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Environmental Effects of Western Coal Surface Mining

Part VIII
Fish Distribution in Trout Creek, Colorado 1975-1976

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ENVIRONMENTAL EFFECTS OF WESTERN COAL SURFACE MINING
PART VIII - FISH DISTRIBUTION IN TROUT CREEK, COLORADO, 1975-1976

by

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FOREWORD

This eighth report in a series discusses the impact of surface coal mining in a Colorado stream. The mining activity is composed of both old and new operations. No striking effects of the mining operation were identifiable within the resolution of the study and natural variation. Other reports will supply data on the chemical characteristics of the water quality.

Norbert Jaworski, Ph.D
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ABSTRACT

A study was conducted on Trout Creek in northwestern Colorado during 1975-1976 to assess the effects of drainage from an adjacent surface coal mine on the distribution of fishes in the creek, and to relate their distribution to physical and chemical variables. A second objective was to determine the possible toxicity of surface coal mine drainage water on fish stocked in ponds receiving surface and groundwater run-off from the mine.

Results did not indicate any direct effects of mine drainage water on the distribution of fishes in Trout Creek, although possible effects may have been masked by elevation, stream flow, streambed alterations, and agricultural irrigation return flows. Brook trout (*Salvelinus fontinalis*) was the dominant salmonid species in the upper reaches of the creek; rainbow trout (*Salmo gairdneri*) and brown trout (*S. trutta*) were found only in the region of the mine. Mottled sculpin (*Cottus bairdi*) and speckled dace (*Rhinichthys osculus*) were the most common fishes found throughout and at all but the uppermost reaches, respectively.

Rainbow trout stocked in mine seepage water ponds for a year evidenced high survival rates over an eight-month period during the winter, but fared poorly during the ensuing summer months, this latter most probably because of extremely high water temperatures. There was no apparent evidence of toxicity to the fish from contaminants in the mine pond water.

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SECTION I

INTRODUCTION

The Edna Coal Mine near Oak Creek, Colorado, lies in the watershed of Trout Creek, a montane stream draining Colorado's Flattop Mountains. Elevation in the study area ranged from 1,980 to 2,440 m. The stream is classified as rithron (mean monthly temperature less than 20°C) owing to its small size, high elevation, and water source primarily from snowmelt runoff. Fish in Trout Creek show a longitudinal zonation of species typical of many mountain streams (Holton 1953, Vincent and Miller 1969, Allen 1969, Moyle and Nichols 1973, Gard and Flittner 1974).

Primary agricultural uses of Trout Creek include livestock watering and pasture irrigation. Much of the lower third of this stream has been channelled to produce more arable land where oats, hay, and wheat are grown. Woody riparian vegetation is reduced in this area. The absence of streamside vegetation results in diurnal summer temperature ranges of about 7°C at the lower stations while the range at the upper stations is only 3°C.

The Edna Coal Mine is situated at approximately the midpoint of the study area. Surface runoff from the most recently active portion of the mine enters Trout Creek from a ditch draining a final-cut strip-pit. Drainage from the older mining area joins an irrigation ditch and enters Trout Creek several hundred meters upstream from a ditch which drains the most recent mining area.

The primary objective of this study was to determine the distribution of fish species in Trout Creek, relative to the Edna Coal Mine, and to relate these distributions to the physical and chemical parameters existing in the stream. Sampling stations were chosen to include sites both above and below the mine. A secondary objective was to determine the toxicity of undiluted coal mine drainage water to rainbow trout (*Salmo gairdneri*).

SECTION II

CONCLUSIONS

The number of rainbow trout and brown trout (*Salmo trutta*) in Trout Creek was maximal at the level of the Edna Coal Mine. This relationship is probably a result of these two species responding to a metabolic temperature optimum at the level of the mine. Brook trout (*Salvelinus fontinalis*) did not show a similar optimum, but increased in numbers with elevation and were predominant in numbers at the upper station. Over their range in Trout Creek, they apparently preferred temperatures in the range of 12-14°C, as opposed to 12-23°C for rainbow and brown trouts.

It was not possible to demonstrate direct effects of the Edna Coal Mine on the distribution of fishes in Trout Creek because of other man-induced alterations in the mining area. The potential coal mine impact area contained irrigation diversions, channelled areas, and irrigation return flows. This problem was further complicated by the fact that the coal mine is located along the stretch of Trout Creek where the stream slope flattens distinctly.

Effluent from the Edna Coal Mine was not acutely toxic to rainbow trout. This was determined by *in situ* toxicity tests in ponds receiving drainage water from the mine site. These tests showed that some of the test fish survived as long as one year in the ponds.

SECTION III

RECOMMENDATIONS

Mining procedures which minimize impacts on Trout Creek such as stabilization of spoils banks by contouring and planting should be followed. Drainage from the Edna Coal Mine to Trout Creek would be most detrimental to the fishery when carrying a significant load of suspended solids. To minimize this impact, service roads which ford Trout Creek should only be constructed when no alternative route is available. The absence of strip-mining in the alluvial valley of Trout Creek is the single most important benefit of current mining practice toward reduction of adverse effects upon the stream. Encroachment of the mine into the valley would increase the silt load of the stream and its bed. This would reduce both the feeding and spawning habitat available to fish.

Fraser (1972) states that a flow of 60 percent of the mean annual flow is considered by some to be the minimum amount necessary to maintain a viable fishery. Unpublished data from David B. McWhorter (Department of Agricultural Engineering, Colorado State University) show a mean annual flow of 1.12 m^3/sec at the Homestead station. On 28 July 1976 the flow at this station was 0.40 m^3/sec or 60 percent of the recommended flow for trout during this critical warm water period. Benefits from further withdrawals of water from this stream should be weighed against an anticipated adverse effect on the fish populations described in this report.

SECTION IV

DESCRIPTION OF THE STUDY AREA AND SAMPLING SITES

STUDY AREA

The area has been previously described by Bass *et al.* (1955) and McWhorter *et al.* (1975). A summary of those descriptions follows.

Physical Characteristics

The study area lies in northwestern Colorado in the southeastern portion of a gently rolling, 2,590 km^2, coal mining region known to the industry as the eastern part of the Yampa coal field. The climate is semiarid with an annual precipitation of 38 to 51 cm; at least half of this occurs as snow.

Trout Creek is west of the town of Oak Creek and southwest of Steamboat Springs (Figure 1). It originates in a mountain region at an elevation in excess of 3550 m, runs several kilometers through national forest, enters a small valley containing Pittsburgh and Midway's Edna Mine, and continues northward to its confluence with the Yampa River near Milner, Colorado. At the higher elevations above the mine, the land is largely vegetated with trees and native grasses. In the valley, vegetation changes to native grasses and some alfalfa fields. Stock ranches utilize the land across the creek from the mine and downstream.

It may be noted in Figure 1 that mining started on the upstream side in the World War II era. Although the strata disrupted by mining in the older area have not been regraded to their original aspect, the area is sparsely vegetated in native scrubbrush (oak) and grasses. Mining operations then moved progressively north, reaching the northern extreme around 1970; these latter were the first spoils to be regraded to the original contours and are now partially vegetated with native plants. Current activity is centered on the upslope (east) side of the mine near the top of the ridge separating the Oak and Trout Creek watersheds.

The area mined during the 1950's includes a bowl-shaped cut, about 200 m^2 x 30 m deep, near the base of the spoils that is barren of vegetation. With this exception, the density of native vegetation is approximately proportional to the age of the spoil material.

The surface material of the previously mined areas is composed largely of mine overburden which is the only soil layer above bedrock. Below the surface, which is graded only in the northern end of the mine, the overburden consists of debris ranging in size from that associated with clays to rocks

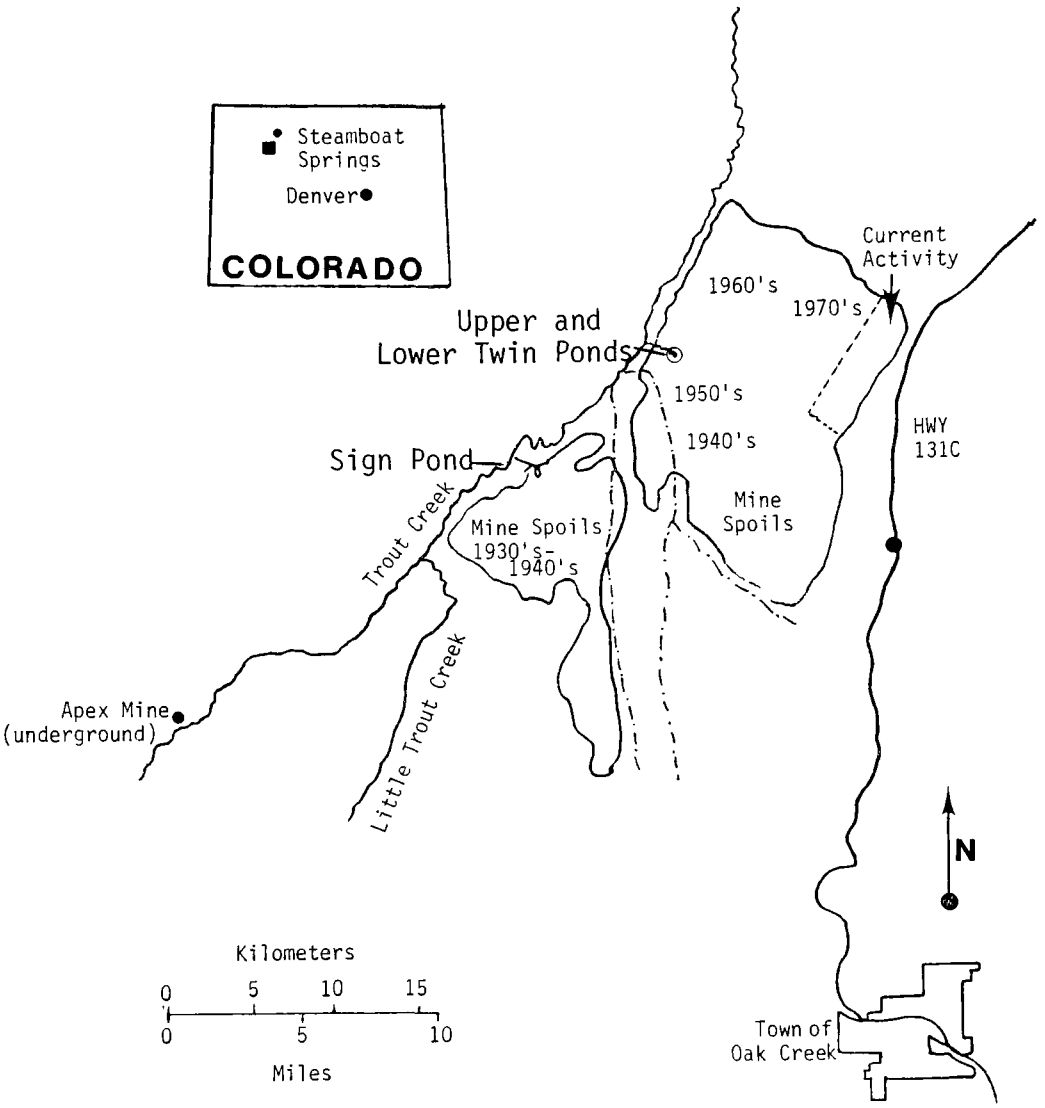

Figure 1. Location map of the Edna Mine study site. (Inset indicates location in Colorado.)

1 m in diameter. This material normally ranges from 10 to 20 m in depth and represents a marked contrast to the relatively well-sorted soils and strata present prior to mining. The mine is typically separated from the creek by approximately 50 m of undisturbed area which serves to some extent as a buffer zone through which mine drainage must pass.

Hydrology

Trout Creek is the major drainage of the 110 km^2 watershed which includes the mine. The hydrology of this drainage has been characterized by McWhorter *et al.* (1975). The mean annual discharge measured just below the mine has been estimated at 2.8×10^7 m^3/year. This is approximately equivalent to a precipitation of 26 cm/year over the watershed. The surface water divides in the area coincide generally with the topographic highs. In the spoil areas, the surface drainage patterns are disrupted in several areas such that precipitation tends to accumulate in depressions and infiltrate into spoils with little or no overland flow. Thus, a high fraction of the precipitation is lost by evapo-transpiration or infiltration into the ground. It is clear that mining has changed the surface and subsurface drainage patterns; this can be inferred from Figure 2. The depth to which water can percolate has been generally changed from a few meters to more than 15-20 m; this increases the potential for the dissolution of spoil materials by water. Although a highwall of undisturbed rock exists between the mine and the creek, at least a small amount of subsurface flow from the mine through the alluvial aquifers and into the creek occurs (McWhorter *et al.* 1975). The quantity of this underflow is not known. Small drainages enter the creek from the ranch area opposite the mine but their contribution to the total inflow is small. In general, the major inflow contributions to the stream originate on the mined site.

SAMPLING SITES

Eleven stations on Trout Creek proper and one on its tributary, Fish Creek, were sampled in the summers of 1975 and 1976. Site locations are shown in Figure 2. Four of the Trout Creek stations were also sampled in the fall of 1975. Bear River, a nearby tributary to the Yampa River, was also sampled to determine if this river contained fish species not present in Trout Creek. No species, not already present in Trout Creek, was found so the Bear River was not sampled after the summer of 1975. The eleven stations on Trout Creek and the one station on its tributary, Fish Creek, are described below.

Routt station.--Located just inside the boundary of the Routt National Forest. The riparian vegetation is a dense stand of willows and conifers. The stream bottom is composed primarily of medium to large cobble.

Apex station.--Adjacent to the county road, approximately 3 km upstream from the Apex mine--a small coal adit supplying private consumers. The stream is partially protected by a canopy of willow (*Salix* sp.) and cottonwood (*Populus angustifolia*). At this station the stream bottom is primarily gravel. Habitat is mostly riffle with a few deep pools interspersed.

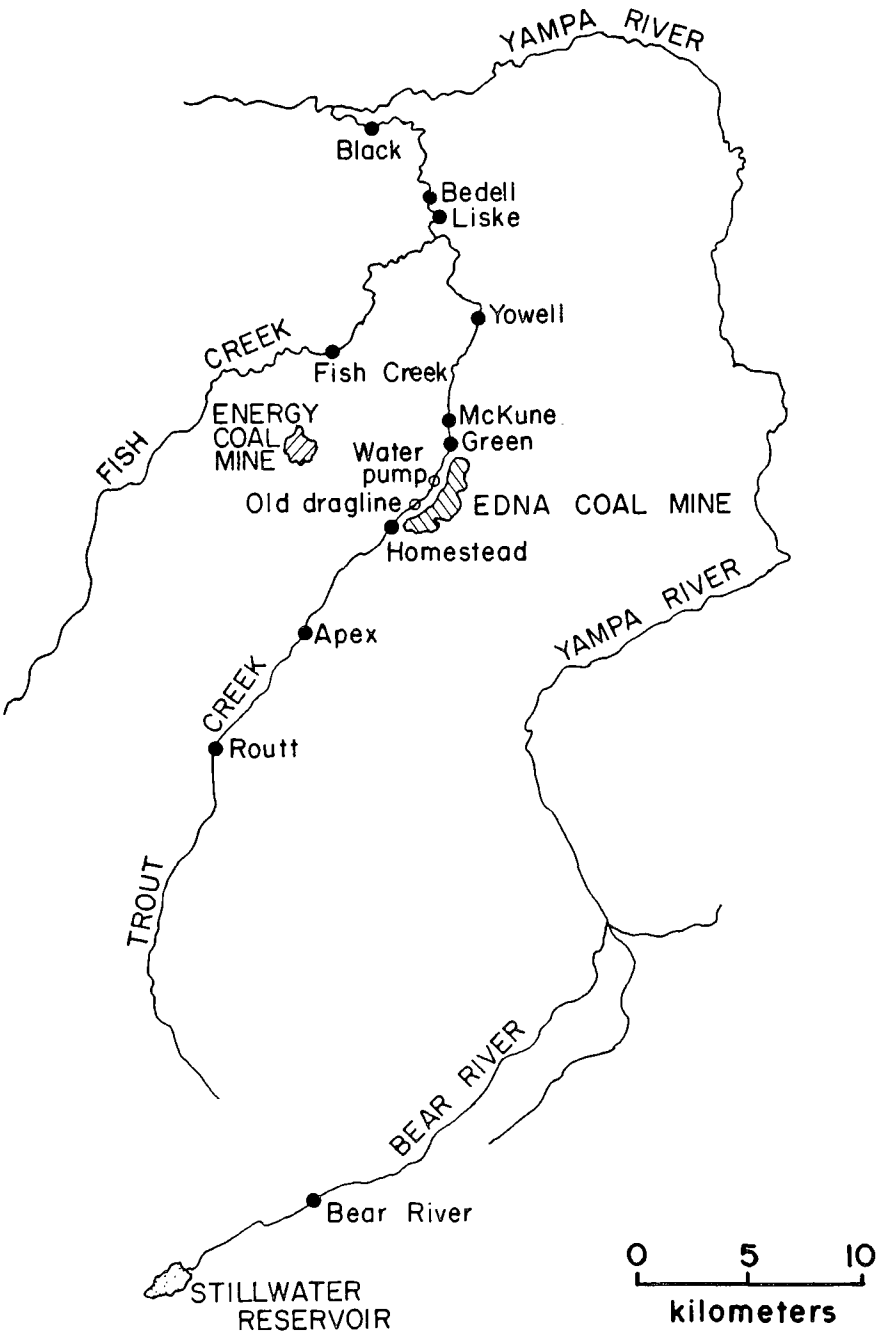

Figure 2. Fish sampling stations on Trout Creek, Colorado

Homestead station.--Directly across from the beginning of the oldest coal mining area. At the center of this section, an irrigation ditch diverts water east to a pasture. The bottom type is gravel. Willows border the east bank, and the west bank is vegetated with grass.

Dragline station.--Located about 0.5 km north of an obsolete dragline, this consists of a mixture of deep pools and short riffles. Riparian vegetation is mostly grass with some willows. An irrigation headgate diverts water from the upper limit of this section and a portion of diverted water re-enters Trout Creek near Pump station. The primary bottom type is gravel.

Pump station.--A gasoline-powered water pump is located at this station and is used to transfer water from a pool to tank trucks. Surface drainage from the most recent mining area enters Trout Creek near this pump. In 1976 a ford was graded across this section of stream, ostensibly as a service road for power lines. Gravel was the principal bottom constituent. The entire section was bordered by a dense growth of willows.

Green station.--Located on the property of Perley Green. The station was relocated slightly in 1976 to accommodate a beaver dam which caused water levels to rise too high for electrofishing. Riparian vegetation is largely pasture types with some willows in the upsteam half. More sandy bottom was found here than at any other station.

McKune station.--Streambank cover is of moderate density here and much of the stream is bordered by pasture. Stream bottom cover in the form of boulders or cobble is lacking as well. Narrow portions along this section are swept clean of alluvium, and the bottom is primarily bedrock.

Yowell station.--Riffles predominate here, with only one large pool found along the 200 m sampled downstream from the county road bridge. The bottom is composed of cobbles and gravel. Riparian vegetation consists almost entirely of grasses.

Liske station.--This station, and those below it, are characterized by low gradients and streambed channelization. Good fish cover in these areas is largely lacking with the exception of some undercut banks. Bottom type is principally gravel with sandy material in the deeper water. Riparian vegetation is entirely legume-type hay.

Bedell station.--The upstream limit of this station is the county road bridge crossing Trout Creek north of the Bedell ranch. Channelization is more extensive at this station than at any other. The stream is bordered by a small grain field to the east and riparian vegetation is absent. The stream bottom is sand and gravel.

Black station.--Located at the first bridge crossing Trout Creek from Milner, Colorado, the station consists of a series of deep pools broken by occasional short riffles. The bottom is a mixture of alluvial deposits ranging from sand to large cobble. Deciduous trees border the right bank.

Fish Creek station.--This one station on Trout Creek's only permanent tributary, Fish Creek, was sampled for species composition. It is bordered by hay and small grain fields at an elevation of 2,060 m. The bottom is small gravel and sand.

SECTION V

METHODS

PHYSICAL FACTORS

Flow, velocity, and discharge were measured at three points along a transverse section at each station, after the methods of Robins and Crawford (1954). Specific conductance (expressed as μmhos/cm) was measured in the stream by use of an Industrial Instruments Solu Bridge. Temperatures were corrected to predicted noonday values using a measured 8 to 9 hour daylight temperature pulse of 0.7°C/hour and 0.4°C/hour for unshaded and shaded stations, respectively. Slopes were calculated from elevations recorded on U.S. Geological Survey topographical maps (7.5 minute series).

FISH POPULATION ESTIMATES

Fish populations were sampled using backpack electrofishing equipment. Three successive passes were made through each 200 m station. Fishes captured during each of three passes were identified, counted, measured, and released. The DeLury regression method (Lagler 1952) was used to estimate population sizes for each species at each station. Population estimate plots were unsuitable in some cases because of positive slopes or very low catches on the final pass. In these instances, the total catch was considered to be the best estimate of the population.

IN SITU TOXICITY TESTS

Three ponds, consisting of strip-pits filled with mine runoff water, are located at the Edna Coal Mine. The first pond (Sign Pond) is located in the older series of strip pits which were mined about 30 years ago. The other two ponds (Upper and Lower Twin Ponds) are at the base of a strip pit which drains a relatively recent mining area. These ponds are separated by a coal dam. Upper Twin Pond has no outlet, but Lower Twin Pond drains into Trout Creek via a small ditch.

Between 25 and 70 rainbow trout were stocked on each of two occasions in each of these ponds, first in the fall of 1975 and again in the spring of 1976. Various fin clips were used to distinguish between these groups. Trout averaged 119 mm at the time of stocking. Planted trout were recovered by seining and gillnetting one month after stocking in the fall of 1975, again in the spring of 1976, and in the fall of 1976. Water samples were collected from each pond at time of stocking in September 1975 and analyzed for specific conductance, hardness, dissolved oxygen, and alkalinity using procedures described in American Public Health Association *et al.* (1971).

SECTION VI

RESULTS

Ten species of fish were observed in Trout Creek during the three sampling periods as follows: mountain whitefish (*Prosopium williamsoni*), cutthroat trout (*Salmo clarki*). rainbow trout, brown trout, brook trout, speckled dace (*Rhinichthys osculus*), redside shiner (*Richardsonius balteatus*), white sucker (*Catostomus commersoni*), mountain sucker (*C. platyrhynchus*), and mottled sculpin (*Cottus bairdi*). Fish Creek contained speckled dace, redside shiner, and white sucker. In addition, the creek chub (*Semotilus atromoculatus*) and hybrids of the creek chub and the redside shiner were found in Fish Creek, but not in Trout Creek.

The occurrence of nine resident fish species (plus the mountain whitefish, which is a fall migrant) in Trout Creek was essentially the same both in 1975 and in 1976 (Table 1). Trout populations were relatively stable, the only significant exceptions being an increase in rainbow trout at the Homestead station in 1976 (possibly due to stocking directly upstream in the fall of 1975) and a decrease in brook trout at the Apex station. The estimated numbers of redside shiner and speckled dace varied more than the trout at the various stations between 1975 and 1976. In 1976 the redside shiner showed higher populations at the lower stations than in 1975. The number of dace showed no trend in location selection; they declined at some stations, and greatly increased at others. The Liske station, in particular, showed a sharp increase in the number of speckled dace, white suckers, and mottled sculpins in 1976. The number of mountain suckers declined considerably at the Green station by 1976. The numbers of mottled sculpin varied in much the same manner as the speckled dace, increasing sharply at some stations in 1976 and declining sharply at others, with no apparent relation to elevation. With the exceptions of mottled sculpins and brook trout, populations of the other species tended to be maximum at some point along Trout Creek with declining numbers both upstream and downstream from this point.

FALL 1975 SAMPLING

Sampling was conducted at Black, Bedell, Green, and Apex stations (Table 2). Surface ice formed on Trout Creek on 25 October, preventing sampling at other stations. Mountain whitefish were taken during fall sampling of Trout Creek, but were not observed in summer sampling. One rainbow trout was captured at the Black station. Green station (~25 km upstream) was the nearest station where rainbow trout were recovered during summer. Fall distribution of brook trout was approximately the same as in summer. The temperature decline in Trout Creek during the fall does not appear to influence the range of brook trout.

Table 1. Estimated numbers of fish per 200 meters of Trout Creek at various sampling stations during late summer of 1975 and 1976.

Station	Year	Cutthroat trout *Salmo clarki*	Rainbow trout *Salmo gairdneri*	Brown trout *Salmo trutta*	Brook trout *Salvelinus fontinalis*	Speckled dace *Rhinichthys osculus*	Redside shiner *Richardsonius balteatus*	White sucker *Catostomus commersoni*	Mountain sucker *Catostomus platyrhynchus*	Mottled sculpin *Cottus bairdi*
Black	1975	0	0	0	0	2	0	8	0	1
	1976	0	0	0	0	69	11	1	0	6
Bedell	1975	0	0	0	0	10	1	3	1	4
	1976	0	0	0	0	82	25	9	1	78
Liske	1975	0	0	0	0	61	0	0	0	18
	1976	0	0	0	0	1,031	21	84	2	855
Yowell	1975	0	0	0	0	675	32	4	9	162
	1976	0	0	0	0	166	1	1	0	13
McKune	1975	0	0	0	0	85	1	0	1	72
	1976	0	0	0	0	549	1	1	5	38
Green	1975	0	1	2	0	450	25	4	67	231
	1976	0	1	1	0	96	1	0	3	38
Pump	1975	0	16	2	0	56	25	0	5	86
	1976	0	13	1	0	46	1	3	11	53
Dragline	1975	0	8	3	0	26	2	4	16	54
	1976	0	8	5	1	131	0	0	7	175
Homestead	1975	0	2	8	1	26	0	0	7	354
	1976	0	24	11	2	63	0	0	15	203
Apex	1975	0	4	3	70	1	0	0	11	128
	1976	0	1	1	3	0	0	0	0	162
Routt	1975	1	0	0	80	0	0	0	0	206
	1976	1	0	0	103	0	0	0	0	217

Table 2. Number of fish collected in one electrofishing pass at four stations on Trout Creek, 22-23 October 1975.

Species	Sampling station			
	Black	Bedell	Green	Apex
Mountain whitefish *(Prosopium williamsoni)*	8	2	0	0
Rainbow trout *(Salmo gairdneri)*	1	0	0	3
Brown trout *(Salmo trutta)*	0	0	3	0
Brook trout *(Salvelinus fontinalis)*	0	0	0	9
Redside shiner *(Richardsonius balteatus)*	0	2	0	0
Speckled dace *(Rhinichthys osculus)*	1	27	5	1
White sucker *(Catostomus commersoni)*	1	4	1	0
Mountain sucker *(Catostomus platyrhynchus)*	0	2	0	2
Mottled sculpin *(Cottus bairdi)*	2	35	55	15

PHYSICAL FACTORS

Discharge, specific conductance, velocity, and noon-corrected temperature were measured at the time of fish sampling during 1975 and 1976 (Table 3). Discharge was considerably lower in the second year at all stations below Apex. The two upper stations, Apex and Routt, had nearly identical flows in 1975 and 1976. The reduced flows recorded at stations below Apex were the result of increased irrigation during this relatively dry year. Physical conditions in Fish Creek were similar in 1975 and 1976; discharge rates in Fish Creek were 0.09 and 0.11 m^3/sec, and specific conductivities were 1,000 and 1,200 μmhos/cm, respectively.

FISH CREEK SAMPLING, SUMMER 1975 AND 1976

Speckled dace, redside shiner, and white sucker, common to both Trout and Fish Creeks, were recovered during summers 1975 and 1976. Creek chubs, not found in Trout Creek, were recovered during the 1976 sampling period in Fish Creek. Also, several creek chub/redside shiner hybrids were observed in Fish Creek (identification by Darrel Snyder, Dep. Fishery and Wildlife Biology, Colorado State Univ., Fort Collins). The recovery of all species was greater in 1976.

IN SITU TOXICITY TESTS

The results of the experimental stocking of rainbow trout in strip pits of the Edna Coal Mine are summarized in Table 4, and physical characteristics measured at time of stocking are listed in Table 5.

In October 1975, one month after stocking, the number of fish recaptured and removed from Lower Twin Pond was 75 percent of those stocked, and for Sign Pond it was 20 percent; several fish were observed in Upper Twin Pond, but none removed. In May 1976, eight months after stocking, there was 56 percent recovery of possible remaining fish in Lower Twin Pond and 48 percent recovery in Upper Twin Pond; no fish were recovered from Sign Pond.

At the time of the May 1976 harvest, 50 additional fish were stocked in each pond, and all three ponds were netted or seined in September 1976. One fish from the May 1976 stocking was recovered in each of Lower Twin Pond and Sign Pond, and no fish were recovered from the September 1975 stocking. Four fish were recovered in Upper Twin Pond from the September 1975 stocking, and none from the May 1976 stocking.

Table 3. Physical characteristics of Trout Creek during fish sampling periods in late summer, 1975 and 1976.

Station	Elevation (m)	Distance from mine (km)	Slope (%)	Date (day/ month/ year)	Discharge (m^3/sec)	Specific conductance (μmhos/cm)	Surface velocity (cm/sec)	Noon-corrected temperature (°C)
Black	1,975	-25.3	0.22	30/7/75	1.33	640	49.5	18.0
				31/7/76	0.39	925	26.5	26.0
Bedell	1,987	-19.6	0.19	31/7/75	1.43	650	59.6	18.0
				30/7/76	0.39	1,000	38.7	24.0
Liske	1,999	-18.0	0.19	31/7/75	1.40	650	71.5	19.5
				31/7/76	0.41	900	29.2	20.5
Yowell	2,048	-8.0	1.00	17/8/75	0.71	500	63.8	16.0
				29/7/76	0.32	645	41.0	21.5
McKune	2,085	-5.6	1.10	1/8/75	1.04	500	49.3	15.5
				22/7/76	0.26	750	35.4	17.0
Green	2,109	-2.2	1.02	19/8/75	0.80	480	86.2	12.5
				21/7/76	0.43	480	18.3	17.0
Pump	2,158	0.0	1.37	5/8/75	0.72	480	34.2	23.0
				27/7/76	0.50	480	28.7	19.0
Dragline	2,170	0.0	1.46	6/8/75	0.89	400	72.1	14.0
				29/7/76	0.42	440	46.2	15.0
Homestead	2,195	0.0	1.24	15/8/75	0.90	320	66.2	13.5
				28/7/76	0.40	410	28.9	15.0
Apex	2,316	+6.4	1.96	7/8/75	0.96	380	60.5	14.5
				21/7/76	1.00	380	68.3	12.0
Routt	2,487	+13.0	3.43	16/8/75	0.83	180	54.7	9.5
				19/7/76	0.80	180	52.3	12.0

Table 4. Percentages of rainbow trout recovered from coal mine strip pit ponds.

Strip Pit Pond	Percent Recovery[a] (Date--Month/Year)		
	(10/75)	(5/76)	(9/76)
Lower Twin Pond			
9/75 Stocking	75	56	0
5/76 Stocking	--	--	2
Upper Twin Pond			
9/75 Stocking	NS[b]	48	8
5/76 Stocking	--	--	0
Sign Pond			
9/75 Stocking	20	0	0
5/76 Stocking	--	--	2

[a] Percentages are based on maximum possible number of fish remaining after stocking or after prior sampling.

[b] Not sampled.

Table 5. Physical and chemical characteristics of three experimental strip pit ponds used for rainbow trout plantings. (Samples taken 24 September 1975.)

Pond name	Width × length (m)	Mean depth (cm)	Specific conductance (μmhos/cm)	Dissolved oxygen (mg/liter)	Hardness (mg/liter as $CaCO_3$)	Alkalinity (mg/liter as $CaCO_3$)
Sign	26 × 36	30-60	4,000	8.1	2,368	96
Upper Twin	17 × 25	24	4,025	7.6	2,868	156
Lower Twin	9 × 38	46	4,050	7.9	2,544	214

SECTION VII

DISCUSSION

LONGITUDINAL ZONATION

Studies of fish distribution in two western streams comparable to Trout Creek are reported in the literature. Gard and Flittner (1974) examined the distribution of fish in Sagehen Creek, California (Figure 3). This stream is approximately the same size as Trout Creek. Its gradient is much steeper in the upper reaches than the section of Trout Creek we sampled, although the mean elevation is lower than Trout Creek. The second stream studied, which was of comparable size and elevation to Trout Creek, is Little Beaver Creek, Colorado (Vincent and Miller 1969). Like Sagehen Creek, Little Beaver Creek has a steeper gradient than Trout Creek; however, unlike Sagehen Creek its elevation is higher than the Trout Creek study area.

The following fish were common to both Trout Creek and Sagehen Creek: Mountain whitefish, rainbow trout, brown trout, brook trout, speckled dace, and mountain sucker. The other species found in Trout Creek, redside shiner, white sucker, and mottled sculpin were congeners of species found in Sagehen Creek, namely lahontan redside (*Richardsonius egregius*), Tahoe sucker (*Catostomus tahoensis*), and piute sculpin (*Cottus beldingi*). The greatest physical differences between the three streams are temperature and gradient.

Figure 3 illustrates the correspondence between the relative occurrence of the fish species in these similar, though geographically distant streams. The elevation at which a particular species was found differed among the three streams. Sculpins and brook trout co-dominate in the upper reaches of Trout Creek. Mottled sculpins occur below the brook trout zone in Sagehen Creek and are not reported in Little Beaver Creek.

SIMPLE LINEAR COEFFICIENTS OF DETERMINATION

Nonlinear models are frequently more representative of the relationship between number of fish and physical factors. However, Gard and Flittner (1974) have used first-order linear models to describe these relationships in Sagehen Creek, California.[1/] In order to compare the results obtained in the present study with those of other authors, linear regressions were computed for the independent variables, elevation, temperature, conductivity, velocity,

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1/ When fitting multivariate models to data by regression methods, linear models are not without merit when computer time and number of observations are limited. Also, the number of independent variables included in the model increases both the amount of computer time and the required number of observations.

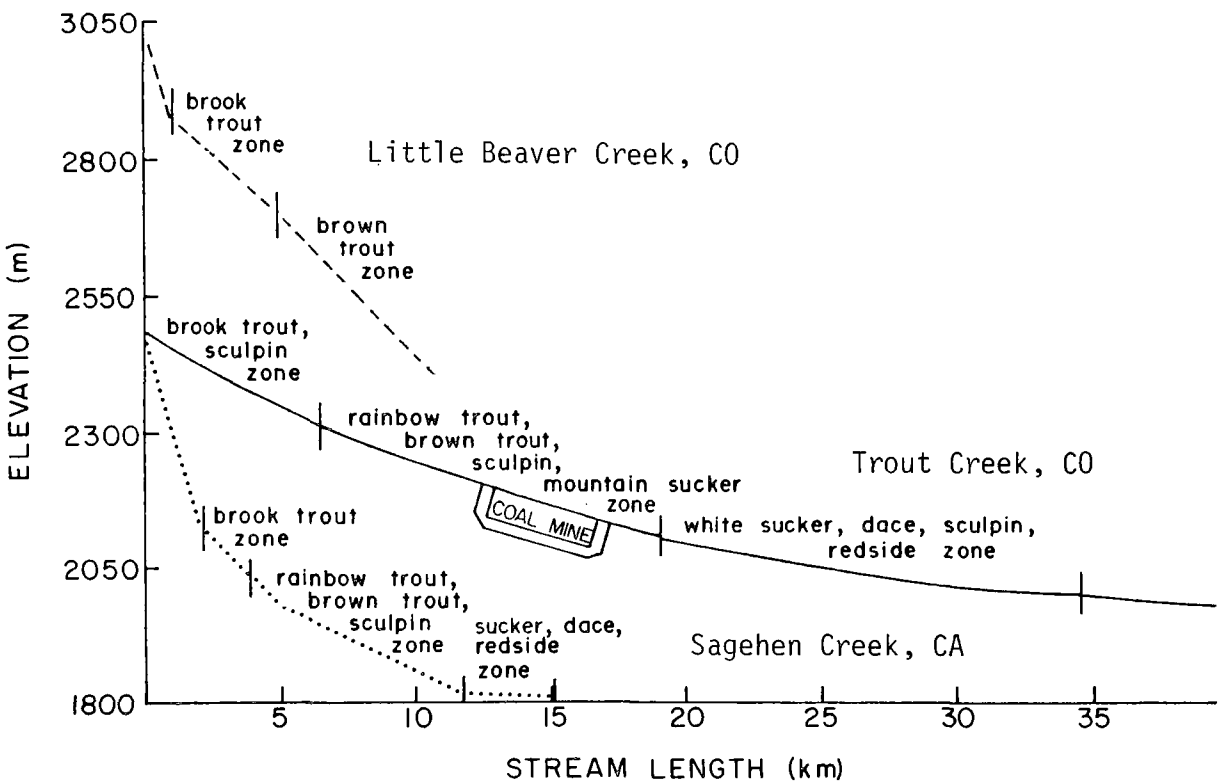

Figure 3. Longitudinal profile of three western mountain streams and the zonation of fish species in these streams. [Little Beaver Creek, Colorado, from Vincent and Miller (1969); Sagehen Creek, California, from Gard and Flittner (1974); Trout Creek, Colorado, from Goettl and Edde (present report).]

discharge, and gradient versus the dependent variables, populations of the various fish species. Only brook trout were significantly ($\alpha = 0.05$) correlated with any of the physical factors in a linear manner. The coefficients of determination (r^2) calculated for this species versus gradient and elevation were 0.65 and 0.67, respectively. The highest value of multiple (four parameters) r^2 calculated by Gard and Flittner (1974) were for brook trout in Sagehen Creek. Here gradient and temperature were considered to be the most important factors measured in controlling brook trout numbers.

The apparent downstream shift of redside shiners in Trout Creek during the low flows of 1976 was examined by calculation of the linear regression of differences in redside shiner numbers at each of the stations (1975 minus 1976) versus the differences in discharge (1975 minus 1976) noted at these same stations.

The coefficient of determination for this regression ($r^2 = 0.88$) indicated a fairly strong inverse relationship between the change in redside shiner numbers and the change in discharge. This species was usually found in sheltered areas of the stream and may be displaced by high flows and strong currents. Gard and Flittner (1974) noted that redside shiners were often found near the surface of larger pools, while dace, an associated species, were generally found in and near riffle areas.

Mountain whitefish were captured in Trout Creek only in the fall and only at the lower stations (Table 2). Brown (1952) states that this species migrates into lower reaches of small tributaries during fall for spawning: Donald Horak (Colorado Division of Wildlife, Fort Collins, personal communication) recovered gravid mountain whitefish as small as 229 mm, although the more common length at sexual maturity is 254 to 279 mm (Sigler and Miller 1963). The largest mountain whitefish captured in Trout Creek was 120 mm. The absence of this fish during August sampling of 1975 and 1976 indicates that these presumably immature fish were fall migrants and their upper limit of distribution indicates they were probably upstream migrants.

Cutthroat trout were found only at the highest station on Trout Creek. One individual was captured at this station during both 1975 and 1976, though not the same fish as shown by fin clipping. Cutthroat trout are the only native trout in Colorado. McAfee (1966) points out that they compete poorly with rainbow, brown, and brook trouts and are displaced by these species where they occur.

Rainbow trout were most numerous at the elevation of the Edna Coal Mine. Although elevation was the best predictor of rainbow trout abundance from the available data, it seems likely that its correlate, temperature, may have been the controlling factor in this relationship. Cherry *et al.* (1975) found that rainbow trout preferred temperatures which increased from 11.6 to 22°C as the acclimation temperature increased from 6 to 24°C. The range of temperatures preferred in these tests never exceeded 1.1°C for any one acclimation temperature. The range of noon-corrected temperatures recorded within the rainbow trout zone of Trout Creek was 12 to 23°C (Tables 1 and 3). This range is probably near the yearly maximum temperature for these stations, as the measurements were taken in July and August. These temperatures correlate

quite closely to those indicated above as preferred temperatures of rainbow trout. Temperatures greater and less than the preferred range of rainbow trout were recorded--at stations outside their observed range--in Trout Creek during summer sampling. It is possible that thermal limitations are imposed on rainbow and brown trouts outside their ranges. That is, reduced feeding or metabolic efficiencies may cause these species to be relatively uncompetitive outside their "thermal optimum" (Li 1975). Using first-order models, Gard and Flittner (1974) found that among the variables they measured (elevation, gradient, percentage pool, and temperature) elevation was the best predictor of rainbow trout abundance. Although we strongly suspect temperature as the controlling variable in rainbow and brown trout abundance, we too have chosen elevation as the best predictor of their numbers. It is quite possible that elevation is a better indicator of mean temperature than temperature itself, given the infrequency of temperature measurements on Trout Creek.

Holden and Stalnaker (1975) have noted movement of rainbow trout into the Yampa River (Trout Creek's receiving stream) from the Green River, apparently in response to cooling of the Yampa River in the fall. Rainbow trout were recovered in the lower reaches of Trout Creek near the Yampa River only during fall sampling when water temperatures were much lower. The behavior of this species appears to be influenced by temperature more than any other species in Trout Creek.

Unlike the rainbow and brown trouts, brook trout did not show a population maximum over the range of stations measured in Trout Creek, but increased in abundance with altitude (Table 1). Vincent and Miller (1969) found no upper altitudinal limit for brook trout in Little Beaver Creek, Colorado. Only extremely low flows (0.015 m^3/sec) limited brook trout in this stream at an elevation of approximately 2900 m. At the highest station, brook and cutthroat trouts occur, the former in much greater numbers. Gard and Flittner (1974) found that gradient and temperature were the most important predictors of brook trout abundance. Unlike Sagehen Creek, whose profile was a series of step-like slopes, Trout Creek shows a gradual, smooth profile, and the parameters elevation and slope are highly correlated.

PHYSICAL FACTORS

Discharge downstream from Apex station was considerable less in 1976 than in 1975 (Table 3). This decrease in flow was the result of increased irrigation at the level of the Edna Coal Mine during this relatively dry year. Temporal effects on this difference in flows seem unlikely as the Black, Bedell, and Liske stations were sampled on nearly the same dates during both years. Flows averaged 41 percent of the 1975 flow at the nine lowest stations in 1976. Along with the reduction in flows below the Apex station in 1976, there were increases in temperature and specific conductance at all stations except the Green station, and with respect to specific conductance, the Pump station. The presence of reduced flows and elevated temperatures raises the question of whether the independent variables are related. Correlations are presented in Table 6. The positive correlation between specific conductance and temperature is probably due to the length of stream bed (including irrigation ditches and fields) over which the water has passed, thus elevating both temperature and specific conductance. The highest

Table 6. Coefficient of determination (r^2) matrix for physical parameters measured on Trout Creek during fish sampling.

	Noon-corrected temperature	Velocity	Conductivity	Discharge	Slope
Elevation	0.514	0.031	0.684	0.001	0.942
Slope	0.502	0.030	0.693	0.001	
Discharge	0.090	0.437	0.074		
Conductivity	0.692	0.147			
Velocity	0.310				

calculated r^2 value was for elevation versus slope--0.94. This result seems quite understandable, as Trout Creek shows a profile typical of a stream flowing over strata of uniform hardness, slowly leveling out as it approaches baseline at Yampa River. Both specific conductance and temperature increase in a downstream direction, each correlating well with elevation and slope. Flow does not increase much as one proceeds downstream (Table 3). It is clear that the magnitudes of the temperature and specific conductance increases are related to irrigation withdrawals. This conclusion might be questioned on the basis of data in Table 6 which show that the correlation of discharge and specific conductance has a quite low value of r^2. This relationship is complicated by the strong negative correlation of elevation and slope to specific conductance and temperature; i.e., both temperature and specific conductance increase in the downstream direction regardless of the overall volume of flow.

An allowance for decreasing elevation can be made by comparing the differences measured for each of the physical factors between the years 1975 and 1976 at each station. Coefficients of determination calculated for these differences are shown in Table 7. The values of r^2 show a change in discharge which is negatively correlated with changes in both temperature and specific conductance. Velocity is not as highly correlated with these variables, indicating the importance of the volume of water involved, which would tend to buffer both increasing specific conductance and temperature.

Jenke (1974) stated that irrigation diversion may produce return flow waters three to ten times higher in their dissolved solids content than the receiving stream from which the water had been originally diverted. This results from evaporative concentration of surface water and percolation into the local water table which displaces salt-laden water into the surface stream. He pointed out that return flows may also be aggravated by nonassociated sources such as natural salt, mining, and oil fields. Walker (1970) noted that approximately 10 percent of the total salinity in the Colorado River is added at Grand Valley, Colorado. Extensive irrigation in this area transfers water onto the surrounding alluvium, forcing water into the river from aquifers which are "in equilibrium with the ambient salt concentration."

In summary, the data collected during the summer of 1976 on Trout Creek, Colorado, indicate that both temperature and specific conductance increase in the downstream direction. The natural increase in these parameters at lower elevations is amplified by point source drainage from the Edna Coal Mine (the ditch draining Upper and Lower Twin Ponds and other small ditches) and by non-point sources such as percolation and infiltration from irrigation of the alluvium forming the valley of Trout Creek.

IN-SITU TOXICITY TESTS

Results of the *in-situ* toxicity tests indicate that the undiluted drainage from the Edna Coal Mine is not acutely toxic to rainbow trout. An escape route to Trout Creek was available to fish planted in Lower Twin Pond during the fall of 1975, but few, if any, fish died or left the pond within one month of stocking, since 75 percent recovery was achieved. No evidence of

Table 7. Coefficient of determination matrix showing values of r^2 calculated for regressions of differences (1975 minus 1976) in the stream physical factors measured on Trout Creek.

	Discharge	Velocity	Conductivity
Temperature	0.29	0.13	0.33
Conductivity	0.85	0.06	
Velocity	0.24		

dead fish was found during sampling, and all fish recovered were in apparently good condition.

Although there was no evidence of over-winter survival of fish in Sign Pond, the high percentage of over-winter survival (50 percent) in both Upper and Lower Twin Ponds is an indication that the mine water leachate itself was not accutely toxic. Further, although percentage of summer survival was extremely low, at least one fish did survive in each of the three test ponds.

Measured water chemistry parameters for all three ponds were comparable. During the winter months water levels in all three ponds remained fairly constant, and water exchange between the aquifer and the ponds was negligible. During the summer months, however, pond water levels dropped appreciably, and volumes decreased to an estimated 25 percent of these winter volumes. During latter summer, water temperatures rose to values most probably near the upper tolerance limits for rainbow trout. These factors, plus possible predation from great blue herrons (*Ardea herodias*) which were observed in the vicinity of the ponds, were most likely responsible for the high summer mortality rates of the stocked fish.

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16. ABSTRACT

A study was conducted on Trout Creek in northwestern Colorado during 1975-1976 to assess the effects of drainage from an adjacent surface coal mine on the distribution of fishes in the creek, and to relate their distribution to physical and chemical variables. A second objective was to determine the possible toxicity of surface coal mine drainage water on fish stocked in ponds receiving surface and groundwater run-off from the mine.

Results did not indicate any direct effects of mine drainage water on the distribution of fishes in Trout Creek, although possible effects may have been masked by elevation, stream flow, streambed alterations, and agricultural irrigation return flows. Brook trout (Salvelinus fontinalis) was the dominant salmonid species in the upper reaches of the creek; rainbow trout (Salmo gairdneri) and brown trout (S. trutta) were found only in the region of the mine. Mottled sculpin (Cottus bairdi) and speckled dace (Rhinichthys osculus) were the most common fishes found throughout and at all but the uppermost reaches, respectively.

Rainbow trout stocked in mine seepage water ponds for a year evidenced high survival rates over an eight-month period during the winter, but fared poorly during the ensuing summer months, this latter most probably because of extremely high water temperatures. There was no apparent evidence of toxicity to the fish from contaminants in the mine pond water.

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