream canopy was mostly open except for the upstream part of the reach and habitat was relatively homogeneous consisting of shallow riffles and runs with cobble or rubble substrate. Only adult longnose dace and juvenile longnose suckers were captured, and in low numbers. High flows limited sampling efficiency in August 1995.

Site 5 was from just downstream of the Shearer headgate downstream for about 300 m. The stream channel was exceptionally shallow at low flow, with most water flowing between the cobble and rubble substrate particles. The channel was open and some bank degradation was evident. A single deep pool that was nearly 1 m deep was created by an undercut tree root system at a channel meander and held nearly all of the juvenile rainbow trout and adult and juvenile longnose suckers captured. Shallow riffles supported only juvenile longnose dace.

Site 6 was from 100 m upstream of the U.S. Highway 36 crossing upstream for about 1 km to a diversion dam. This site had a partial and sometimes dense canopy, but habitat at low flow was particularly poor and consisted only of shallow riffles and runs and very few natural pools. The deep pool just downstream of the upstream diversion dam supported most of the longnose sucker juveniles captured in the reach.

Site 7 was from just upstream of the U.S. 36 crossing upstream for about 100 m. Habitat was mixed and consisted of shallow runs and pools. The canopy was mostly open and the stream channel was straight and had cobble and rubble substrate. This site had some boulder flow deflectors designed and installed to create plunge-pool habitat for trout. Although pool habitat was slightly enhanced, most structures were no longer functional before high spring flows in 1995, because previous high flows had rearranged them. One structure appeared to increase lateral erosion by directing higher flows into the bank. The pools created by these structures created little of the trout habitat for which they were intended and likely never held many large trout because of lack of cover. Further, summer water temperatures may be marginal for rainbow trout. The two largest rainbow trout sampled in this study were collected at this site (509 and 486 mm total length) and were from a natural pool with an undercut tree root system. This site also supported longnose dace and longnose suckers and represented the most upstream collection site for fathead minnows in the study. A thermograph was placed just downstream of this site in fall 1994 and in summer-fall 1995.

Site 8 began about 200 m downstream of South Boulder Road and proceeded upstream for about 150 m to just above the confluence of a drain canal entering South Boulder Creek from the west side. Multiple fish collections and habitat measurements were made at this site and invertebrate collections were made just upstream of South Boulder Road three times. The canopy was relatively enclosed at this site, especially in the upstream portion, by willow and introduced Russian olive *Eleagnus angustifolia*. The channel meandered slightly and was narrower up- and downstream of the mid-reach diversion dam than at more upstream sites (Table 3). Substrate was mixed and mostly cobble, rubble and gravel, but sand and silt were present in appreciable amounts. During fall 1994 and spring 1995 sampling some silt was noted but substrate was relatively silt-free after high summer flows in fall 1995. On 18 October 1995 flows were lower here than at sites 1, 2, and 6 and estimated to be about 0.20 m^3/sec, which may confound habitat comparisons with those upstream sites. Maximum depth at this site was 0.7 m.

Habitat heterogeneity was slightly higher at this site than at others because overhanging vegetation, undercutting, and a large tree at the bottom of the site created deep pools. The side channel entering South Boulder Creek from the west typically had low but very warm flow, and created a large ponded backwater. This was the primary habitat for most fathead minnows and all plains topminnow at this site. Water flowing down the canal was sometimes turbid and silty. Input from this canal may warm South Boulder Creek substantially, especially when the latter is low, and may also be a likely source for the silt noted here and at most downstream sites. A thermograph was placed at the lower end of this site in late-summer 1995 to provide comparative data to the upstream one and so that the effects of the upstream diversions and the canal inflow at the upstream part of site 8 could be assessed. This site represented the most upstream distribution for many fish species in South Boulder Creek which may be an indication of increased habitat diversity, increased water temperature, and other habitat changes.

Site 9 was a small off channel pond connected by overflow to a drainage canal and South Boulder Creek just east of the East Boulder Recreation Area. The pond was fed by overflow from a wetland to the south and had a maximum depth of 1.1 m and a silt bottom. *Spyrogyra* was common throughout the pond. About 100 plains topminnows were captured and more were observed.

Site 10 was South Boulder Creek from about 40 m upstream of Baseline Road at the Bobolink Trailhead upstream for about 200 m. This site was sampled multiple times for fish and macroinvertebrates and for habitat in fall 1995. The riparian canopy was reasonably dense at this site, covering about 50% of the stream. The channel was relatively straight in the upper parts of the reach but meandered slightly more downstream. On 18 October 1995 flows were similar to that at Site 8 (0.2 m^3/sec) and habitat characteristics were also similar. Measurements at site 10 indicated that slightly more silt, sand, and gravel substrate were present than at upstream sites (Table 3). Maximum depth at this site was 0.8 m. Similar to site 8, habitat at this site was relatively heterogeneous for South Boulder Creek, because pools, riffles and runs were all common, and pools > 0.8 m deep especially so after scouring floods in spring 1995. Substrate was relatively cleaner after 1995 floods compared to fall 1994 and spring 1995 when much silt and embedded substrate was present. This site was the most upstream extent of central stoneroller in South Boulder Creek and also represented the only site where native orangespotted sunfish and non-native black crappie were found.

Site 11 was South Boulder Creek under and downstream of Arapahoe Road. The channel was mostly open and very wide and shallow, substrate was composed primarily of silt and sand substrate, and habitat was badly degraded. Nevertheless, the particularly low species richness and low fish abundance was surprising when this site was first sampled in fall 1994. Observations during high water in spring 1995 indicated that most of the "stream" channel was submerged by the pool impounded by the diversion dams for Valmont Reservoir upstream of Arapahoe Road. Heavy silt deposition and habitat alteration during flooding are the probable reasons for the low species richness and absence of most stream fish species in the reach. Qualitative invertebrate samples were collected at this site.

Site 12 was a 150 m reach in the floodway downstream of the Valmont Reservoir diversion but about 300 m upstream of KOA Reservoir. Habitat was homogeneous and poor, and consisted mostly of pools, with little intervening riffles because almost no flow existed. Substrate in pools was silt or sand and streamside vegetation was grasses. Surprisingly, central stoneroller was the most common species collected during a fall 1994 sample. However, species richness and fish abundance was very low.

Site 13 was a 50 m reach in the floodway downstream of the Valmont Reservoir diversion but about 150 m upstream of KOA Reservoir that was sampled during high water in spring 1995. At that time South Boulder Creek was actively flowing in the floodway and was about 30 m wide. Common carp had moved upstream, apparently from KOA Reservoir into the floodway.

Site 14 was the west arm of KOA Reservoir west of the trail crossing. This area was flooded grass and willows and provided habitat for an abundant population of plains topminnows. Juvenile largemouth bass, bluegill, and adult common carp were abundant in the reservoir.

Site 15 was South Boulder Creek downstream of KOA Reservoir downstream for up to 1 km to just upstream of Boulder Creek. Habitat was very homogeneous consisting of shallow pools and runs (most < 0.05 m deep), had an open canopy, and a sand bottomed stream channel. Algae grew in extensive mats over the substrate. Fish species richness and abundance was low at this site and was composed mostly of juvenile bass escaped from KOA Reservoir. This was also the only site in South Boulder Creek where western mosquitofish were found.

Effects of habitat on fish community structure.--Differences in habitat among sites can affect abundance and size structure of the fish community present. Size frequencies of rainbow trout and longnose sucker were compared among sites 1 and 2 to illustrate these effects (Figs. 4 and 5). These sites were chosen because they were geographically close, had nearly identical species composition, flow, and water temperature regimes, but dissimilar habitat (Table 3). Site 1 was deeper (as measured by > mean and maximum depth), had more complex and variable habitat (> CV for depth and velocity) while site 2 had shallower and simpler habitat. Rainbow trout and longnose sucker were chosen for comparison because they were the predominant species at each site and because each has life stages with a variety of habitat requirements including pool-dwelling adults with relatively large body size (> 200 mm TL). A longnose sucker length-frequency distribution was calculated for site 8, which also had relatively complex habitat and a more diverse community with up to 12 species present; too few rainbow trout captured there to calculate a length frequency distribution.

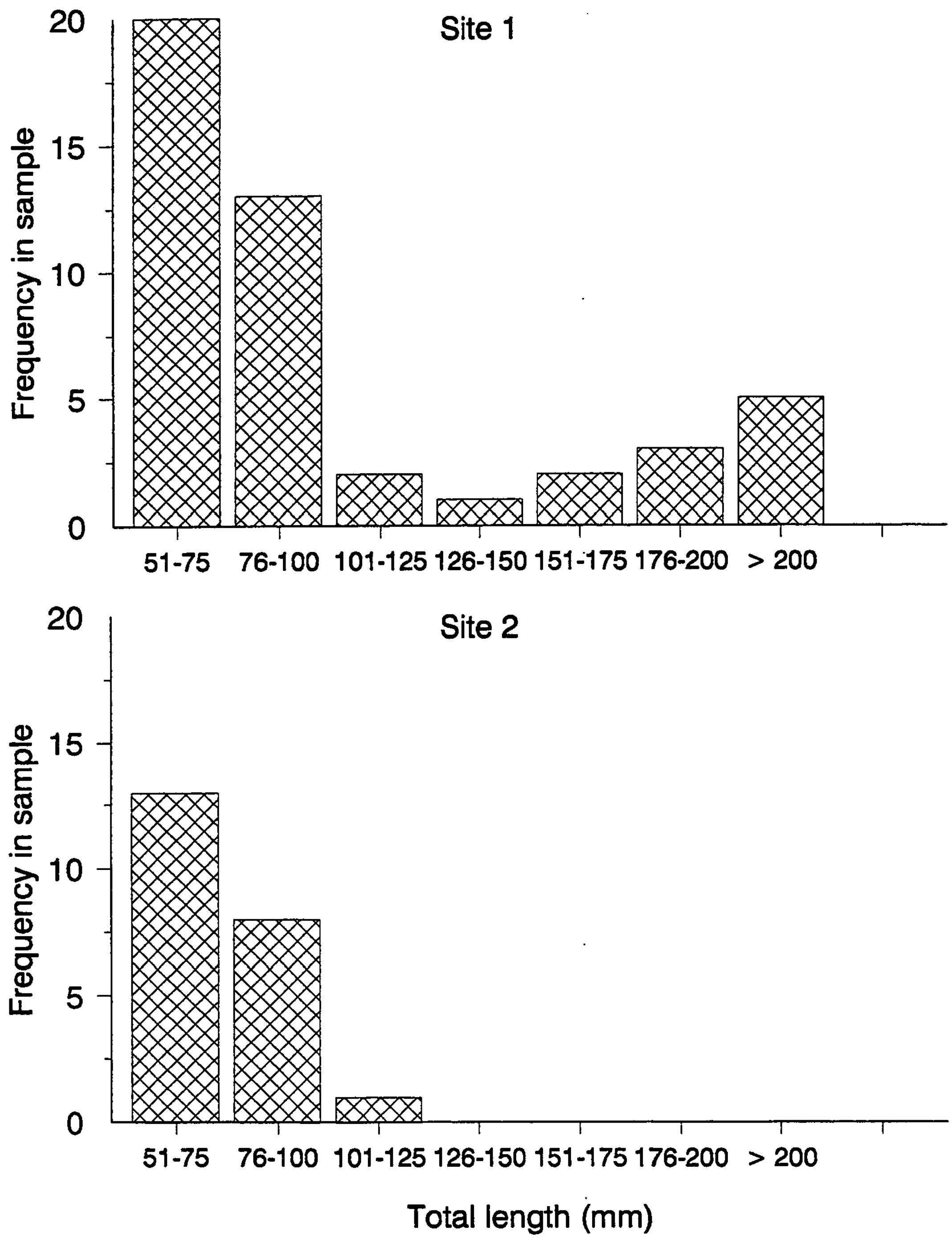

Figure 4.--Length frequency distributions (total length) for rainbow trout sampled from sites with complex (Site 1) and simple (Site 2) habitat in South Boulder Creek, December 1994.

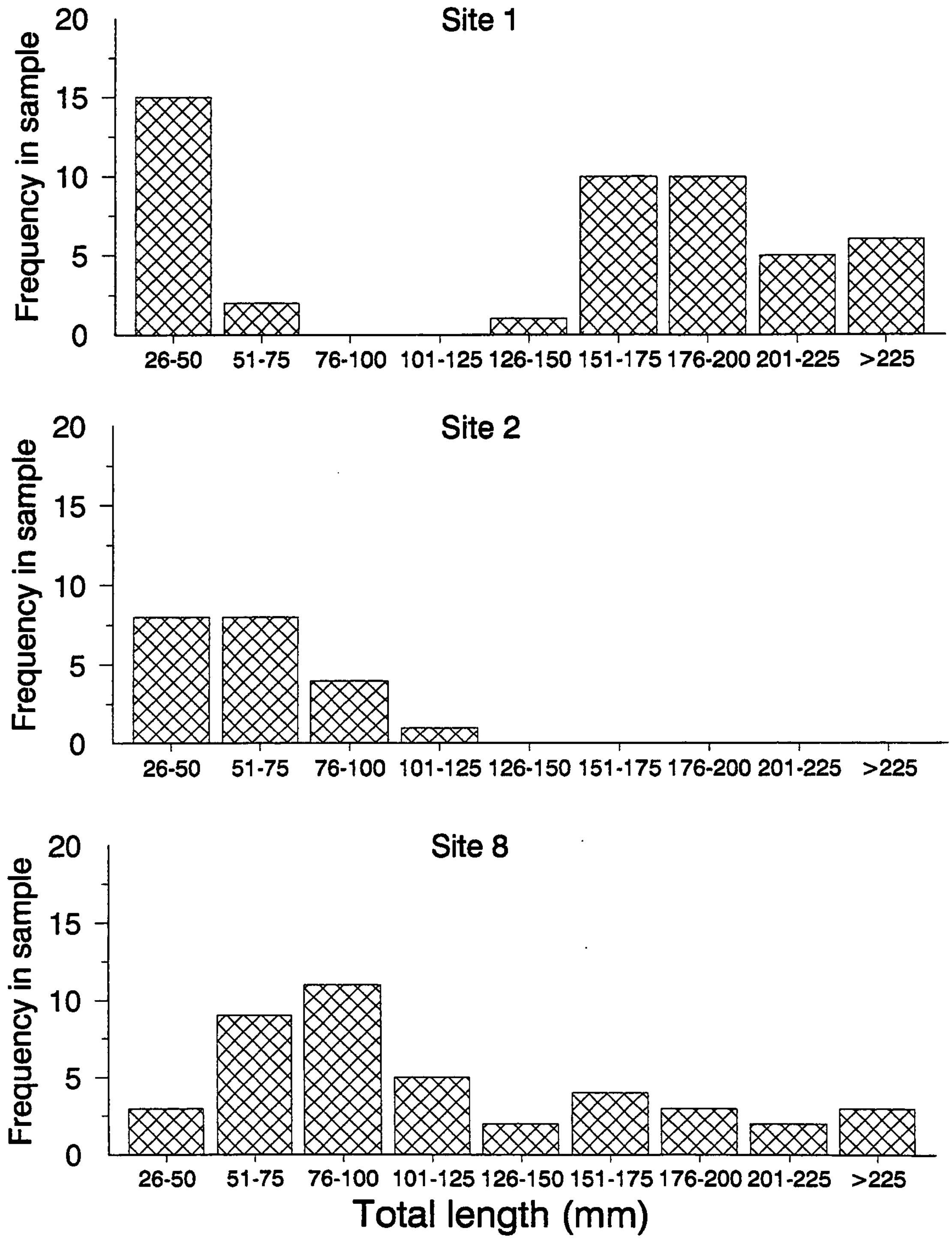

Figure 5.--Length frequency distributions (total length) for longnose suckers sampled from sites with complex (site 1, 8) and simple (Site 2) habitat in South Boulder Creek, December 1994.

Rainbow trout at site 1 had a wide size range including many individuals > 150 mm TL, most of which were captured in relatively deep pools. Rainbow trout at site 2 had a limited size distribution composed exclusively of fish < 125 mm TL, reflecting the shallow and homogeneous habitat at that site. Although these length-frequency distributions were sub-samples of the 150 (site 1) and 50 (site 2) individuals sampled, fish not measured were all < 100 mm TL so size ranges presented are representative.

Longnose suckers showed length-frequency distribution differences between sites 1 and 2 similar to that for rainbow trout (Fig. 5); small to large individuals were present at site 1 but only relatively small fish were present at site 2. Large, intermediate, and small longnosesuckers were also present at site 8, which had deeper pools and habitat variability similar to site 1.

Higher abundance of rainbow trout at site 1 (N = 150) and longnose suckers at sites 1 (N = 49) and 8 (N = 42) compared to abundances of those species at site 2 (N= 50 and 22, respectively) was also likely due to deeper and more complex habitat, because sample site length and sampling time were similar among sites or greater at site 2.

The relatively small rainbow trout and longnose suckers at site 2 represented juveniles. Lack of reproducing adult fish at such sites with shallow and homogeneous habitat suggested that the limited populations of juveniles present are recruited from fish dispersing from up- or downstream. Fish populations in stream reaches with low quality habitat may be especially limited if dispersal into the reach is reduced.

Water temperature records.--Water temperature records were collected for South Boulder Creek downstream of U.S. 36 from 1 September 1994 to 18 October 1994 (Fig. 6).

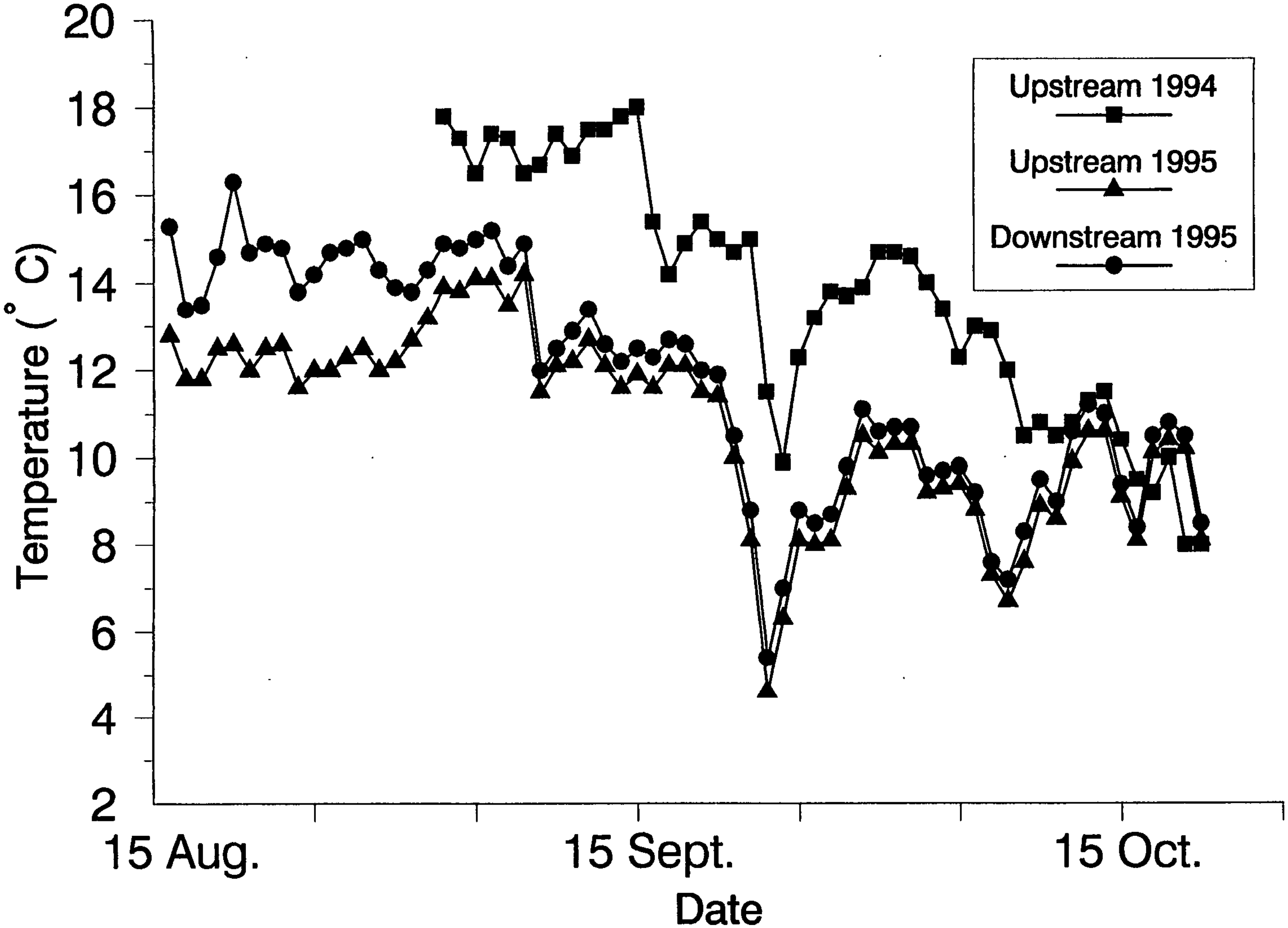

Figure 6.--Thermograph records (°C) for South Boulder Creek sites upstream and downstream of the South Boulder Road diversion, late summer-fall, 1994 and 1995.

After fall 1994 fish sampling was completed and differences in fish communities were noted for South Boulder Creek up- and downstream of the diversion just downstream of South Boulder Road, temperature was monitored at the 1994 station as well as downstream of the South Boulder Road diversion in 1995 from 15 August to 18 October. High flows in 1995 did not permit setting thermographs in South Boulder Creek prior to then.

Temperatures were much higher in 1994 than in 1995 probably due to much lower flows in South Boulder Creek. Water temperatures were substantially higher downstream of the South Boulder Road diversion than above for the last two weeks in August in 1995. After that temperatures were similar. Those two stations were < 1 km apart and differences in water temperature would not normally be expected.

These data suggested that during normal low-flow years, water in South Boulder Creek upstream of South Boulder Road diversion was warm, and probably achieved daytime highs near or above 20°C. Higher late August temperatures in South Boulder Creek downstream of the South Boulder Road diversion in 1995 were likely due to faster warming of water due to lower flows and warm input from the canal on the west side of South Boulder Creek at site 8. Water temperature measured in the canal on 19 May 1995 was 17°C, but only 11°C in South Boulder Creek suggesting that canal inflows could substantially warm South Boulder Creek especially during low flows. Water temperatures were more similar from early September through October 1995 probably because no water was diverted and flows were equal up- and downstream of the South Boulder Road Diversion.

DISCUSSION

Fishes of South Boulder Creek.--Despite the presence of many non-native taxa, the present fish fauna of South Boulder Creek is numerically dominated by native species. These species are mostly habitat generalists and tolerant and thus can survive in a variety of habitat types including degraded ones. Among species that presently exist in South Boulder Creek, taxa with limited distribution such as central stoneroller and creek chub are probably the next most likely species to be locally extirpated in South Boulder Creek. These taxa are perhaps most susceptible to stochastic extirpation events because of small population size and because the substrate for these gravel-spawning species in the reach between site 8 and 10 becomes silted at low flows.

Species richness of the native community was reduced from historic conditions, as three taxa are known to have been extirpated, one as recently as after 1979. As many as six other taxa were likely resident but extirpated before collections were made that could detect them. Most extirpated species were ones that may have required off-channel habitat or silt-free gravel substrate in which to spawn.

Introduced species.--The effects of nonnative fishes on native forms are unknown in South Boulder Creek. Most taxa, with the exception of rainbow trout, were restricted in distribution and rare. Rainbow trout are likely innocuous, although larger individuals may be piscivorous and potentially detrimental to native fish community when flows are low and fish are restricted to pools. It is also highly likely that rainbow trout hybridized with native cutthroat trout when first introduced into South Boulder Creek (Behnke 1992). It is unlikely that widespread and naturally reproducing rainbow trout could be removed and prevented from re-entering South Boulder Creek, both of which are pre-requisites for re-establishment of native greenback cutthroat trout.

Species richness of the non-native fish community in South Boulder Creek will probably continue to increase in the future because non-native game and forage fish species continue to be introduced into Colorado waters. Several such non-native species that were typically confined to reservoirs were occasionally captured in large numbers in South Boulder Creek. Fortunately, these mostly centrarchid species were not well adapted to relatively shallow and fluctuating stream habitat. Populations of non-native piscivorous species in off-channel ponds often results in reductions of native taxa (Bestgen 1989) so their establishment should be discouraged.

Western mosquitofish is a potentially ecologically damaging species that was introduced into lower South Boulder Creek below KOA Reservoir. Western mosquitofish were found in fall 1994 and fall 1995 samples at site 15. However, whether those represent permanent overwintering populations or were the result of introductions in each year is unknown. Mosquitofish have been indiscriminantly introduced throughout the western United States to control various dipteran larvae, mostly mosquitos. Introduction and expansion of populations of mosquitofish has often resulted in serious declines of native fishes, because the mosquitofish is a known predator on other fish larvae (Meffe 1985). Many introductions were conducted despite the presence of native fishes that also eat mosquito larvae. No interactions between native and introduced forms have been noted yet. However, stocking of nonnative species when morphologically and functionally similar native ones are present should be avoided.

Experiments that describe potential for negative interactions among introduced western mosquitofish and native plains topminnow should be conducted to determine if the latter is at risk. Experiments designed to compare relative effectiveness of native taxa such as plains topminnow for mosquito control may eliminate the need for stocking potentially detrimental western mosquitofish.

Macroinvertebrates of South Boulder Creek.--Aquatic macroinvertebrate communities were relatively pristine upstream of South Boulder Road, as indicated by relatively high overall species richness and high EPT index values. Similar to the fish community, the benthic macroinvertebrate community showed an abrupt change downstream of South Boulder Road but was reduced in species richness rather than increased. Quantitative samples at Baseline Road and qualitative samples at Arapahoe (site 11) and Valmont (site 15) roads indicated a proponderance of tolerant taxa and severe reductions in the number of sensitive EPT taxa.

Siltation and streamflow reductions are the likely cause for the abrupt reduction in species richness downstream at the Baseline Road site. Excess silt reduces the amount and quality of substrate interstitial spaces that consitute invertebrate living space. Silt may also directly suffocate early instars or eggs laid on substrate particles. Interestingly, overall species richness, number of EPT taxa, and Shannon diversity index values were highest at Baseline Road in October 1995 compared to other sampling dates. Those same metrics showed no change in October 1995 samples at upstream sites South Mesa Trailhead, Lafayette Water Treatment Plant, and South Boulder Road sites compared to previous samples. This may indicate recovery at the Baseline Road site following the high spring and summer flows which removed much of the silt from substrate interstices. Although no qualitative samples were collected at sites 11 (Arapahoe Road) and 15 (Valmont Road) in October, no improvement in invertebrate communities should be expected at those sites compared to previous sampling occasions because high spring and summer flows did not improve habitat at those sites.

Apparent increases in species richness at the Baseline Road site also demonstrated the recovery potential and resiliency of aquatic macroinvertebrate communities when upstream source populations are available to recolonize impacted reaches. It also suggests that higher streamflows may benefit the benthic macroinvertebrate community in this reach and perhaps throughout the stream. The community at this site should be monitored in the future as it may further illuminate effects of siltation and altered streamflows on benthic macroinvertebrates in South Boulder Creek.

The high variation in macroinvertebrate density observed at sites among seasons is not unusual for Front Range streams (Grotheer et al. 1994). The streamwide reduction in macroinvertebrate density indicated from the October 1995 samples was probably due to the high and extended spring and summer streamflows in South Boulder Creek.

We were unable to compare the present macroinvertebrate community with that which was historically found because historic data are lacking. Data presented in this report do provide baseline information to which future collections can be compared.

Factors affecting distribution and abundance of fishes and macroinvertebrates

At least three major factors affect habitat and distribution and abundance fishes and macroinvertebrates in South Boulder Creek. These factors include habitat degradation through stream bed and bank alterations such as channelization and siltation, extreme low flows caused by diversion for irrigated agriculture and reservoir storage, and effects of diversions which are obstructions to upstream fish dispersal. Water temperature changes caused by discharge differences up and downstream of diversions may also be important. Although the effects of each factor are discussed singly below, it is important to understand that these effects often interact in complex ways, and very often have negative consequences for the aquatic community.

Habitat alterations.--Channel morphology, discharge, and land-use patterns are important factors in controlling the structure and variability of stream habitat. In natural systems, unconstrained streams sometimes leave their banks during periods of high discharge, such as occurs during spring and early summer snowmelt, and spread onto the floodplain. Such flooding often creates and restores off-channel habitats such as wetlands, marshes, and oxbow ponds. Such seasonally flooded areas are often important feeding locations for a variety of waterfowl and other wildlife, and if maintained by groundwater seeps or springs, off-channel habitat may provide unique year-round habitat for certain fishes and macroinvertebrates.

Thus, a naturally functioning stream and its floodplain has several dimensions including an up to downstream one, a vertical one, and a lateral one that may be seasonally important (Ward 1989). Naturally functioning streams provide habitat for a variety of life history stages and may promote retention of native biota. Lowered peak flows during spring runoff, such as may have occurred after Gross Reservoir began operation in 1956, may reduce the frequency of floodplain inundation.

Within the stream itself, a mix of habitat types that include riffles, runs, pools, and backwaters provides a wide variety niches or living space for fishes and macroinvertebrates. Within these larger habitat types, a wide mixture of different stream velocities, depths, and substrate types is important in providing optimal habitat for fishes in a stream. Habitat diversity promotes a diverse, healthy, and productive fish and invertebrate communities.

Unfortunately, South Boulder Creek has lost much of its natural function and habitat. The preponderance of diversions for irrigation and channelization has affected most reaches of South Boulder Creek. Lack of channel meandering and natural channel functioning is also likely the most permanent and difficult to restore habitat feature of the stream. This is so because a channelized stream tends to scour substrate vertically, rather than in a natural lateral scour pattern, and the resultant incision reduces the elevation of the stream bed. Not only does the resulting shallow and homogeneous channel provide poor fish habitat, lack of meanders and high and incised banks continue to constrain the channel and reduce development of channel meanders and complex habitat. Effectiveness of springs and seeps to sustain off-channel wetlands may also be reduced by the lowered stream.

The new and lower base level elevation of the stream following channelization and incision combined with slightly lower peak flows further eliminates overbank flooding and severs important ephemeral connections of the stream and its associated floodplain. This is an example of how multiple factors such as peak stream discharge and channelization interact with negative consequences for the aquatic community.

Reasons for extensive channelization of South Boulder Creek were likely due to many factors but most were associated with water diversions. A straight channel that does not permit the stream to meander out of its banks probably facilitated delivery of water into canals and likely reduced undermining or washing out of diversion dams and destruction of canals. The numerous and well-spaced diversion structures throughout South Boulder Creek likely provided impetus to channelize most or all stream reaches at one time or another.

Although no channelization events occurred during this study or even in the recent past in South Boulder Creek, effects of past channelization were obvious. The most common result of channelization was to create a homogeneous channel of uniform depth, velocity, and substrate. Such activities also reduced the amount of bank and instream cover that was especially important for fishes with large body size.

Channelization also exacerbates potentially negative effects of high flows on fishes. Fishes in transition and plains streams are naturally adapted to variable flow regimes, as stream discharge in the natural state of these rivers fluctuated widely with spring runoff and drought events. During floods however, channelized streams act as a conduit or sluiceway to direct high flows downstream. Because of the homogeneous nature of the habitat and lack of cover, fishes in channelized habitat have little refuge from high velocity flows. The result is often higher mortality of resident fishes or transport of fishes to downstream areas.

Macroinvertebrates are probably less sensitive to channelization than fishes because they are small-bodied and can survive in homogeneous and shallow riffle and run habitat if suitable cobble and rubble substrate is available. Extreme low flows may reduce overwinter survival because of ice formation between substrate interstices and subsequent freezing of macroinvertebrates, as was noted at site 2 in December 1994.

Siltation may be a pervasive problem for fishes and macroinvertebrates. Sediment residing in stream banks or in floodplains that is mobilized by channelization or floodplain disturbances is transported to the stream during runoff from storm events or by irrigation or canal returns and fills interstitial spaces between substrate particles. Interstitial spaces between substrate particles are often used seasonally by fish for egg deposition and year-round by stream macroinvertebrates for living space.

Fish species in South Boulder Creek that spawn during or immediately after cleansing high spring flows, such as longnose dace and longnose suckers, may not be as affected by siltation. However, species that spawn at lower flows when water temperatures are warmer may be more severely affected. Such species include those found in the middle reach of South Boulder Creek and probably also includes most extirpated species. Continued presence of some warm-water, gravel-spawning species in South Boulder Creek (e.g., creek chub, central stoneroller) probably is due to the ability of these species to find limited clean substrate.

Macroinvertebrates seem as much or more affected by siltation than fishes in South Boulder Creek. Low species richness, Shannon, and EPT index values at site 10 where siltation was evident, compared with much higher index values calculated from samples made upstream of the South Boulder Road site supports this contention. Low invertebrate diversity index scores and high abundance of tolerant taxa such as Amphipoda, Annelida, Isopoda, and Oligochaeta in qualitative samples at silt-laden sites 11 and 15 further supports the notion that downstream reaches of South Boulder Creek have numerous impacts and overall support more limited aquatic biota. Only partial recovery of the macroinvertebrate community at site 10 after substrate-cleansing spring-summer flows may be due to insufficient recolonization time.

Interstitial spaces between substrate particles are important pathways for upstream, downstream, and lateral movements of macroinvertebrates within the stream substrate (Resch and Rosenburg 1993). Thus, excessive sedimentation that clogs substrate interstices may disrupt invertebrate recolonization of some stream reaches. Any activity such as instream channelization or sediment mobilization in the floodplain should be minimized to reduce damage to aquatic communities.

Fish and macroinvertebrates appear differentially affected by various impacts identified as important in South Boulder Creek. Channelization and diversion dams which impact large stream reaches may affect distribution and abundance of fishes relatively more because these taxa rely on continuous up- and downstream dispersal routes to recolonize habitat. Fish are affected by siltation primarily via reduced reproductive success, although the invertebrate food base is likely reduced year-round.

Alternatively, immature aquatic macroinvertebrates have much less stringent physical habitat requirements and can survive in shallow and homogeneous channelized reaches. Most species also have aerial adult life stages so dispersal for recolonization is probably relatively unimportant. Siltation is probably more detrimental to macroinvertebrates because immature life stages of these taxa are dependent upon clean interstitial spaces in substrate throughout the year.

Riparian vegetation was generally in good condition in South Boulder Creek, in spite of cattle grazing in some reaches, stream banks were generally in good condition. However, lack of large woody debris in the riparian zone and in the stream channel limits habitat variability and abundance of deep pools. Efforts to restore channel meandering in channelized reaches may increase aquatic habitat variability, especially in reaches where large woody vegetation is present or can be enhanced. The increased structural habitat diversity caused by large woody debris in the stream channel may also enhance macroinvertebrate communities (Benke 1985).

Streamflow alteration.--Natural cycles of discharge are important in the ecology of streams. High spring flows serve to clean silt and other small sediment particles from the substrate that would otherwise reduce fish reproductive success and invertebrate communities. Siltation of stream substrate reduces the abundance and diversity of stream macroinvertebrates (mostly insects) that are an important component of the stream ecosystem and serve as fish food. High flows also create diverse habitat by scouring deep pools and undercut riparian trees that fall into the river and serve as cover for fishes. Upstream reservoirs hold runoff water in South Boulder Creek so that spring floods are not as high as they were historically. This results in a lowered capacity of the stream to rejuvenate substrate and create habitat and may result in a reduction in abundance and diversity of stream biota.

The impact of a dry riverbed on fishes and macroinvertebrates is obvious and is clearly the most serious impact on stream biota. Reduced flows can also reduce habitat diversity and niche space that may subsequently reduce fish species diversity and abundance. When flows are reduced, fishes restricted to pools are often more susceptible to predation from birds or other fish predators than they would be in a naturally flowing stream. This is a good example of a change in a physical process (flow reduction from drought or diversion) that results in a subsequent change in a biotic process (predation), all of which may interact to affect the distribution and abundance of stream biota.

De-watering or producing unseasonable low flows impact water courses by altering channel morphology, and water temperature and chemistry, which can in turn affect aquatic organisms (Hill 1976). Mayflies and stoneflies are usually replaced by chironomid midges, oligochaete worms and snails in streams de-watered due to agricultural activities. At the de-watered and relatively heavily silted Baseline Road site, only 8-13 EPT taxa were collected over the sampling period, a significantly (P= 0.05) lower number than the other three sites. Hoffman and Kondratieff (1995) found a similar pattern in Spring Creek, an urban Fort Collins, Colorado, drainage system extensively modified by agricultural irrigation canal diversions. Usually the transition zone of Colorado Great Plain streams exhibit communities that are a diverse mixture of cold water species and cool to warmer water adapted species. This especially true during spring snow melt runoff regimes. However, no real transition aquatic invertebrate communities exist in South Boulder Creek as compared to less impacted regional streams (B. C. Kondratieff, personal observation and Grotheer et al. 1994). Returning seasonal flows may enhance the diversity and abundance of aquatic invertebrate communities in the lower portion of South Boulder Creek.

Low stream discharge, especially in winter, and lack of habitat variability and deep pools resulting from channelization and other factors, may severely limit overwinter survival of fishes some reaches of South Boulder Creek. The comparative size frequency data for rainbow trout and longnose sucker for site 1 which had relatively good habitat and site 2 which had relatively poor habitat, suggests that ephemeral fish populations exist in some reaches. Presence of higher flows or better habitat would probably singly enhance fish survival in reaches with ephemeral populations although both factors are probably important for sustaining balanced community structure and diversity. Experiments which measure overwinter survival of fishes and macroinvertebrates in stream reaches with different habitat conditions and with experimentally manipulated flows may illuminate the relative importance of each factor.

Diversions.--The numerous diversions present in South Boulder Creek isolate the fish populations between them prevent upstream dispersal and may increase susceptibility of these smaller populations to extirpation. Local extirpations of species were likely common in the evolutionary history of many of these stream fish species because of stochastic events that reduced or eliminated populations in small habitats. Re-invasion of these habitats from populations in off-channel habitats or different streams systems outside of South Boulder Creek drainage basin (e.g. main Boulder Creek) was a likely scenario for many plains stream fishes (Fausch and Bestgen In press).

A conceptual diagram of fish dispersal among populations within a stream and among off-channel habitats illustrates the potential negative effects of dispersal barriers to recolonization of habitat (Fig. 7). The advent of extensive water diversion structures, many of which are probably impassable fish barriers, and channelization served to isolate populations and deter reinvasion of depopulated reaches. Progressive isolation of South Boulder Creek fish populations into smaller units probably made them more susceptible to extirpation.

Effects of limited dispersal capability is evident for some fish species in reaches of present-day South Boulder Creek. For instance, in spite of suitable habitat, central stoneroller does not occur at site 8 which is separated from a large population at downstream Site 10 by a diversion dam. Impassable barriers to upstream fish movement may also be a partial

RECOLONIZATION PATHWAYS

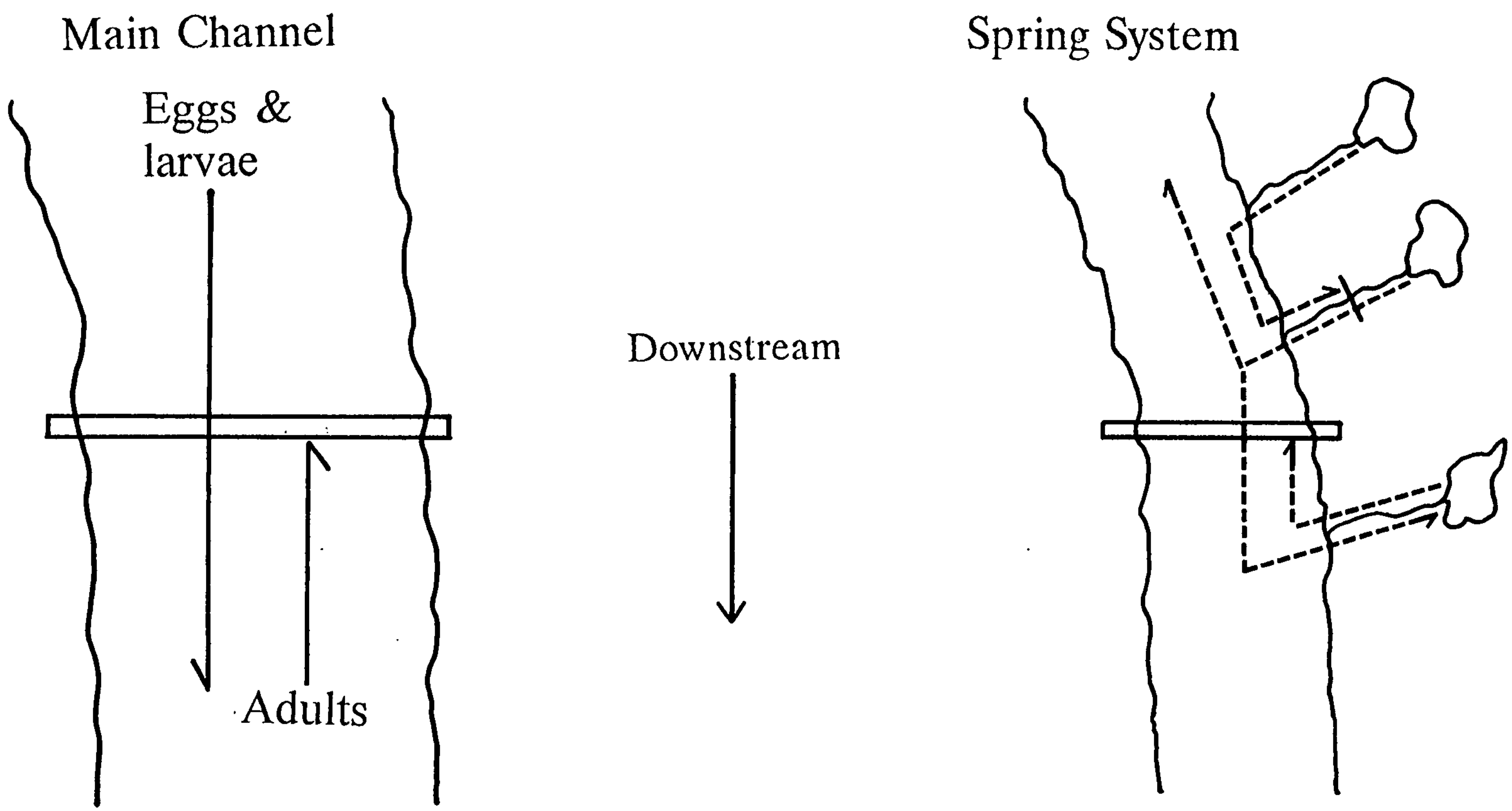

Figure 7.--Conceptual diagram depicting irrigation diversion dams and other instream obstructions as barriers to fish dispersal in streams. Eggs and larvae can disperse downstream over obstructions but subsequent dispersal by juveniles and adults into off-channel or spring habitats or upstream is blocked.

explanation for the depauperate fish community of South Boulder Creek upstream of the South Boulder Road diversion, although temperature and habitat may also play a role.

Effects of diversion dams on upstream fish dispersal may depend on diversion design and the relationship between timing of fish movements and diversion use patterns. Simple but relatively inefficient rock barriers that divert water into canals are doubtless less restrictive to upstream fish movement, because small-bodied South Boulder Creek fishes can likely negotiate these through particle interstices. Experiments to determine fish movements up and downstream of dams may yield insights into effectiveness of various structures in restricting fish movement.

Water temperature.--Habitat may be marginal for most warmwater fishes in years of high flow (e.g. 1995) in South Boulder Creek upstream of South Boulder Road because water temperatures may be too cold for reproduction. Longnose suckers generally reproduce in spring and early summer in Colorado transition zone streams and are 40-70 mm TL by fall (KRB, unpublished data). Presence of 11.5 to 20 mm TL longnose suckers (15-30 d-old) throughout South Boulder Creek (sites 1, 2, 8, 10) in early to mid-October and absence of other larger age-0 fish suggested extremely late spawning by this species. Overwinter survival of longnose sucker larvae of this size will doubtless be low or non-existent. Collections at sites 8 and 10 in mid-August 1995 suggested that most warmwater species such as creek chub, central stoneroller, and fathead minnow had not yet spawned and may not have spawned at all in 1995.

The depauperate fish fauna of South Boulder Creek upstream of South Boulder Road may be due in part to temperature differences up- and downstream (Fig. 6). Although exact threshold temperatures for spawning for most warm water taxa that occur downstream of the diversion are unknown, temperature regimes in that reach may be adequate in some years especially when flows are low (e.g., 1994). Creek chub spawned in the Big Thompson River in May 1993 when daytime high water temperatures reached 16-18°C. Temperatures > 18°C upstream of South Boulder Road were observed in 1994, suggesting that other factors such as access or habitat may be limiting fish populations in that reach.

The disjunct distribution pattern of some fishes observed in South Boulder Creek up- and downstream of the South Boulder Road diversion is likely due to several interacting factors. The upstream extent of distribution for many stream fishes is likely controlled by a suite of environmental variables such as habitat and availability of water temperatures suitable for reproduction. In wetter periods when streamflows are higher and colder the upstream extent of some species may contract, while during periods with lower and warmer discharge, fish distribution may expand upstream. Maintenance of continuous fish populations in streams minimally requires unimpeded upstream dispersal.

Because many South Boulder Creek stream fishes may be near their upstream thermal tolerance limits, distribution of populations in this transition zone area can be expected to be dynamic. It may be that populations of species such as creek chub were once present upstream of South Boulder Road, but an extreme environmental event such as drought eliminated a perhaps small population. Impassable diversion dams may have limited upstream dispersal resulting in the disjunct distribution pattern now observed.

Fishes recolonized drought-defaunated reaches of an Illinois stream soon after streamflow resumed (Larimore et al. 1959) suggesting that time, or lack thereof, is not a reasonable explanation for lack of certain fish species upstream of South Boulder Road. Rather, obstruction of dispersal by diversions and other factors such as habitat may be involved. A test of this hypothesis would be to re-introduce species into suitable habitat and monitor their progress. This would present an opportunity to experimentally test factors which control distribution and abundance of fishes in South Boulder Creek.

Lower temperatures and higher flows have been suggested as factors which enhance survival of stream macroinvertebrates in lower absolute dissolved oxygen environments, by reducing their metabolism and increasing the perceived dissolved oxygen content of the water (Hilsenhoff, 1982). Conversely higher temperatures and lower flows can have negative effects on the ability of aquatic macroinvertebrates to withstand oxygen stress. Stream velocities below 0.3 m/sec should be avoided if viable aquatic invertebrate communities are to be maintained (Hilsenhoff 1988). Such stream velocities are common in South Boulder Creek during parts of every year when flows are naturally low and when water diversions are severe.

Slight temperature differences were noted for South Boulder Creek up- and downstream of South Boulder Road may also explain, along with siltation and low flows, the absence of some taxa (e.g. most Plecoptera) at the Baseline site. Thermal tolerances of some Ephemeroptera and Plecoptera are < 20°C, and if present in South Boulder Creek, such taxa would not be expected in lower South Boulder Creek because summertime temperatures there often exceed 20°C (Resch and Rosenberg 1993).

Differential effects of various impacts on fish and macroinvertebrates suggests that both taxonomic groups are important in determining the relative health of an aquatic ecosystem and that both groups should be used for monitoring.

Monitoring program for fishes

Study Design Considerations--Stream biota are often affected by a wide variety of complexly interacting processes rendering biological data such as that presented in this report difficult to interpret. Compounding that complexity is a lack of knowledge regarding the ecology of plains stream fish communities. The effects of flow regime, habitat, and species interactions on historical and present patterns of species distribution and richness and fish abundance are all potentially intertwined but relatively little is known about any of those factors even singly. Effects of alterations in flows and habitat are also intertwined and are difficult to separate from natural variation in fish communities.

When man-caused perturbations (channelization, changes in stream flow and water quality) are superimposed on those complex interactions, changes in the biota are often difficult to interpret. Impacts to habitat may also have lasting or ephemeral effects on biota. The direct and immediate effects of a channelization event on stream fishes and their habitat is usually obvious to a trained biologist. Less clear, however, are the long-term effects of such an event. For instance, we do not know how long it takes for habitat and the fishes that occupy a channelized reach to recover from such an event. Long-term data that describe natural variation of communities under a given suite of environmental conditions are useful for determining effects of environmental changes.

Optimal design of environmental impact studies to assess changes in biota over time ideally have reference (control) sites upstream and impact (treatment) sites located downstream of a presumed perturbation (e.g., sewage treatment plant). Monitoring of fishes at up- and downstream sites over time then provides a measure of how much the community has changed and whether downstream sites are strongly affected by the perturbation. Stability of upstream communities and reductions in downstream ones might suggest some effect from the impact site. In contrast, concurrent changes in up- and downstream communities may suggest some wider-scale change in environmental conditions that may not be attributable to the specific impact. Implicit in such a design are several assumptions, one of the most important ones being that environmental conditions are similar and remain stable between all sites, with the exception of the explicit impact (e.g., a sewage treatment plant effluent).

In South Boulder Creek, this experimental design is confounded for a number of reasons. First, sites upstream and downstream are not homogeneous. Second, anthropogenic disturbances such as channelization and discharge reduction are present throughout and are not of similar magnitude. Third, natural fluctuations in biological variables along the reach may cause high variability that prevents detection of an impact. Thus, comparisons among sites within South Boulder Creek would not be an effective means to evaluate response of biological communities to restoration or other activities. Response of a treatment stream to a different control stream could also be done, but few streams are present in the area with similar histories, impacts, and faunas, thus eliminating this approach.

Given these limitations, perhaps the best way to determine which factor(s) have the greatest effect is to remove the effect from a site and monitor recovery of the community. This could be accomplished by changing the discharge regime in part or all of the stream or restoring habitat in channelized reaches and monitoring fish community response. Pre-treatment data at the site then serves as a logical control with which to assess treatment effects.

Such a design requires that adequate, high-quality pre-treatment data be collected at several sites. Sites should be chosen that are representative of the habitat and fish communities throughout the reach and should be ones not expected to undergo significant physical modifications such as channelization, habitat improvements, changes in riparian structure, or flow modifications other than those that are of interest for evaluation.

In order to adequately assess composition and abundance of the fish community in a reach of river, all habitat types present must be sampled. In general, sampling reach lengths equivalent 20 stream widths should be more than adequate to encompass all habitat types including at least three South Boulder Creek pool-riffle sequences (Knighton 1984, KRB unpublished data).

It is also important to determine whether collecting gear is obtaining a representative sample (species composition and abundance) of fishes at a site. This can be accomplished through depletion sampling of stream reaches that are block-netted to prevent immigration or emigration of fishes.

Periodic habitat measurements at each site would also allow determination of changes over time due to changes in stream flow or other factors. Additional habitat measurements would also be useful in order to explain variation in fish community structure and function among sites within years.

Finally, if investigators are unfamiliar with plains stream fishes, periodic quality control checks on specimen identification is recommended. Random samples of field identified specimens would be preserved and re-identified in the lab to determine if species composition and abundance measurements were accurate.

Considerations for design and implementation of an invertebrate monitoring program is presented in Appendix III.

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LITERATURE CITED

Baumann, R. W. 1979. Nearctic stonefly genera as indicators of ecological parameters (Plecoptera: Insecta). Great Basin Naturalist. 39: 241-244.

Baumann, R. W., A. R. Gaufin, and R. F. Surdick. 1977. The stoneflies (Plecoptera) of the Rocky Mountains. Memoirs of the American Entomological Society. Number 31.

Becker, G. C. 1983. Fishes of Wisconsin. Univ. Wisconsin Press, MAdison. 1052 pp.

Behnke, R. J. 1992. Native trout of western North America. American Fisheries Society Monograph 6:1-275.

Benke, A. C., R. L. Henry III, D. M. Gillespie, R. J. Hunter. 1985. Importance of snag habitat for animal production in southeastern streams. Fisheries (Bethesda) 10(5):8-13.

Bestgen, K. R. 1989. Distribution and notes on the biology of Phoxinus eos (Cyprinidae) in Colorado. Southwestern Nat., 34:225-231.

Bestgen, K. R., K. D. Fausch, and S. Riley. 1991. Rediscovery of a relict southern population of lake chub, *Couesius plumbeus*, in Colorado. Southwestern Naturalist 36:125-127.

Brower, J. E. and J. H. Zar. 1977. Field and laboratory methods for general ecology. Wm. C. Brown Publishers, Dubuque, Iowa.

Edmunds, G. F. Jr., S. L. Jensen, and L. Berner. 1976. The mayflies of North and Central America. University of Minnesota Press, Minneapolis, Minnesota.

Ellis, M. M. 1914. Fishes of Colorado. Univ. Colorado Studies, 11:1-136.

Fausch, K. D., and K. R. Bestgen. In press. Ecology of fishes indigenous to the central and southwestern Great Plains. In F. L. Knopf and F. B. Samson, eds. Ecology of Great Plains vertebrates and their habitats. Springer-Verlag, NY.

Grotheer, S. A., J. M. Chudd, Sen-Her Shieh, N. J. Voelz, and J. V. Ward. 1994. Developing a Biotic Index for Colorado Stream Quality. Colorado Water Resources Research Institute, Colorado State University. Report 187.

Hawkes, H. A. 1979. Invertebrates as indicators of river water quality, pp. 2-1 - 2-45. In A. James and L. Evison, Biological indicators of water quality. John Wiley and Sons, New York.

Hellawell, J. M. 1986. Biological indicators of freshwater pollution and environmental management. Elsevier Applied Science Publishers, New York.

Hendricks, L. J. 1950. The fishes of Boulder County, Colorado. Unpubl. M.S. thesis, Univ. Colorado, Boulder, 55 pp.

Hilsenhoff, W. H. 1982. Using a Biotic Index to Evaluate Water Quality of Streams. Technical Bulletin No. 132, Dept. of Nat. Res. Madison, Wisconsin.

Hilsenhoff, W. H. 1988. Seasonal Correction Factors for the Biotic Index. Great Lakes Entomol. 21: 9-13.

Hoffman, S. and B. C. Kondratieff. 1995. Final Report, Water Quality Work Plan for Spring Creek and Fossil Creek, Fort Collins, Colorado. Stormwater Utility, City of Fort Collins, Colorado.

Juday, C. 1904. Fishes of Boulder County. University of Colorado Studies 2:113-114.

Karr, J. R. 1991. Biological integrity: A long-neglected aspect of water resource management. Ecological Applications 1:66-84.

Karr, J. R., and D. R. Dudley. 1981. Ecological perspective on water quality goals. Environmental Management 5:55-68.

Karr, J. R., K. D. Fausch, P. L. Angermeier, P. R. Yant, and I. J. Schlosser. 1986. Assessing biological integrity in running waters, a method and its rationale. Illinois Natural History Survey, Special Publication 5.

Knighton, D. 1984. Fluvial forms and processes. Edward Arnold Press. 218 pp.

Kuehne, R. A. 1962. A classification of streams illustrated by fish distribution in an eastern Kentucky stream. Ecology 43:608-614.

Larimore, R. W., W. F. Childers, and C. Heckrotte. 1959. Destruction and re-establishment of stream fish and invertebrates affected by drought. Transactions of the American Fisheries Society 88:261-285.

Li, H. W. 1968. Fishes of the South Platte River basin. Unpubl. M.S. thesis, Colorado State Univ., Fort Collins, 67 pp.

Magurran, A. 1988. Ecological diversity and its measurement. Princeton University Press, Princeton, New Jersey.

Meffe, G. K. 1985. Predation and species replacement in American southwestern fishes: A case study. Southwestern Naturalist 30:173-187.

Merritt, R. W., and K. W. Cummins. 1984. An introduction to the aquatic insects of North America, 2nd edition. Kendall/Hunt Publishing Co., Dubuque, IA.

Ohio Environmental Protection Agency. 1988. Biological criteria for the protection of aquatic life. Division of Water Quality Monitoring and Assessment, Surface Water Section, Columbus, Ohio.

Pennak, R. W. 1989. Freshwater invertebrates of the United States, 3rd edition. John Wiley and Sons, New York.

Platts, W. S., W. F. Megahan, and G. W. Minshall. 1983. Methods for evaluating stream, riparian, and biotic conditions. USDA Forest Service General Technical Report INT-138.

Propst, D. L. 1982. Warmwater fishes of the Platte River basin, Colorado; distribution, ecology, and community dynamics. PhD dissertation, Colorado State University, Fort Collins. 283 pp.

Propst, D. L., and C. A. Carlson. 1986. The distribution and status of warmwater fishes in the Platte River drainage, Colorado. Southwestern Nat., 31:149-168.

Resch, V. H., and D. M. Rosenburg. 1993. Freshwater biomonitoring and benthic macroinvertebrates. Chapman and Hall, New York, New York.

Schindler, D. W. 1987. Detecting ecosystem responses to anthropogenic stress. Canadian Journal of Fisheries and Aquatic Sciences 44(Suppl. 1):6-25.

Shannon, C. E. and W. Weaver. 1949. The mathematical theory of communication. The University of Illinois Press, Urbana Illinois.

Stewart, K. W. and B. P. Stark. 1988. Nymphs of North American stonefly genera. Entomological Society of America, U.S.A.

Thorp, J. H. and A. P. Covich. 1991. Ecology and classification of North American Freshwater Invertebrates. Academic Press, San Diego, California.

United States Geological Survey. Published anually. Streamflow records for Colorado. U. S. Geological Survey, Denver, CO.

Voshell, J. R. Jr, and S. W. Hiner. 1990. Shenandoah National Park long-term ecological monitoring system, section III, aquatic component user manual. In National Park Service, Shenandoah National Park long-term ecological monitoring system user manuals. Natural Resources Technical Report Series, NPS/NRSHEN/NRTR-90/02.

Ward, J. V. 1989. Riverine-wetland interactions. Pages 385-400 *in* R. R. Sharitz and J. W. Gibbons, editors. Freshwater wetlands and wildlife. D. O. E. Symposium Series 61, Oak Ridge, TN.

Ward, J. V. and B. C. Kondratieff. 1991. An illustrated guide to the mountain stream insects of Colorado. University Press of Colorado, Niwot, Colorado.

Washington, H. G. 1984. Diversity, biotic, and similarity indices, a review with special reference to aquatic ecosystems. Water Res. 18:653-694.

Weber, C. I. 1973. Biological field and laboratory methods for measuring the quality of surface waters and effluents. U.S. National Environmental Research Center, U.S. Environmental Protection Agency, Cincinnati, Ohio.

Wiggins, G. B. 1977. Larvae of the North American caddisfly genera (Trichoptera). University of Toronto Press, Toronto.

Wilhm, J. L. 1970. Range of diversity index in benthic macroinvertebrate populations. Journal of the Water Control federation. 42: R221-R224.

South Boulder Creek Fish Community Survey

Site 1: Colorado, Boulder County, South Boulder Creek,
South Mesa Trailhead, upstream of footbridge for 150 m,
T1SR70WS29-30 boundary, KRB 1002,
K. R. Bestgen, C. K. Miller

10 November 1994

Common name	Abundance (No.)	(%)
rainbow trout	150	73.9
brown trout	3	1.5
longnose dace	1	0.5
longnose sucker	49	24.1
(4 species)		
Totals	203	100.0

3 October 1995

Common name	Abundance (No.)	(%)
longnose sucker	15	100.0
(1 species)		
Totals	15	100.0

18 October 1995

Common name	Abundance (No.)	(%)
longnose sucker	48	100.0
(1 species)		
Totals	48	100.0

Site 2: Colorado, Boulder County, South Boulder Creek,
300 m upstream of LaFayette Water Treatment Plant
T1SR70WS20-21 boundary, KRB 1003
K. R. Bestgen, C. K. Miller

10 November 1994

Common name	Abundance (No.)	(%)
rainbow trout	50	60.2
longnose dace	19	22.9
longnose sucker	14	16.9
(3 species)		
Totals	83	100.0

19 May 1995

Common name	Abundance (No.)	(%)
rainbow trout	4	21.0
longnose dace	1	5.3
longnose sucker	14	66.7
(3 species)		
Totals	19	100.0

Site 3: Colorado, Boulder County, South Boulder Creek,
pond at South Boulder Ck. West trailhead, just west of Broadway
Ave. T1SR70WS16SW1/4, KRB 1004,
K. R. Bestgen, C. K. Miller

10 November 1994

Common name	Abundance (No.)	(%)
plains topminnow	44	84.6
green sunfish	8	15.4
(2 species)		
Totals	52	100.0

19 May 1995

Common name	Abundance (No.)	(%)
plains topminnow	13	86.7
green sunfish	2	13.3
(2 species)		
Totals	15	100.0

Site 4: Colorado, Boulder County, South Boulder Creek, about 1.1 km downstream of Broadway Ave., 200 m upstream of Shearer headgate T1SR70WS16NE1/4, K. R. Bestgen, C. K. Miller

15 August 1995

Common name	Abundance (No.)	(%)
longnose dace	8	42.1
longnose sucker	11	47.9
(2 species)		
Totals	19	100.0

Site 5: Colorado, Boulder County, South Boulder Creek, about 1.3 km downstream of Broadway Ave., 200 m downstream of Shearer headgate T1SR70WS16NE1/4, KRB 1010, K. R. Bestgen, C. K. Miller

11 November 1994

Common name	Abundance (No.)	(%)
rainbow trout	25	12.4
longnose dace	53	26.2
longnose sucker	124	61.4
(3 species)		
Totals	202	100.0

19 May 1995

Common name	Abundance (No.)	(%)
rainbow trout	1	4.6
longnose dace	9	40.9
longnose sucker	12	54.5
(3 species)		
Totals	22	100.0

Site 6: Colorado, Boulder County, South Boulder Creek, from 100 m downstream to 1 km upstream of U.S. 36 T1SR70WS9-10 boundary, KRB 1000, K. R. Bestgen

1 September 1994

Common name	Abundance (No.)	(%)
rainbow trout	3	1.3
fathead minnow	18	8.0
longnose dace	6	2.7
longnose sucker	197	87.9
(4 species)		
Totals	224	100.0

Site 7: Colorado, Boulder County, South Boulder Creek, an 80 m section beginning 70 m upstream of U.S. 36 T1SR70WS9-10 boundary, KRB 1005, K. R. Bestgen, B. Richards

11 November 1994

Common name	Abundance (No.)	(%)
rainbow trout	32	26.4
fathead minnow	21	17.4
longnose dace	2	1.7
longnose sucker	66	54.5
(4 species)		
Totals	121	100.0

Site 8: Colorado, Boulder County, South Boulder Creek,
South Boulder Road, 200 m downstream of, on Gebhardt Property
T1SR70WS3SW1/4, KRB 1006,
K. R. Bestgen, C. K. Miller, B. Richards

11 November 1994

Common name	Abundance (No.)	(%)
rainbow trout	25	7.4
brown trout	5	1.5
fathead minnow	188	56.0
creek chub	27	8.0
longnose dace	18	5.4
longnose sucker	42	12.5
white sucker	10	3.0
plains topminnow	13	3.9
pumpkinseed	1	0.3
green sunfish	7	2.1
(10 species)		
Totals	336	100.0

19 May 1995

Common name	Abundance (No.)	(%)
fathead minnow	67	81.7
creek chub	8	9.6
longnose sucker	3	3.7
plains topminnow	1	1.2 (+200 observed in side canal)
pumpkinseed	3	3.7
(5 species)		
Totals	82	100.0

15 August 1995

Common name	Abundance (No.)	(%)
rainbow trout	2	1.1
brown trout	2	1.1
fathead minnow	97	51.6
creek chub	15	8.0
longnose dace	1	0.5
longnose sucker	27	14.4
white sucker	16	8.5
plains topminnow	17	9.0
pumpkinseed	1	0.5
green sunfish	8	4.3
bluegill	1	0.5
largemouth bass	1	0.5
(12 species)		
Totals	188	100.0

Site 9: Colorado, Boulder County, gravel pit pond off of west side of South Boulder Creek, directly northeast of the East Boulder Recreation Area. T1SR70WS3 S boundary of NW1/4, K. R. Bestgen

19 May 1995

Common name	Abundance (No.)	(%)
plains topminnow	+100	100
(1 species)		
Totals	+100	100.0

Site 10: Colorado, Boulder County, South Boulder Creek, 40 m upstream of Baseline Rd., at Bobolink Trailhead, for 300 m T1SR70WS3 N. boundary, KRB 1001, K. R. Bestgen, C. K. Miller

10 November 1994

Common name	Abundance (No.)	(%)
rainbow trout	1	0.3
brown trout	8	2.7
central stoneroller	81	27.6
fathead minnow	1	0.3
creek chub	96	32.8
longnose dace	58	19.8
longnose sucker	21	7.2
white sucker	24	8.2
green sunfish	3	1.0
(9 species)		
Totals	293	100.0

19 May 1995

Common name	Abundance (No.)	(%)
central stoneroller	42	9.8
fathead minnow	267	62.1
creek chub	78	18.1
longnose dace	5	1.2
longnose sucker	13	3.0
white sucker	7	1.6
green sunfish	2	0.5
pumpkinseed	13	3.0
orangespotted sunfish	1	0.2
bluegill	1	0.2
black crappie	1	0.2
(11 species)		
Totals	430	100.0

15 August 1995

Common name	Abundance (No.)	(%)
central stoneroller	22	17.1
fathead minnow	9	7.0
creek chub	36	27.9
longnose dace	41	31.8
longnose sucker	13	10.1
white sucker	6	4.7
green sunfish	2	1.6
(7 species)		
Totals	129	100.0

Site 11: Colorado, Boulder County, South Boulder Creek, at and downstream of Arapahoe Rd. to Valmont Res. diversion T1NR70WS27-34 boundary, 11 November 1994, KRB 1007, K. R. Bestgen, C. K. Miller, B. Richards

Common name	Abundance (No.)	(%)
brown trout	5	33.3
creek chub	1	6.7
white sucker	1	6.7
green sunfish	1	6.7
largemouth bass	7	46.7
(5 species)		
Totals	15	100.0

19 May 1995
Observed water backed up to under the Arapahoe Road bridge, no collection made.

Site 12: Colorado, Boulder County, South Boulder Creek, about 300 m upstream of KOA Res., downstream of Valmont Res. diversion T1NR70WS27(middle), KRB 1008, K. R. Bestgen, C. K. Miller, B. Richards

11 November 1994

Common name	Abundance (No.)	(%)
central stoneroller	19	51.4
creek chub	4	10.8
white sucker	7	18.9
plains topminnow	2	5.4
largemouth bass	5	13.5
(5 species)		
Totals	37	100.0

Site 13: Colorado, Boulder County, South Boulder Creek, about 200 m upstream of KOA Res., downstream of Valmont Res. diversion T1NR70WS27(middle), KRB 1008,

19 May 1995 (observations only)

Common name	Abundance (No.)	(%)
common carp		
fathead minnow		
plains topminnow		
(3 species)		

Site 14: KOA Reservoir, northwest arm of KOA reservoir, west of bike path. T1NR70WS27NW1/4

19 May 1995 (observed most species)

Common name	Abundance (No.)	(%)
common carp		
plains topminnow	48	
bluegill		
largemouth bass		
(4 species)		
Totals	48	100.0 (+observed other species)

Site 15: Colorado, Boulder County, South Boulder Creek, at and downstream of Valmont Rd. for about 300 m, directly below KOA Res., T1NR70WS22SW1/4, KRB 1009, K. R. Bestgen, C. K. Miller

11 November 1994

Common name	Abundance (No.)	(%)
fathead minnow	3	2.2
creek chub	2	1.5
white sucker	5	3.6
western mosquitofish	4	2.9
green sunfish	1	0.7
largemouth bass	122	89.1
(6 species)		
Totals	137	100.0

18 October 1995

Common name	Abundance (No.)	(%)
western mosquitofish	13	39.4
bluegill	2	6.1
largemouth bass	17	51.5
(3 species)		
Totals	33	100.0

Appendix II. Macroinvertebrate taxa collected from South Boulder Creek, Boulder County, Colorado, December 1994, April 1995, and October 1995. Voucher specimens are deposited in the C. P. Gillette Museum of Arthropod Diversity, Colorado State University, Fort Collins, Colorado.

Stations	1[1]	2[2]	3[3]	4[4]
Ephemeroptera				
Baetidae				
Acentrella insignificans (McD)		X		X
Baetis tricaudatus Dodds	X	X	X	X
Baetis sp.				
Fallceon quilleri (Dodds)				X
Ameletidae				
Ameletus validus McD	X			
Heptageniidae				
Nixe criddlei (McD)	X			
Rhithrogena hageni Eaton	X	X	X	X
Epeorus longimanus Eaton	X	X	X	X
Leptophlebiidae				
Paraleptophlebia debilis (Walker)	X	X	X	
Paraleptophlebia sp.	X	X	X	X
Ephemerellidae				
Ephemerella infrequens McD	X	X	X	
Drunella coloradensis (Dodds)	X			
Drunella grandis (Eaton)	X	X		
Drunella doddsi (Needham)	X			
Tricorythidae				
Tricorythodes minutus Traver			X	X
Plecoptera				
Nemouridae				
Malenka californica (Claassen)	X	X		
Prostoia besametsa (Ricker)	X	X		
Capniidae				
Capnia confusa Claassen	X			
Eucapnopsis brevicauda (Claassen)	X			
Pteronarcyidae				
Pteronarcella badia (Hagen)	X	X		
Perlodidae				
Isoperla fulva (Claassen)	X		X	
Skwala americana (Klapalek)	X	X	X	
Chloroperlidae	X	X	X	X
Sweltsa sp.	X	X		
Suwallia pallidula (Banks)	X	X		
Paraperla frontalis (Banks)	X			
Triznaka signata (Banks)	X	X	X	
Perlidae				
Claassenia sabulosa (Banks)	X			
Hesperoperla pacifica (Banks)	X			
Hemiptera				
Gerridae				
Aquarius remigis (Say)	X	X	X	X

Gerris sp.	X	X	X	X
Veliidae				
Rhagovelia distincta Champ.				X
Trichoptera				
Brachycentridae				
Brachycentrus americanus (Banks)	X	X	X	
Glossosomatidae				
Agapetus boulderensis Milne	X	X		
Glossosoma sp.	X	X	X	
Helicopsychidae				
Helicopsyche borealis (Hagen)			X	
Hydropsychidae				
Cheumatopsyche pettiti (Banks)	X		X	X
Hydropsyche occidentalis Banks		X	X	X
Hydropsyche oslari Banks	X	X	X	
Hydropsyche sp.	X	X	X	
Hydroptilidae				
Leucotrichia pictipes (Banks)			X	
Lepidostomatidae				
Lepidostoma pluviale (Milne)	X	X	X	
Leptoceridae				
Oecetis sp.		X	X	
Limnephilidae				
Hesperophylax occidentalis (Banks)			X	X
Rhyacophilidae				
Rhyacophila coloradensis (Banks)	X	X		
Coleoptera				
Dytiscidae				X
Agabus seriatus (Say)	X	X	X	
Hydroporus dimidiatus G.& H.	X			
Laccophilus maculosus Say	X			
Oreodytes congruus (LeConte)	X			
Rhantus frontalis (Marsham)		X		
Stictotarsus striatellus (LeConte)	X			
Elmidae				
Optioservus castanipennis (Fall)	X	X	X	
Optioservus divergens (LeConte)	X	X	X	
Optioservus sp.				X
Narpus concolor (LeConte)	X			
Zaitzevia parvula (Horn)	X	X	X	
Hydrophilidae				
Helophorus				

orientalis Motschulsky			X	
Helophorus sp.				
Hydrobius fuscipes (L.)			X	
Laccobius agilis (Randall)			X	
Paracymus confusus Wooldridge			X	
Tropisternus sp.	X	X	X	X
Diptera				
Deuterophlebiidae				
Deuterophlebia coloradensis Pennak	X	X		
Tipulidae				
Tipula sp.	X		X	
Antocha sp.	X	X		
Dicranota sp.			X	
Hexatoma sp.	X	X	X	
Chironomidae				
Diamesinae				
Diamesa sp.	X	X	X	X
Pagastia sp.			X	
Orthocladiinae	X	X	X	X
Cricotopus sp.	X		X	
Parametriocnemus sp.	X	X		
Heleniella sp.	X			
Tvetenia sp.	X	X		
Eukiefferiella sp.		X		
Chironomini			X	
Phaenopsectra sp.			X	
Polypedilum sp.			X	
Tanytarsini	X		X	
Micropsectra sp.	X		X	
Tanytarsus sp.			X	
Paratanytarsus sp.				X
Tanypodinae		X		X
Thienemannimyia grp.	X	X	X	X
Simuliidae				
Simulium articum Malloch	X	X	X	
Simulium vittatum Zetterstedt			X	
Simulium sp.				X
Tanyderidae				
Protanyderus margarita	X			
Athericidae				
Atherix pachypus Bigot		X		
Empididae				
Chelifera sp.	X	X	X	
Lepidoptera				
Pyralidae				
Petrophila sp.			X	X
Hydracarina	X	X		
Decapoda				
Orconectes virilis (Hagen)				
Amphipoda				

		1	2	3	4
	Hyalella azteca (Saussure)			X	X
Isopoda					
	Caecidotea sp.				X
Nematoda		X	X	X	X
Oligochaeta		X	X	X	X
Turbellaria					
	Dugesia dorotocephala (Woodworth)		X	X	X
Gastropoda					
	Physella sp.		X	X	X
	Ferrissia sp.				
Bivalia					
	Sphaerium sp.			X	

[1]Mesa Trailhead; [2]"Lafayette";[3]"South Boulder";[4]Baseline

Appendix III. Processing and analysis of field collected macroinvertebrate samples, South Boulder Creek, Boulder County, Colorado.

This appendix presents the methods for field collection of water chemistry and benthic macroinvertebrate samples using the Surber square foot bottom sampler. Additionally, it summarizes macroinvertebrate sample processing methods. It is helpful to keep a field notebook in order to record site code, date, persons doing the field work, and any observations, comments and questions. Other sections of this appendix include a sample field checklist and data sheet (Appendix IV) and field and laboratory equipment list (Appendix V).

Sentinel Sites

Four permanent sampling sites were established on South Boulder Creek for benthic macroinvertebrate sampling (see text). It is suggested that these four sites be marked with distinct, long-lasting site markers. The following method to affix markers is modified from Voshell and Hiner (1990, Fig. C-1). The markers consist of 0.9 m (3 ft) high, 5 cm (2 inch) diameter PVC pipe and are secured to 102 cm (40 inch) long, 1.3 cm (1/2 inch) diameter sharpened steel rebar. Before going to the field, drill a 1 cm (5/16 inch) hole in the PVC about 30 cm (12 inches) from the bottom. Drive the rebar about 2/3 the length into the ground and attach a chain link to the rebar with a hose clamp. Pass a 0.6 x 7.6 cm (1/4 x 3 inch) hexhead bolt through the chain link and pre-drilled holes in the PVC pipe. Finally, attach an end cap to the PVC pipe. For greatest visibility, we suggest the PVC markers be white with black end caps.

Benthic Macroinvertebrates

Macroinvertebrates are generally considered those invertebrates, such as worms, mollusks, and arthropods, large enough to be seen with the unaided eye (Weber 1973). However, the very early stages of these organisms are often only detectable with the aid of a stereomicroscope or magnifier. The term benthic refers to organisms living on the bottom of aquatic environments or on firm substrates protruding above the bottom. Benthic faunal communities usually contain a wide variety of organisms. Many of the community members are the immature stages (nymphs and larvae) of insects which leave the water for a terrestrial adult stage. During this terrestrial period, reproduction and dispersal take place.

Quantitative benthic sampling is accomplished with a Surber bottom sampler (Merritt et al. 1984, Fig. 2-1). Three replicate Surber samplers should be taken at the four South Boulder Creek sites. The placement of the sampler is limited by stream depth, current, and substrate. The depth and current must be sufficient to dislodged organisms into the catch net, but the sampler cannot be completely submerged. The substrate must be regular enough so organisms will not be washed under the sampler.

In addition to the sampler, the equipment needed for sampling are a vegetable brush, a small hand rake (garden cultivator), a wash bottle, and forceps. Sample labels, preservative, and Zip-loc bags are needed for sample storage. Plastic labeling tape (such as Dymo brand) with the back still attached makes an effective permanent label. Appendix V includes an equipment checklist for benthic sampling.

Three quantitative samples should be taken in riffle reaches at each site. Take samples in different segments of the reach, always begin downstream and walk upstream to find the next suitable the sampling area. Benthic macroinvertebrates are motile, and measurements of their abundance will be affected by walking through areas to be sample. After placing the sampler on the bottom, check to make sure that the frame of the sampler makes good contact with the substrate. The best position for the person taking the sample is to kneel or crouch behind the sampler with the catch net passing between the legs. A second person to assist in holding down the sampler may be desirable. Brush each individual rock on all sides with the vegetable brush, so that the organisms will be dislodged and swept into the catch net. This is best done by holding the rocks underwater to make sure that no organisms are thrown out of the sampler. Each rock should also be visually examined at close range, because many aquatic insects have special means of attaching themselves very tightly to rock surfaces. Use forceps to remove any organisms found clinging after brushing. After all of the larger rocks have been brushed, examine and removed, rake the remaining fine substrate to stir up the sediment inhabiting organisms. Try to rake down to a depth of about 8-10 cm.

The catch net is now washed several times to concentrate the contents into the end. This is best accomplished by raising the sampler out of the water, then briefly submersing the net raising it rapidly. Splashing water along the sides of the net is also effective. The contents of the sample are placed into a plastic Zip-lock bag by inverting the net. It is usually necessary to invert and rewash the net several times to get all of the contents into the bag. Rinse any remaining organic matter into the sample bag with a wash bottle. Visually inspect the catch net, pick off any invertebrates with forceps and place them in the bag. The appropriate label (site, date, replicate) should be placed in the bag immediately. Add an appropriate preservative. After preservative is added, squeeze bag to let as much air out as possible before sealing the bag. To insure integrity of sample, place this sealed bag into another bag. If the samples are to be processed within 24 hours they may be placed on ice, to be kept as near freezing as possible, in lieu of adding preservative.

Several fluids are commonly used to preserve benthic samples, including formaldehyde, ethanol and isopropyl alcohol. Formaldehyde is recommended for benthic samples because of bacterial load of the detritus and sediment in the samples. There are health concerns associated with formaldehyde, so it must be used with caution. The final dilution of formaldehyde should be 5% of the standard stock solution. The standard stock solution, sometimes called formalin, contains about 37% formaldehyde, therefore, the final concentration of formaldehyde in the sample is approximately 2%. (Voshell and Hiner 1990). To preserve the sample with formaldehyde solution, add some stream water to the bag with the sampler and add enough preservative to equal about 5% of the liquid.

Ethanol and isopropyl alcohol are adequate substitutes for formaldehyde. Use a 70% solution of these alcohols. Special attention must be given to dilution when preserving with alcohol. Lower concentrations are not adequate to retard bacterial decomposition, and higher concentrations make specimens brittle. We recommend that when preserving by this method, if the samples are to be stored for longer than a week, the alcohol be replaced by laboratory diluted solution of 70% alcohol to ensure protection from bacterial decomposition.

Qualitative sampling of macroinvertebrates may be desired at this time. This sampling is conducted to supplement the species list. In order to obtain adult stages of benthic insects, an aerial net should be used to sweep the riparian vegetation up and down the stream banks. Selected specimens may be retained in a small bottle with 70-80% ethanol and at least a temporary site label. A standard D-frame kick net may be used to obtain specimens from stream microhabitats not sampled with the quantitative sampler. Hold net downstream and dislodge organisms by hand or by kicking. Common microhabitats to sample include leaf packs, underneath log, underneath large rocks, and by exposed roots and vegetation. As with the aerial net sampling, preserve selected specimens in a small bottle with 70-80% ethanol. Additionally, mature specimens may be returned to a laboratory for rearing to adult stages, if facilities are available.

Sampling Frequency

We recommend quantitative sampling be conducted once every season, spring (late April), summer (late June, if water levels are satisfactory), autumn (early October), and winter (December).

Sample Processing

Store bags with the benthic samples in airtight containers to reduce escape of formaldehyde fumes. The processing steps for benthic macroinvertebrate samples are 1) washing, 2) sorting, and 3) identification and enumeration. It is important to keep the sample label with the sample through all the steps, and keeping a log that includes the date each step was completed, initials of the person completing the step, and any notes, is recommended.

The first step in sample analysis is to wash organisms and formaldehyde preservative from the sampler. First rinse the sampler over a fine mesh sieve with tap water. A U. S. standard No. 60 sieve (sieve openings 0.25 mm) was used in this study. Others recommend sieves with larger openings, such as No. 30 (sieve openings 0.6 mm, Weber 1973). A finer sieve retains early instars, while a coarser sieve reduces sample volume, and therefore hastens processing. Empty plastic bag with the sample into the sieve. Gently stir the sample and shake the sieve under the water to clean the sample, but take care not to damage the delicate specimens. Transfer the sample from the sieve into a glass beaker. Cover the sample with water if it is to be picked immediately, or add 70% ethanol if not. Always keep the original sample label with the sample.

Picking the organisms from the sample, or sorting, is the next step. Into the bottom of a clear petri dish, pour enough of the sample to cover the bottom of the dish. Under a binocular dissecting microscope at low power (about 10X) separate the invertebrates from the debris and place the specimens in a vial with 70-80% ethanol. Patent lip vials with neoprene stoppers or screw cap vials with a polyethylene liner are both adequate for storage of samples and reducing evaporation of alcohol. The 7 g (4 dram, usually 7 * 21 mm) size vials are a good size for storage of samples. Look through the petri dish in a systematic manner, and then scan the dish again to check the work. Depending on the expertise of the person sorting the sample, different taxa may be separated into a sorting tray or separate vials. It is imperative that every vial have a label. If paper is used for the label it should be have at least 50% rag content, preferably 90-100%, and written with #2 pencil or India ink.

The final step in processing the sample is identifying the organisms to the lowest practical taxonomic level and counting the number in each taxon. Each specimen needs to be examined with a good quality binocular dissecting microscope. Taxonomic publications with descriptions and keys are utilized to make identifications. Merritt and Cummins (1984) thoroughly treat all the aquatic and semiaquatic insect orders. More specialized works and included references for individual orders include Edmunds et al. (1976), Ephemeroptera (mayflies); Stewart and Stark (1989), Baumann et al (1977), Plecoptera (stoneflies); and Wiggins (1977), Trichoptera (caddisflies). A good reference for macroinvertebrates other than insects is Pennak (1989) and Thorp and Covich (1991). Benthic macroinvertebrates should be identified to at least the following taxonomic levels:

- Insecta - genus, species (except Diptera)
  - Diptera - family (except Chironomidae - genus)
- Collembola - order
- Turbellaria - genus
- Nematoda - class
- Annelida - class
- Amphipoda - genus
- Isopoda - genus
- Acarina - order
- Gastropoda - genus
- Pelecypoda - genus

It may not be possible to identify early stages of macroinvertebrates to these levels. Note that taxonomic references are written for people who are already familiar with the taxonomic group covered. Formal training with a specialist is necessary for accurate identifications. It is also a good idea to have representative specimens verified by specialists. Appendix A is a data sheet that includes many of the species encountered during benthic sampling of South Boulder Creek. The list is a preliminary list and probably does not list all species or all life stages that may be encountered.

Each sample may be stored in a single vial or several vials, separated by taxonomic group. Every vial needs to have an identifying label, with site, date and replicate, and the original field label should be kept with the corresponding sample. Inevitably, through the data entry and analysis process, questions will be raised and specimens need to be reexamined. Cardboard unit trays are available for vial storage. The Monument must decide how long to keep the samples after identification, data entry, and data analysis. A minimum of one year after data analysis is recommended. It is helpful to keep several specimens of each taxon collected each year as a voucher collection. This voucher collection can serves as a tool to answer taxonomic questions, is helpful in training employees or consultants, and may be used as an educational tool (Voshell and Hiner 1990).

Data Analysis

Density, taxa richness, EPT taxa richness, and Shannon index were the analyses used in this report. Sample values were obtained by calculating the mean number of each taxon found in the three replicates samples at each site and date. Analyses were performed with the sample values. Density values, on a m^2 basis, were obtained by dividing the number of organisms collected by the surface area of the samplers (each Surber = 0.0929 m^2). Taxa richness and EPT taxa richness were obtained by counting the number of nonzero taxa within a sample. The Shannon index was computed using the formulas described in Section 2.1.3.

Appendix IV. Field checklist and data sheet.

FIELD RECORDS

Site ______________________ Date ______________________

Workers ____

Air temp. ____________°C

H_2O temp. ____________°C

pH ____________ Method: ______________________________

Water Samples: ______________________________________

Surber Samples: _____________________________________

All samples labeled?

Notes: ____

____

____

____

____

____

Appendix V. Field and laboratory equipment list.

I. General Field

- ______ Hip Waders
- ______ Field Notebook
- ______ Pencil

II. Water Chemistry Sampling

- ______ Water bottles for samples
- ______ Cooler with ice left in vehicle
- ______ pH meter or Hellige colorimeter
- ______ Thermometer

III. Benthic Macroinvertebrate Sampling

<u>Quantitative sampling</u>

- ______ Surber sampler
- ______ Vegetable brush
- ______ Small hand rake (garden cultivator)
- ______ Wash bottle
- ______ forceps
- ______ Zip-loc bags (10 per site)
- ______ Sample labels (Site, Date, Replicate)
- ______ Preservative (Formaldehyde recommended)

<u>Qualitative sampling</u>

- ______ Aerial net
- ______ D-frame kick net
- ______ enamel pan
- ______ small bottles with ethanol
- ______ rag paper for labels

IV. Macroinvertebrate Sample Processing

- _____ Binocular dissecting microscope
- _____ Sieve
- _____ Ethanol
- _____ Beakers
- _____ Petri dishes
- _____ Fine forceps
- _____ Sorting tray
- _____ Vials for storage
- _____ Cardboard unit trays
- _____ Tally counter