Application of Physical Habitat Simulation in the Evaluation of Physical Habitat Suitability

By Robert T. Milhous

Chapter E21 of

Integrated Investigations of Environmental Effects of Historical Mining in the Animas River Watershed, San Juan County, Colorado

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Abstract

The suitability of physical habitat in the Animas River watershed for supporting trout populations was evaluated by analysis of field-collected data and historical information from U.S. Geological Survey and State of Colorado streamflow-gauging stations. A physical habitat suitability simulation model based on stream velocity, channel depth, discharge, and substrate character was used to evaluate the data. Results indicated that suitable habitat is limited during winter. Although low velocities required for suitable trout habitat may exist, the stream depths are too shallow to offer good habitat. The overall availability of suitable trout habitat in the river is low and adversely affects the probability of survival of adult fish. In addition, comparison of the Animas River conditions to data from a similar river system suggested that high snowmelt runoff events in the spring could impair reproductive success by scouring the redds (fish nests) during incubation, thus preventing emergence of juvenile fish. Effects of this high flow might be mitigated by the presence of cobble, boulders, or other types of cover occurring in the river. This reconnaissance study demonstrated that factors other than those related to mining practices could limit the success of a trout fishery.

Introduction

The Animas River in southwestern Colorado flows south to join the San Juan River near Farmington, N. Mex. The watershed study area of this volume is defined as the drainage areas of Mineral and Cement Creeks and the Animas River upstream from Silverton, Colo. (von Guerard and others, this volume, Chapter B). Typical of mountainous regions, the winters are cold with considerable snowfall and little snowmelt. Streamflows during the winter months remain low and reasonably stable; then from April through June snowmelt, runoff dominates streamflow.

Historically, only a few native fishes—including Colorado River cutthroat trout (*Oncorhynchus clarki pleuriticus*) and possibly mottled sculpin (*Cottus bairdi*)—occurred in the Animas River watershed study area. By the early 19th century, non-native species, including brook trout (*Salvelinus fontinalis*), rainbow trout (*Oncorhynchus mykiss*), and brown trout (*Salmo trutta*), had been introduced (Besser and others, this volume, Chapter D). Currently, fish distribution within the watershed is patchy, but brook trout are the most widespread species. Although contamination of water and aquatic sediment creates toxic conditions in many areas of the watershed (Besser and others, this volume; Besser and Leib, this volume, Chapter E19), the presence or absence of fish is also influenced by the quality and quantity of physical habitat in the stream.

Purpose and Scope

The availability of suitable physical habitat is a major factor influencing the success of a fishery in any aquatic environment. Habitat requirements for trout vary seasonally and may also be species specific. Traditionally, the assessment of physical habitat in a riverine environment requires exhaustive sampling of stream reaches during multiple seasons. The development of an effective reconnaissance-level approach for physical habitat evaluation would be useful for understanding population level responses in a watershed. Therefore, a reconnaissance study was designed to determine the suitability of trout habitat in the Animas River watershed. In this study, physical aquatic habitat, including stream velocities, depths, and the nature of the bed material, was evaluated at select locations in the Animas River watershed study area.

The two principal objectives of this study were:

- To improve understanding of the influence of mining-derived sediment on aquatic physical habitat, and
- To determine the utility of a reconnaissance-level physical habitat suitability model in assessment of the impacts of mining on the aquatic ecosystem.

Methods of Study

Fourteen sample sites were selected throughout the study area to characterize physical habitat (fig. 1). Samples of bed material were collected at each site; these included samples of the armor (defined as the space between and under rocks on the streambed surface where trout can take cover), the substrate, and the sand-sized and finer particulates deposited on the substrate surface. At selected sites, the stream morphology was also measured. These measurements included from one to three cross sections, the stream discharge, and the water surface elevations (depths). Discharge information generated at four U.S. Geological Survey discharge-gauging stations (sites 2–5, fig. 1) and one gauging station near Howardsville operated by the State of Colorado (site 1, fig. 1) was entered into a physical habitat simulation system (PHABSIM; Milhous and others, 1989). This model was developed to predict the habitat conditions in rivers as a function of discharge and to determine the relative suitability of those predicted conditions for aquatic life. The two basic components of PHABSIM are the hydraulic and habitat simulations of a stream reach using defined hydraulic parameters and habitat suitability criteria. Hydraulic simulation is used to describe the area of a stream having various combinations of depth, velocity, and channel index as a function of flow. Simulation of physical habitat is accomplished using the physical structure of the stream and discharge. This information is used to calculate a habitat measure called Weighted Usable Area for the stream segment from suitability information based on field sampling of the various aquatic species of interest. PHABSIM consists of four major steps. The first is to simulate water depths, the second is to simulate velocities, the third is to simulate the physical habitat versus discharge relationship, and the fourth is to simulate the physical habitat when combinations of flows are involved.

As used in this chapter, physical aquatic habitat is defined as the relationships between velocities, depths, and the nature of the bed material, weighted by the life history requirements of selected aquatic species. The equation relating the physical habitat area (HA) in a stream to discharge is:

$$HA = \int \mathrm{f}(v, d, ci)\, da \tag{1}$$

where

HA is the physical habitat area,
v is the velocity,
d is the depth,
ci is an index to the physical characteristics of the stream channel,

and

da is the incremental area.

The integration is over the area of a reach of stream. In most applications of PHABSIM, the function f( ) is divided into independent functions of velocity, depth, and the channel index. The function used in this equation is then:

$$\mathrm{f}(v, d, ci) = \mathrm{h}(v)^*\mathrm{g}(d)^*\mathrm{j}(ci) \tag{2}$$

where h(v), g(d), and j(ci) are independent functions among velocity, depth, and the channel characteristics, respectively. The physical habitat areas calculated are the habitats available for a life stage and species of aquatic animal weighted by how well the area meets the needs of the species. Examples of life stages are spawning, fry, juveniles, and adults. Factors other than physical habitat may limit aquatic populations; therefore, physical habitat alone is not always a good predictor of population size or strength. However, a self-sustaining population cannot exist in the absence of suitable physical aquatic habitat.

Results and Discussion

Physical Aquatic Habitat

The physical habitat criteria for different life stages of trout used in the PHABSIM analysis were developed during previous studies (Culp and Homa, 1991). However, the criteria for trout have been modified to include both brook and brown trout. The acceptable velocities for suitable habitat are about 0.15 m/s greater than in the original trout habitat criteria. Similar physical habitat criteria are available for benthic habitat suitability. For these criteria, benthic biomass area relates to the ability of the habitat conditions to support benthic invertebrates.

The physical habitat for trout and benthic invertebrates was related to annual discharge and the daily discharge at the gauge (site 1, fig. 1) during water year 1996 in the Animas River near Howardsville (fig. 2). The discharge data from Howardsville for water year 1996 were used in this figure because the median discharge (2.92 m^3/s) for the period of record (1936–1996) was similar to the average annual discharge for water year 1996 (2.89 m^3/s).

There are two periods during which trout may experience habitat stress resulting from habitat conditions being less than optimal. One of these periods occurs during high-flow conditions in the spring, and the second results from low-flow conditions in the winter.

High Streamflow Conditions

High velocities limit the availability of trout habitat during spring runoff (fig. 3). An index describing the stress on the trout population during the spring runoff period has been used to investigate the variation in stress from year to year. The conceptual basis of the stress index is that high velocities reduce the quality of the physical habitat, and that the more days the velocities exceed some critical value, the greater is

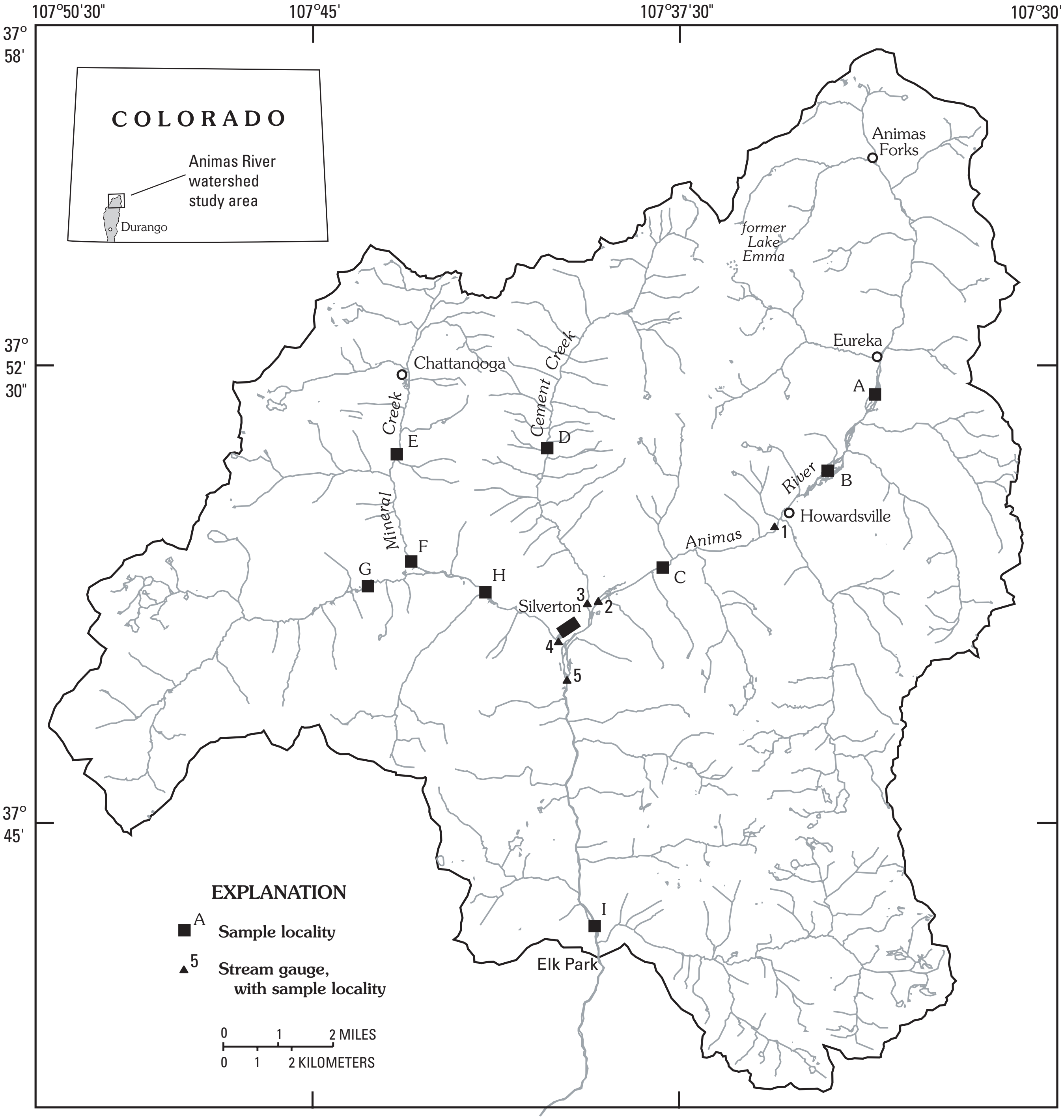

Figure 1. Locations of sample sites and stream gauges on principal streams in Animas River watershed study area. Locations (solid triangles) are designated numerically as follows: 1, Howardsville; 2, Silverton; 3, Cement Creek; 4, Mineral Creek; 5, Downstream from Silverton. Substrate samples were collected near the five gauges and at sites A–I.

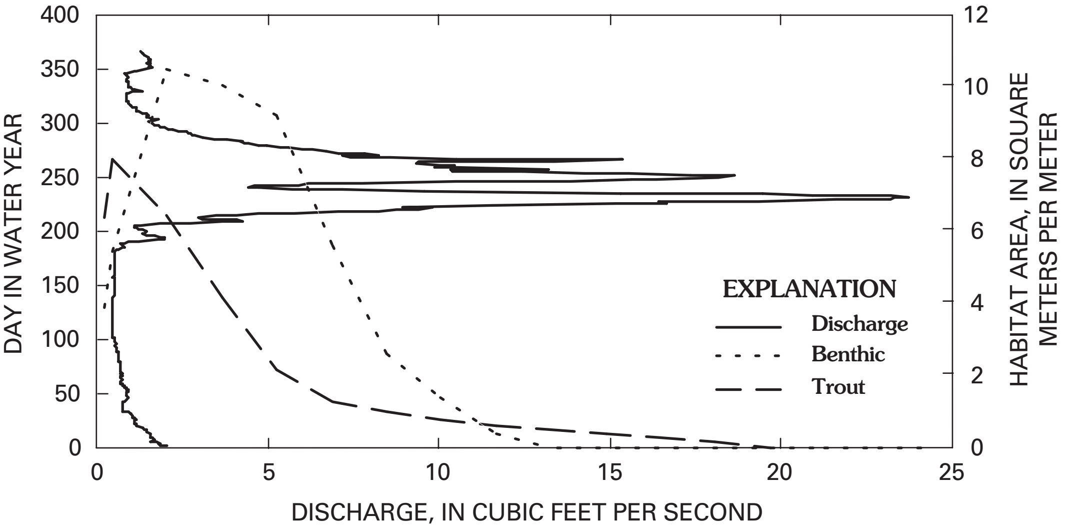

Figure 2. Daily streamflows from State of Colorado streamflow gauge at Howardsville during 1996 and the relation between habitat and discharge for trout and for total benthic invertebrate biomass in Animas River. (The Colorado State Engineer has operated this gauge since 1983; USGS operated it 1936–1982.)

the stress on the trout population in the stream. The equation used to calculate the stress on the trout population caused by high velocities is:

$$FSI = \Sigma((Qd - Qcrt)/Qref) \tag{3}$$

where

FSI is the Fish Stress Index for a selected time period (usually a year),

Qd is the daily discharge,

Qcrt is the critical discharge above which the stress on fish is significant,

and

Qref is an arbitrary reference discharge used to make the index dimensionless.

The summation is for a water year.

The discharge–habitat quality weighting function was used to determine the critical velocity. The assumption is that a suitability of 0.1 or less introduces stress to trout populations that could limit the size (either biomass or numbers) of the populations. A relation between the mean channel velocity and the discharge was determined using least absolute deviation regression. The equation is:

$$v_{\text{ARNH}} = 0.376(Q_{\text{ARNH)}})^{*}0.556 \tag{4}$$

where the *velocity, v*, is in m/s; the *discharge, Q*, is in m^3/s; and ARNH means Animas River Near Howardsville. From this relation the discharge at an average channel velocity of 1.1 m/s (suitability weight of 0.1) was determined to be 5.26 m^3/s and is the critical discharge (*Qcrt*) in equation 3. The reference discharge (*Qref*) selected for the calculations of the fish stress index was 3.0 m^3/s. The equation for fish stress index (*FSI*) is then:

$$FSI = \Sigma(Qd - 5.26)/3.0 \tag{5}$$

where the daily discharge, *Qd*, is in m^3/s and the summation is for a water year. Fish stress fluctuated greatly during the period of record (1936–1996) at the Howardsville gauge (fig. 4). Not included in the analysis is the reduction in stress on the trout population resulting from the presence of velocity cover (usually cobbles and boulders). The velocity cover provides areas of locally low velocity where the fish are sheltered from the overall high channel velocities.

Few fish population data are available for the Animas River. However, some data are available for the Gunnison River to the north of our study area. In the Gunnison River basin (fig. 5; table 1), the limiting factor on the production of juvenile trout is the fry habitat during the months just following the emergence of the fry from the gravels the previous year (Nehring and Miller, 1987). Rainbow trout spawn in the spring and incubate during the spring runoff; the fry emerge towards the end of the spring runoff. Flow conditions between spawning and emergence may play a critical role, as high flows can effectively scour the redds (nests) and reduce juvenile survival.

An example of the effect of flow conditions on trout production comes from a comparison of data from table 1 and regression lines in figure 5 (p. 882), which shows that in 1983 the expected production of fry (fig. 5) was five juveniles per hectare; instead, the measured production (table 1) was one. The lower than expected production may have resulted when the relatively low discharge during spawning was followed by a relatively high discharge during incubation, resulting in scoured-out redds.

Analysis of fry and juvenile habitat and conditions during incubation in the Animas River watershed has not been done. The spring conditions in the upper Animas River are sufficiently similar to those of the Gunnison River to warrant such a comparison.

Low Streamflow Conditions

The adult trout habitat criteria for winter are not the same as for the rest of the year. The velocity criteria for physical habitat at winter low flow require a lower velocity for the same level of habitat suitability than during other times of the year. During winter, when the velocities are low enough for reasonable habitat, the depths are too shallow. The winter habitat time series presented in figure 6 was calculated using the measured minimum 2-day and maximum 2-day discharges in the period 1 December through 28 February for each water year (fig. 6). The winter physical habitat is stable with reasonably small variation. The data in figure 6 and table 2 clearly show just how limiting winter conditions are in the upper Animas River. The result is that little winter trout physical habitat exists in the Animas River.

The reduction in winter habitat shown in table 2 is a result of the velocities being too high for trout habitat. Winter conditions similarly limited the reproduction of brown trout in the Gunnison River (table 3). Brown trout production is further

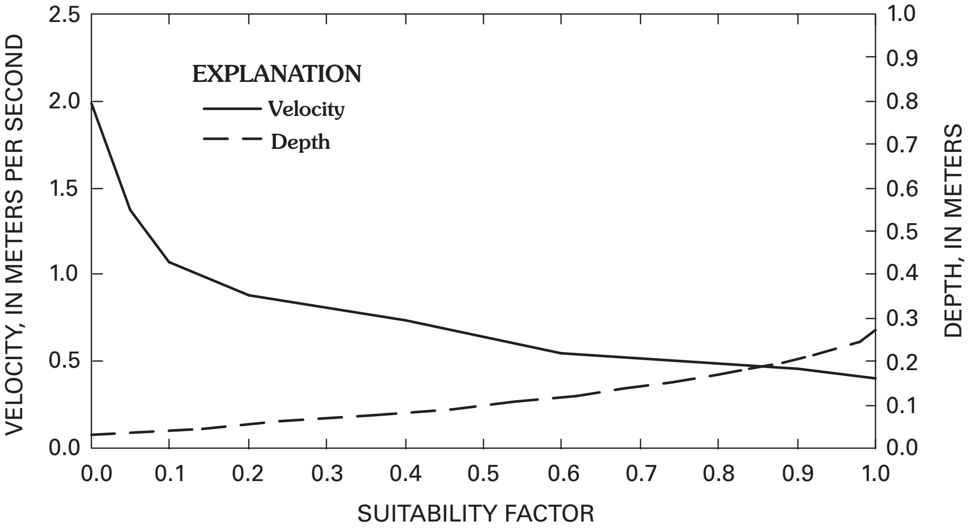

Figure 3. Habitat criteria for adult trout in Animas River.

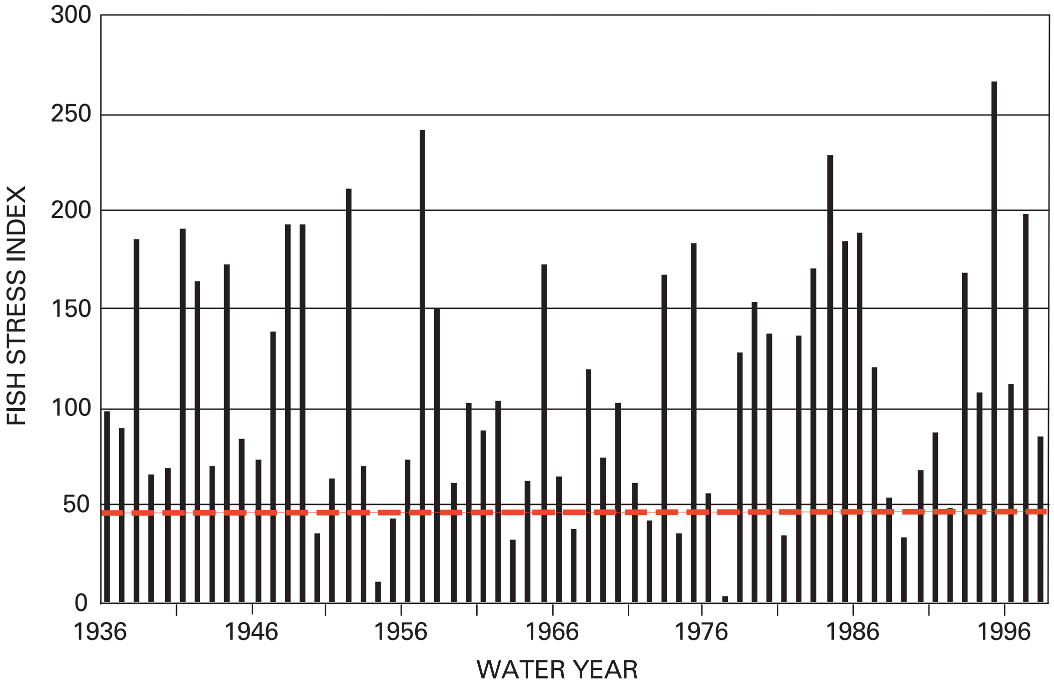

Figure 4. Yearly fluctuation of a calculated Fish Stress Index for trout in Animas River. Horizontal dashed line is median index for the 63 years of record.

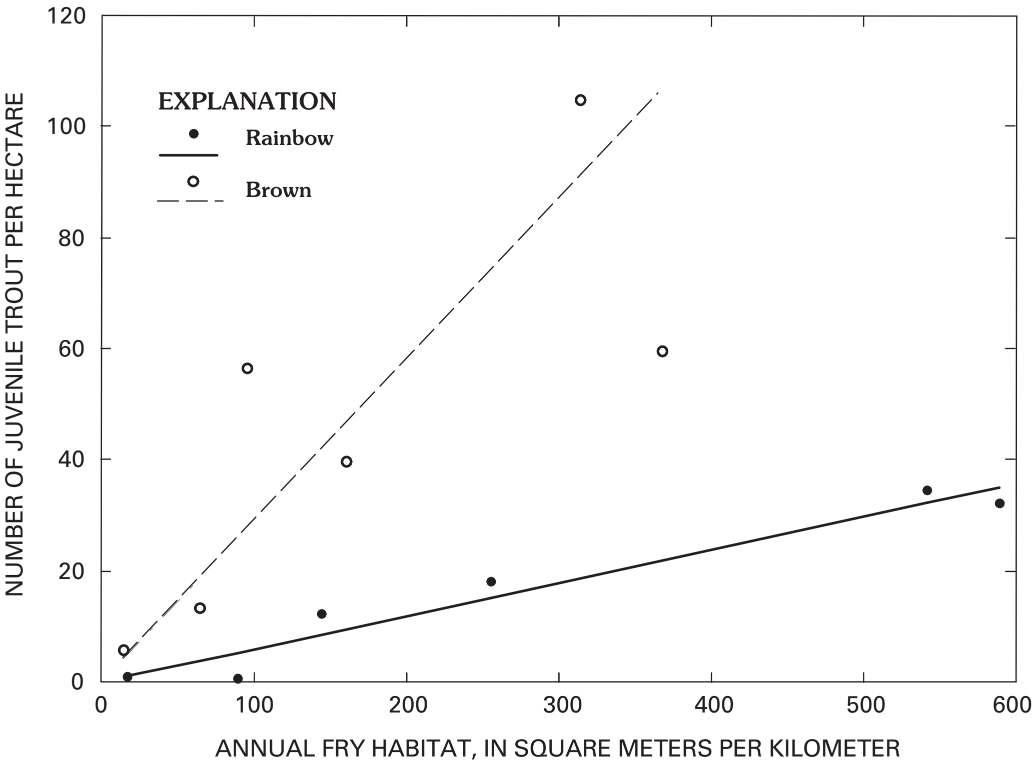

Figure 5. Effective habitat versus population density relations for juvenile brown and rainbow trout in upper Gunnison River, Colo. (data from Nehring and Miller, 1987).

limited in the Gunnison River by the conditions of spring runoff when fry emerge from the spawning gravels. (A significant winter difference is that the Gunnison River is regulated, which means winter flows are not as limiting as in the upper Animas River—but the overall process is similar (Milhous, 1995).) Two data points for brown trout in figure 5 are outliers. The likely cause of the outliers is the incubation conditions before emergence of the fry in the spring. The brown trout spawning period used in the following analysis is from 1 October to 15 November and the incubation period from 1 November to 15 April. Winters in the Gunnison River basin can range from cold and dry (low winter runoff) to relatively warm and wet (high winter runoff). If the streamflows during the fall are high, more fish will tend to spawn successfully. If the streamflows during the incubation period are relatively high, more of the redds will produce fry. In contrast, if flows during the incubation period are low, fewer of the redds will yield fry. Good spawning flows followed by good incubation (high) flows should give a point to the left of the regression line (fig. 5), but if the incubation flows are low, the predicted reproductive success should be to the right. The outlier to the right in figure 5 occurred in 1981 and the one to the left in 1985. The spawning flows were good in 1981, but the incubation flows were much reduced. This was followed by good fry habitat, but by that time poor incubation conditions had reduced the fry that could emerge. A comparison of data from 1981 to 1982 shows the incubation discharge to be slightly reduced, but because the spawning flows were also low, a reduction in fry production probably did not occur. In 1985, the spawning and incubation flows were similar in magnitude and the expected result was a larger than average production of fry, causing a larger than expected production of juveniles a year later. The differences in winter flows in the Animas River watershed study area are not usually as large as those typical for the Gunnison River, but the range is probably adequate to limit the production of fall spawning fish such as brown trout and brook trout.

Table 1. Spawning and incubation flows, rainbow trout fry habitat, and juvenile rainbow trout densities at the Duncan/Ute Trail site on the Gunnison River, Colo.

[Juvenile population and weighted usable area data from Nehring and Miller (1987); m^3/s, cubic meters per second; m^2/m, square meters per meter]

Water year	Spawning discharge (m^3/s)	Incubation discharge (m^3/s)	Fry habitat (m^2/m)	Juveniles (number/hectare)
1980	57	72	589	32
1981	7	8	542	35
1982	12	32	255	18
1983	45	257	89	1
1984	151	274	16	1
1985	92	135	144	12

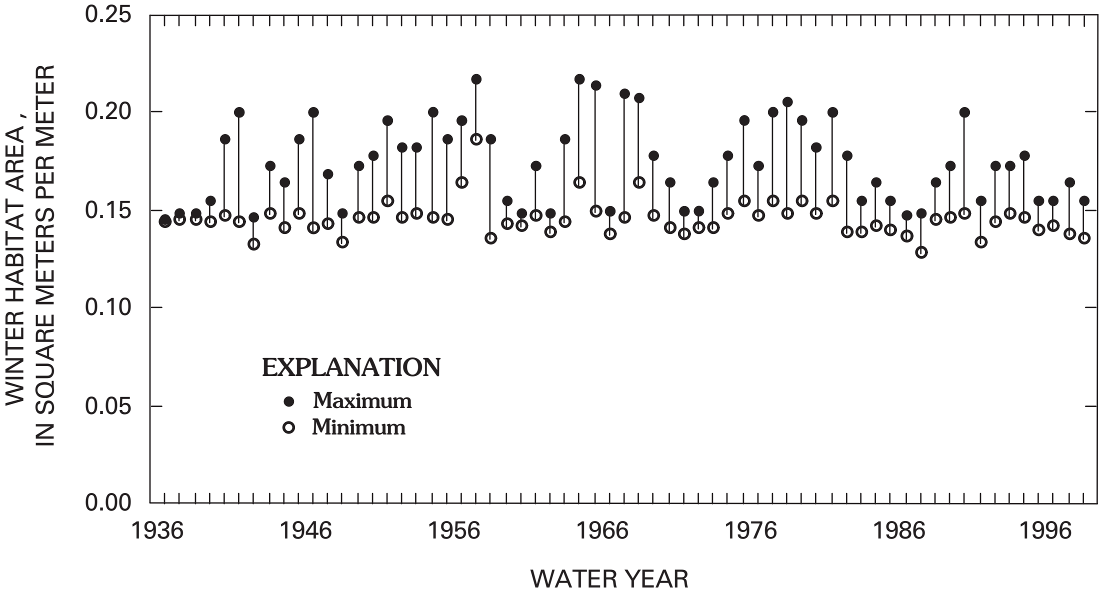

Figure 6. Annual range in the winter physical habitat in the Animas River near Howardsville. The physical habitat was calculated from minimum and maximum 2-day discharge between 1 December and 28 February.

Table 2. Physical habitat as related to discharge, for low-flow (winter) discharges of the Animas River at Howardsville.

[m³/s, cubic meters per second; m²/m, square meters per meter]

Discharge (m³/s)	Surface area (m²/m)	Adult trout (m²/m)	Winter trout (m²/m)	Benthic biomass (m²/m)
0.23	7.6	6.4	0.28	3.9
0.47	8.6	8.0	0.33	5.4
2.07	11.1	6.4	0.11	10.5
3.67	12.2	4.2	0.00	4.0

Table 3. Spawning and incubation flows in the Gunnison River as measured downstream from the diversion tunnel, brown trout fry habitat, and the juvenile brown trout densities at the Duncan/Ute Trail site downstream.

[Juvenile population was measured the following year; juvenile population and weighted usable area data are from Nehring and Miller (1987); m³/s, cubic meters per second; m²/m, square meters per meter]

Water year	Spawning discharge (m³/s)	Incubation discharge (m³/s)	Fry habitat (m²/m)	Juveniles (number/ hectare)
1980	22.4	14.0	314	105
1981	34.6	4.9	366	59
1982	11.6	4.1	160	40
1983	38.1	20.4	63	13
1984	33.7	15.4	14	6
1985	47.3	38.7	95	57

Sediment Considerations in Habitat Analysis

Winter habitat is associated with cover such as large rocks and loose gravels into which fish can burrow (Meyer and Griffith, 1997). These factors are not adequately represented in the PHABSIM model used to calculate the physical habitat presented in figure 6 and table 2. Both factors are related to the sediment in the streambed. In addition, the habitats that fish use to avoid high velocities during the spring high discharge period are also related to the characteristics of the streambed material. Fish in the Animas River use the voids within the streambed as places to burrow during the winter and as habitat for redds for spawning.

Bed Material Characteristics

The particle size of the substrate downstream from the armor is an important aspect of the physical habitat for fish and benthic invertebrates. Particle size distributions of armor from samples collected upstream (site B) and downstream from Howardsville (site 1) during August discharge ranged in size (fig. 7). The low gradient reach upstream from Howardsville has few large particles in the armor; in contrast, the reach downstream from Howardsville has large particles. The large particles at site 1 are associated with mass movement into the river. The river is not actively transporting the larger particles. All the armor at the other three locations is river-transported sediment.

The specific weight and porosity for the sample from the exposed bar (one of two at site B) upstream of Howardsville and from the sample downstream of Silverton (site 5) were

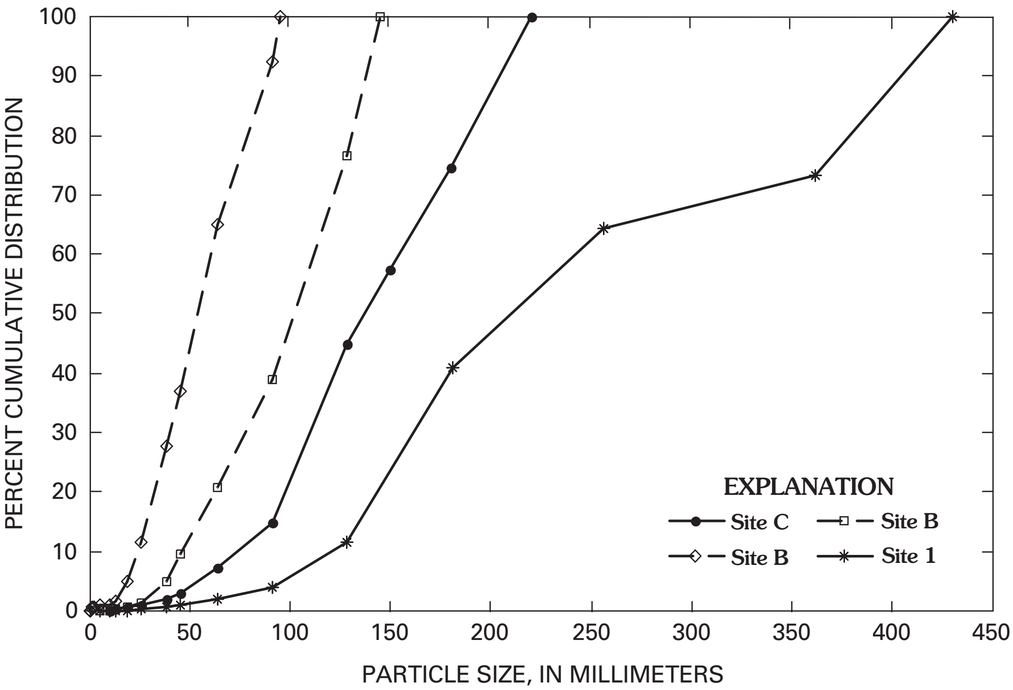

Figure 7. Particle size distribution of armor material in Animas River upstream (B) and downstream (C and 1) from Howardsville.

determined and the results compared to those for samples from rivers in Oregon and Wyoming (table 4). The samples collected from these other two rivers have more fine material than the sample from downstream from Howardsville. This difference in particle size may explain the lower porosity found for the Animas River at Howardsville in comparison to the other two rivers.

Pore Water Characteristics

For the reach of the Animas River upstream from Howardsville, another aspect of the sediment related to physical habitat is that metal concentrations in the pore water of the substrate may be higher than in the surface water. Two methods were used to sample the pore water. Nimmo and others (1998) dug a hole in a sand bar near the river and assumed that the water obtained from the hole had the same concentration of metals as the pore water. The results they obtained for a bar just upstream of the gauging station downstream from Silverton (site 5, fig. 1; table 5) show that the pore water has higher concentrations of metals than the surface water and that they can have a significant impact on the quality of the substrate for aquatic biota.

The second approach was to place an aquarium air stone in the substrate with a tube to the surface that was sealed. The air stone and attached tube were left in the substrate for at least 2 days before the pore water was sampled. Two samples were analyzed from each site. Selected results from the study are given in tables 6 and 7. As was obtained from the dug hole, these results show that the pore water can be of significantly different quality than the stream water.

Benthic invertebrates, small fish, and eggs deposited in the trout redds use the substrate as habitat at least part of the year. Metals found in the pore water of the substrate may be at higher concentrations than in the surface water. This is the situation for the site upstream from Howardsville (tables 6 and 7). Thus, the substrate may not be acceptable habitat because of toxic components in the sediment even when the surface water is not toxic.

Table 4. Specific weight, specific gravity, and porosity of bed material of three unregulated rivers.

[kg/m, kilograms per meter; g/cm^3, grams per cubic centimeter; porosity expressed as fraction of void space]

Stream	Specific weight (kg/m^3)	Specific gravity (g/cm^3)	Porosity	Percent of sample <3 mm
Oak Creek, Oregon	1,680	2.85	0.41	13
Soda Butte Creek, Wyoming and Montana.	1,700	2.65	0.36	25
Animas River upstream from Howardsville (site B).	2,160	2.80	0.22	20
Animas River downstream from Silverton (site 5).	1,764	2.70	0.35	3

Table 5. Concentration of selected metals in surface water and pore water from a sand bar in the Animas River downstream from Silverton.

[Samples collected at site 5 were filtered through a 0.45 micrometer filter and acidified (Nimmo and others, 1998); µg/L, micrograms per liter]

Constituent	Surface water (µg/L)	Pore water (µg/L)
Iron	20	75
Manganese	390	145
Aluminum	<100	250
Copper	3.5	235
Zinc	100	465

Table 6. Concentration of selected metals in surface water and pore water of the Animas River upstream from Howardsville.

[Pore water samples from site B are the first and third samples removed from the substrate; samples collected in August 1999 were filtered through a 0.45 micrometer filter and then acidified; µg/L; micrograms per liter]

Constituent	Surface water (µg/L)	Pore water (µg/L)	
		Sample 1	Sample 2
Calcium	22,500	21,300	20,500
Iron	68	4,400	1,100
Manganese	366	2,760	845
Copper	9.6	84.5	25.0
Zinc	276	777	395
Cadmium	1.1	3.4	1.6
Arsenic	0.33	5.30	1.6

Sediment and Physical Habitat

Meyer and Griffith (1997) indicated that a primary type of winter cover for rainbow trout is the space between and under rocks on the streambed surface (the armor). Another type of cover used as winter habitat by rainbow trout is within the gravel substrate, provided that the substrate is coarse enough and loose enough for the fish to burrow. These two factors suggest that winter trout habitat in the Animas River near Howardsville might be better than the habitat values in table 2 calculated using velocity and depth alone. In both spring and winter, boulders and cobbles are important in providing velocity cover to trout.

Two cover types of river sediment are important in defining habitat considerations: (1) the size of the sediment on the surface of the streambed (armor) and (2) the characteristics of the substrate (provides cover for trout and habitat for benthic invertebrates). The presence of each of these cover types was investigated for the Animas River considering the size distribution and pore water data presented previously.

Habitat Evaluations Procedures developed by the U.S. Fish and Wildlife Service indicate that good trout cover exists when there are reasonable amounts of particles larger than 100 mm in the stream armor (Raleigh, 1982). Based on this criterion, the upstream locations near Howardsville have less cover than the downstream locations (table 8).

The specific weight information (table 4) shows that the upstream location near Howardsville (site B) may not provide good substrate habitat because the substrate is relatively dense and the voids are small. The lower percentage of sands in the substrate downstream from Howardsville (site C; fig. 8) suggests that there may be better winter habitat conditions within the substrate downstream because trout may be better able to burrow into the substrate.

The sizes of the particles in the armor are also larger downstream than upstream (table 8). The river downstream has large particles that are scattered across the surface; the upstream location does not. Also, the larger ratio between the particle size at which 90 percent are smaller (d_{90}) and the median sizes suggest the presence of more voids within the armor that could be used by fish as winter cover.

Overall, the numbers and sizes of the fish are expected to be larger downstream from Howardsville than upstream from Howardsville, if velocity cover is the only factor limiting fish populations. The only trout found in the reach of the Animas River upstream of Howardsville are brook trout; in contrast, downstream from Howardsville both brook trout and rainbow trout are found (State of Colorado, unpublished records of a biological survey of the Animas River, 1992). Because brook trout tend to be smaller than the other trout, the addition of rainbow trout downstream of Howardsville will tend to skew the calculated biomass. The number of trout collected at a location near the site where the substrate samples were

Table 7. Concentrations of selected metals in pore water at three locations in the Animas River watershed.

[Samples were collected using the air stone method, filtered through a 0.45-micrometer filter, and acidified; mg/L, milligrams per liter; µg/L, micrograms per liter]

	Calcium (mg/L)	Copper (µg/L)	Zinc (µg/L)	Cadmium (µg/L)	Arsenic (µg/L)
South Fork Mineral Creek (site G)					
Stream water	20.3	1.6	17.4	0.1	0.38
Pore water 1	25.2	23.4	994	1.4	9.27
Pore water 2	21.5	8.4	324	0.49	3.64
Animas River downstream from Silverton (site 5)					
Stream water	27.9	19.5	214	1.3	1.11
Pore water 1	27.0	319	1,140	3.4	14.60
Pore water 2	23.9	46.4	360	1.4	5.3
Animas River upstream from Minnie Gulch (site A)					
Stream water	21.0	17.9	374	1.78	0.45
Pore water 1	18.6	119	1,140	4.21	10.6
Pore water 2	19.1	41.4	374	2.15	3.26

Table 8. Comparison of the sizes of armor material from the streambed of the Animas River upstream and downstream from Howardsville.

[d_{90}, grain size of 90th percentile expressed in millimeters]

Location	Median (mm)	d_{90} (mm)	Ratio (d_{90}/median)	Percent of sample >100 mm
		Armor		
Site 1	134.6	203.3	1.51	78
Site B	100.3	137.5	1.37	52
Site B	53.2	66.0	1.24	6
Site C	209.7	404.4	1.93	94
		Substrate		
Site 1	30.4	95.7	3.15	not applicable
Site B	20.2	72.7	3.61	
Site B	20.6	68.5	3.33	

obtained upstream from Howardsville was 41 brook trout in 91 meters of stream with a biomass density of 18.3 kg per hectare. Near the downstream sample site, the number of brook trout was 13 in 116 meters (7.0 kg/hectare) along with 14 rainbow trout (31.5 kg/hectare); the total trout biomass was 38.5 kg/hectare.

Changes in Substrate

An analysis presented in Milhous (2000) showed that two substrate-related factors are important in the evaluation of river restoration alternatives in watersheds with significant effects from historical or abandoned mines and mills. The two factors are (1) potential changes in the size distribution and specific weights of the substrate, and (2) potential changes in quality of the pore water, caused by metals associated with the tailings in the substrate. These factors are also important in understanding the dynamics of the physical habitat in rivers.

Vincent and Elliott (this volume, Chapter E22) obtained samples of the material from a trench dug across the river flood plain upstream from Minnie Gulch. Their analysis showed that 75 percent of the fines in the upper portion of the sediment across the flood plain were mill tailings. Based on similar assumptions, the sample collected upstream from Howardsville showed the sand and fine sediment in the substrate to be about 17 percent.

The specific weights of the substrate at two locations in the Animas River are compared to the specific weights measured for two other streams and are presented in table 4. The Oak Creek watershed in Oregon has been little disturbed. The Soda Butte Creek sites in Wyoming and Montana are on a stream with less upstream mining impact than has occurred in the upper Animas River basin. A tailings dam failed on Soda Butte Creek, but sufficient periods of high flows have occurred following the failure to remove tailings from the stream gravels but not from the flood plain.

Large quantities of tailings may increase the specific weight of the substrate and reduce interstitial space available to over-wintering small fish and to benthic invertebrates. The conclusion is based on the high specific weight of the sample obtained upstream from Howardsville compared to the results from the other rivers. The lower specific weight (and higher porosity) in samples downstream from Silverton is probably a result of the lower fraction of the substrate that is less than 3 mm.

The studies by Vincent and Elliott (this volume) also demonstrate that considerable quantities of the tailings are available for transport in the flood-plain sediment downstream of the mill site. If 75 percent of the sand and fine sediment is tailings, and the sand and fines in the sample obtained upstream from Minnie Gulch are the same, then no more than 10 percent of the active river substrate is tailings upstream from Minnie Gulch. Recent decades' floods have remobilized fine-grained mill tailings downstream from Eureka and deposited these tailings on the braided plain and on the willow-covered flood plains downstream (Vincent and Elliott, this volume).

At the beginning of the study, one objective was to determine whether the amount of sediment, sand sized and finer, found in the substrate of rivers in historical mining districts differs from that found in rivers not affected by mining. Milhous (2000) showed that the percent fines in the Animas River downstream from the tailings from the Sunnyside Eureka Mill (site # 164, Church, Mast, and others, this volume, Chapter E5) averaged 13 percent, compared to 6 percent in South Fork Mineral Creek (few mines and mills in the watershed). This is a relatively small impact even if all the difference (7 percent) was caused by the addition of mill tailings.

A river will remove fine particulates and sand from the substrate if the delivery of fine silt and sand is less than the capacity of the river to move this fine-grained sediment. When tailings are available on the flood plain, the river will move sediment to the river only during floods. An index of the ability of the river to move tailings from the flood plain to the river was presented in Milhous (2000) and is shown in figure 9. The river has the capacity to remove sand and fine silt from the channel during almost all of the years (the capacity to clean the river substrate is zero for only 2 of the 63 years (Milhouse, 2000)). In contrast, the capacity to mobilize sediment from the flood plain and channel margins occurs in about 15 percent of the years. From the physical habitat viewpoint this means that the characteristics of the substrate are not a constant, but a variable dependent on the time pattern of streamflow.

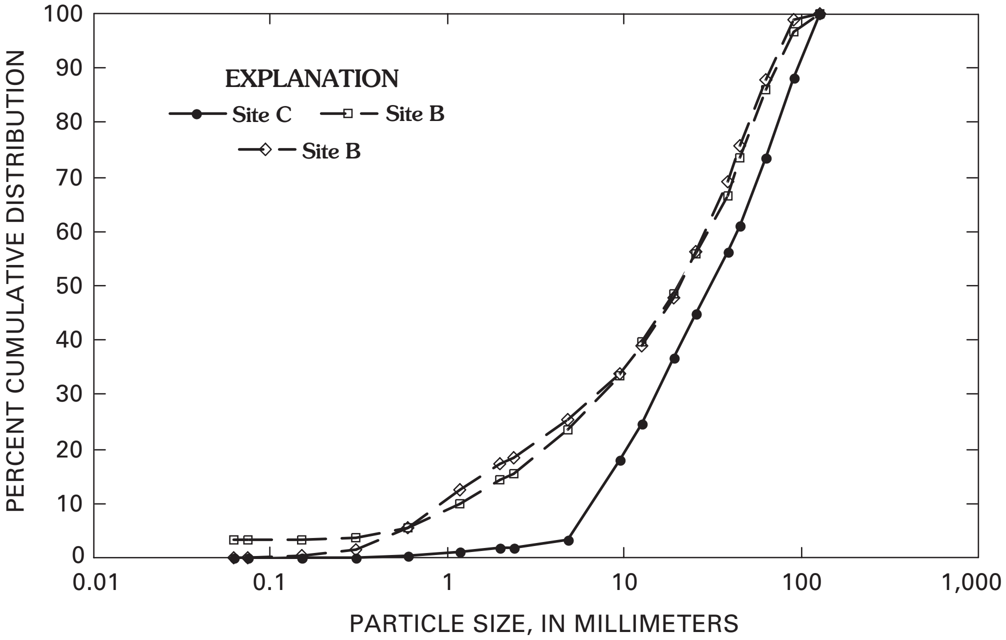

Figure 8. Particle size distribution of subsurface material in Animas River upstream (B) and downstream (C) from Howardsville.

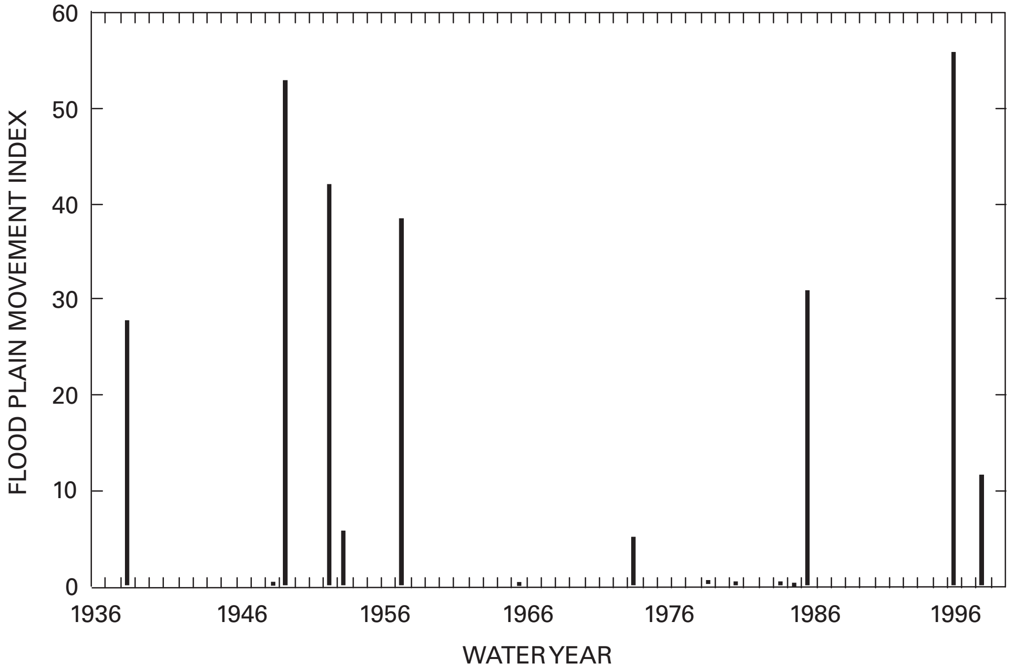

Figure 9. Annual flood-plain and channel mobilization index (FPMI) for Animas River at Howardsville (Milhous, 2000). Prior to 1936 there were major floods with significantly more capacity to move sediment than in that time period.

Conclusions

Sediment from historical mining activity has two possible impacts on the physical habitat. The first is on the size of the sediment in the substrate, and the second is on the suitability of sediment as physical habitat. In the upper Animas River, the effects of the sediment from historical mining on the particle size distribution of sediment in the streams appear to be minor (fig. 8 and table 4). This may be because the last discharge of sediment to the stream from mills was more than 50 years before the study (Jones, this volume, Chapter C).

However, the impact of sediment quality on the suitability of the substrate may be important because of the potential toxicological effect of metals in the substrate and associated pore water (tables 5–7). In some locations, and at some times, the surface water may be of adequate quality for trout but the pore water may be of poor quality. The quality of the pore water is most likely poor because metal-containing fines from mining are still in the substrate.

In the Animas River watershed study area, this reconnaissance-level study of the physical habitat shows that suitable habitat for trout survival is limited by winter streamflows and that fall-spawning fish commonly do not have adequate streamflow conditions for spawning success. The analysis also showed that trout populations are limited in some years because of high stream velocities at critical times. Overall, the use of reconnaissance-level studies of physical habitat suitability can be useful because this approach identifies limits on the quality of a fishery that may result from factors other than the effects of mining.

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