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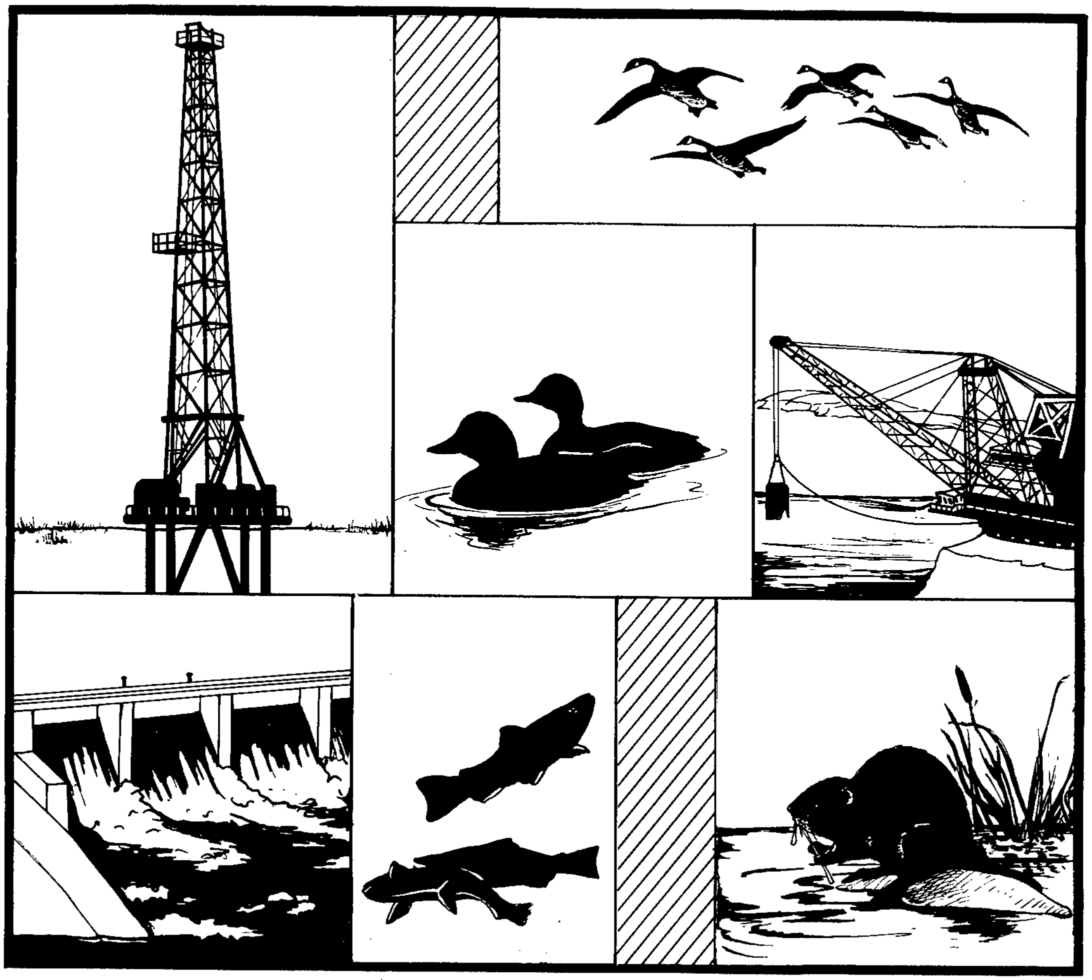

Fish and Wildlife Service
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Biological Report

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ABSTRACT.—We assessed the biological significance of an increase in minimum flow to the brown trout (*Salmo trutta*) population in Douglas Creek, Wyoming. Douglas Creek is a regulated stream that underwent an increase in the required minimum flow in 1986 to 5.5 cubic feet per second (cfs) after 23 years of minimum flows at 1.0 cfs. We compared population and habitat data obtained during the period when minimum flow was 1.0 cfs (1972–76) with data collected after the minimum flow was increased to 5.5 cfs (1988–89).

We measured a more than twofold increase in brown trout standing stock between 1973 and 1988–89 in a 1.6-km (1-mile) reach between Rob Roy Dam and the point of water diversion. Within this reach, discharge was occasionally as low as 3.0 cfs before 1986, but the low flow was not as severe as downstream from the water diversion.

A four- to sixfold increase in brown trout standing stock was indicated between 1972 and 1988–89 in a 10.3-km (6.4-mile) reach immediately downstream from the point of water diversion. Within this reach, the minimum low flow was 5.5 times greater than in the 1970's, wetted width at low flow was doubled, and weighted usable area for adult fish was almost 5 times greater.

At sites more than 10.3 km (6.4 miles) downstream from the water diversion structure, where the effect of reduced flow had been less because of the addition of water from tributary streams, there were no measurable changes related to the enhanced minimum flow.

We assessed the biological significance of an increase in minimum low flow to brown trout (*Salmo trutta*) in Douglas Creek on the Medicine Bow National Forest, Wyoming. Douglas Creek is a regulated stream that underwent an increase in the required minimum flow to 5.5 cubic feet per second (cfs) in 1986, after 23 years of minimum flows at 1.0 cfs. We compared population and habitat data gathered by the Wyoming Water Research Center (WWRC) during the period when minimum flow was 1.0 cfs (1972–76) with data collected after the minimum flow was increased to 5.5 cfs (1988–89).

Instream flows as mitigation to protect fish and other aquatic organisms have been widely prescribed for streams that have experienced water development (Wesche and Rechard 1980). Two major assumptions underlie the success of any flow recommendation: (1) flow releases have some biological significance to the organisms of concern, and (2) project operators will comply with the required flow releases. Raley et al. (1988) found that compliance with instream flow agreements was poor at sites in Colorado, Montana, and Wyoming where streamflow data were available to enable an assessment. Availability of projects that comply with instream flow agreements and monitor flows was a major factor limiting the ability to evaluate the biological significance of instream flow agreements. Douglas Creek was one of only a few sites in the three-State area that could be used in such an evaluation.

A literature review showed that most of the research on minimum flows has focused on development of instream flow and habitat models (Orth 1987). Many studies comparing methodologies for instream flow and habitat assessment are available, including Orsborn and Allman (1976), Stalnaker and Arnette (1976), Wesche and Rechard (1980), E. A. Engineering, Science, and Technology, Inc. (1986), and Fausch et al. (1988). Because of the relation between physical habitat in a stream and discharge, instream flow models and habitat assessment models have developed along similar paths, with the same model often used for both purposes. Despite the large amount of work, there is little evidence that fish populations respond to changes in minimum instream flow.

Our goal was to investigate the response of the brown trout population in Douglas Creek to an increase in the minimum flow release. Our objectives were to (1) describe the brown trout population in Douglas Creek at 2 and 3 years after the increase in minimum flow and to compare the data with those obtained during the period of 1.0-cfs minimum flow, (2) describe the physical habitat in Douglas Creek at a 1.0- and 5.5-cfs minimum low flow, and (3) determine possible mechanisms through which the enhanced minimum flow in Douglas Creek may have improved the brown trout fishery.

Description of Study Area

Douglas Creek is on the Medicine Bow National Forest in southeastern Wyoming (Fig. 1). The headwaters are on the southwest slope of the Snowy Range, at 3,172 km (10,400 feet) above mean sea level. The stream flows in a southwesterly direction for 47 km (29 miles) and enters the North Platte River at an elevation of 2,287 km (7,500 feet) just north of the Colorado–Wyoming border. The upper Douglas Creek drainage consists primarily of coniferous forests, which gradually give way to sagebrush and grassland hills at lower elevations. The brown trout is the most common fish species inhabiting Douglas Creek. Other species found in the drainage (Baxter and Simon 1970) include brook trout (*Salvelinus fontinalis*), white sucker (*Catostomus commersoni*), longnose sucker (*Catostomus catastomus*), longnose dace (*Rhinichthys cataractae*), and creek chub (*Semotilus atromaculatis*).

The sport fishery in Douglas Creek is dominated by brown trout. Wesche (1973) reported that the trout stock was composed of 76% brown trout and 22% brook trout at a study site 0.88 km (0.55 mile) downstream from Rob Roy Dam in 1972. Jesperson (1980) reported that 87% of the trout population in Douglas Creek downstream from Rob Roy Dam was composed of brown trout.

The brown trout in Douglas Creek are relatively small and appear to grow slowly. The mean total length of brown trout sampled by Jesperson (1980) was 15.2 cm (6.0 inches; all fish lengths are given as total lengths) and the largest fish was 37.3 cm (14.7 inches). Similar sizes were reported by Wesche (1973) and by the Wyoming Game and Fish Department in 1979 (D. Miller, Wyoming Game and Fish Department, Laramie, Wyoming, personal communication). Length–frequency data from Wesche (1973) and Jesperson (1980) indicated that brown trout reach 5.1 cm (2 inches) by the end of their first summer and 10.2–12.7 cm (4–5 inches) by the end of their second summer. On the basis of scale analysis, maximum age has been estimated at 5 years (Wesche 1972), but

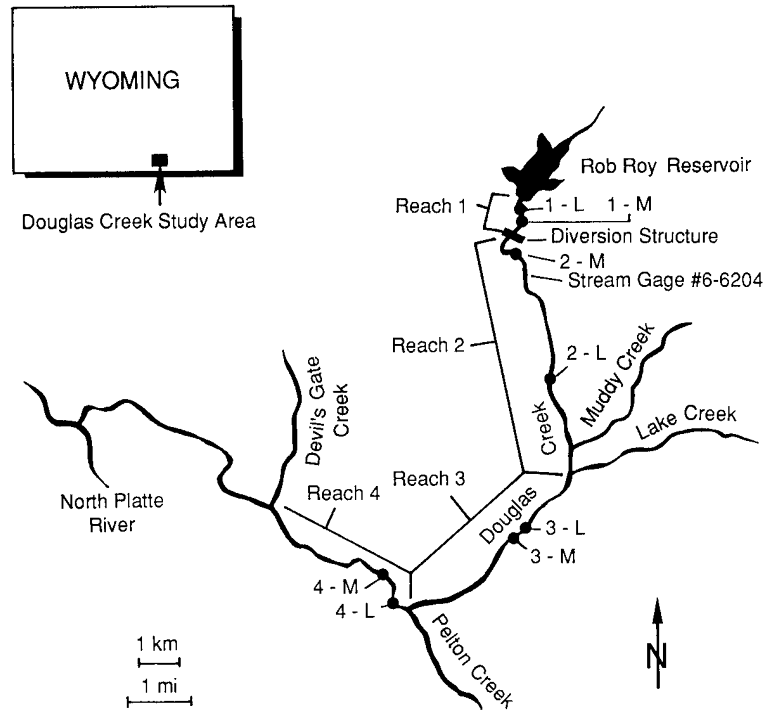

Fig. 1. Map of the Douglas Creek study area, Medicine Bow National Forest, Wyoming. The eight sample sites are labeled with a number representing one of four reaches and letter representing stream gradient (L, <1.0%; M, ≥1.0%).

otolith analysis would probably yield a higher estimate (Kozel and Hubert 1987).

Douglas Creek has been altered by both railroad tie-drives and gold dredging (Thybony et al. 1986). Tie driving was the practice of using streams and rivers to transport logs. Most of the timber was used as railroad crossties and was shaped into ties before transport, hence the name tie-drive. Timber was usually harvested in winter and stacked on streambanks until spring. After spring runoff began, logs were floated downstream. To facilitate the downstream progress of the masses of floating ties, stream channels were straightened, and snags, debris, and boulders were removed, primarily by blasting (Thybony et al. 1986).

The Douglas Creek watershed was also known for gold. Large steam shovels were used to excavate the streambed and banks. Excavated material was passed through sluice boxes to remove the gold. Processed material was dumped along the banks forming spoil piles, which are still a common sight along Douglas Creek. Most of the dredging took place in the low-gradient sections of the stream.

Both the tie-drives and mining activities altered the physical habitat of Douglas Creek. The resultant channel is unnaturally wide and shallow in many areas, as much as 3.6 times wider than would be expected for a natural stream with a similar drainage area (R. Schmal, Medicine Bow National Forest, Laramie, Wyoming, personal communication). In many places instream cover in the form of large boulders, woody debris, or deep water is almost absent, and overhead bank cover is generally lacking.

Douglas Creek also was influenced by water development when construction of Rob Roy Reservoir was completed in 1963. The reservoir, at an elevation of 2,843 km (9,320 feet), was part of a system used to store (capacity = 8,895 acre-feet) and convey water to Cheyenne, Wyoming, for municipal use. Water released from the reservoir flowed in the stream channel for 1.6 km (1 mile) where it could be diverted by a small dam into a pipeline for transport to Cheyenne. This system, termed Stage I, provided Cheyenne with 7,400 acre-feet of water annually. As part of the use permit issued by the U.S. Forest Service, a minimum flow of 1.0 cfs was required downstream from the diversion structure, from which Douglas Creek flows 35 km (22 miles) before emptying into the North Platte River.

The City of Cheyenne, anticipating the need for additional municipal water, proposed to enlarge the project. Stage II would include increasing the storage capacity of Rob Roy Reservoir to 35,400 acre-feet to provide Cheyenne with 23,200 acre-feet of water per year.

Consequently, studies were initiated in the 1970's to assess the instream flow needs of fish in Douglas Creek downstream from Rob Roy Reservoir. Wesche (1973), through the Wyoming Water Research Institute at the University of Wyoming, conducted a study funded by the Office of Water Resources Research and Wyoming Game and Fish Department. Jesperson (1980), a fisheries biologist employed by the U.S. Forest Service, conducted a study on the Medicine Bow National Forest.

Wesche (1973) evaluated the minimum streamflow for trout in Douglas Creek after construction of Rob Roy Reservoir. His primary study area was 0.88 km (0.55 mile) downstream from Rob Roy Reservoir, which corresponds to Site 1-L in our study. A stream gage (Number 6–6204); 1.9 km (1.2 miles) farther downstream and operated from 1955 to 1971 showed a maximum discharge of 865 cfs (1957) and a minimum discharge of 1.3 cfs (1958). The average daily flow (adf) during the 16-year period was 31 cfs. In 1972, Wesche evaluated habitat features over a range of flows from 12.5% adf (3.9 cfs) to 200% adf (62.0 cfs). He measured depth, velocity, wetted width, wetted perimeter, hydraulic radius, and cross-sectional area at 16 transects over the 207-m (680-foot) study reach. He also measured potential trout cover (undercut banks and rubble–boulder areas) over the range of flows. Wesche recommended a minimum flow of 25% adf (7.8 cfs). He found the greatest rate of decrease in hydrologic parameters, water surface area, and available trout cover at flows between 25 and 12.5% adf.

Jesperson (1980) developed instream flow recommendations for a study reach downstream from the Stage I diversion structure, which corresponds to Site 2-M in our study. He used streamflow data from Gage Number 6–6204 and water diversion records from September 1963 through September 1972 to reconstruct the natural flow that would have occurred through the study reach. He used the U.S. Forest Service's R-2 Cross method (Silvey 1976) to assess changes in water velocity, depth, wetted perimeter, surface area, hydraulic radius, and maximum depth over a range of flows at six transects. Jesperson found that the 1.0-cfs minimum flow provided only 16 to 35% of the natural low flow downstream from the diversion structure and severely affected the availability of trout habitat. Subsequently, he recommended a bypass flow of 5.5-cfs at the Douglas Creek diversion structure. Jesperson's data suggest a rapid decline in available habitat at discharges below 7.8 cfs, as was observed by Wesche (1973), yet he recommended a minimum low flow of 5.5 cfs, with no explanation of the logic for the recommendation.

In addition to a minimum bypass flow of 5.5 cfs, Jesperson (1980) recommended a flushing flow of 130 cfs for 72 h, coinciding with natural peak runoff each spring. These recommendations were subsequently incorporated into the U.S. Forest Service use permit for Stage II of the Cheyenne water project. A minimum bypass flow of 5.0 cfs was required at the Douglas Creek diversion and 0.5 cfs at the Horse Creek diversion. Horse Creek is a small stream that flows into Douglas Creek immediately downstream from the diversion structure. The combined minimum flow of Douglas Creek and Horse Creek created a 5.5-cfs minimum flow downstream from the diversion structure.

The flow pattern through the study area during Stage I, which was influenced by the Rob Roy Dam, followed a natural regime, with high flows of several hundred cubic feet per second in June, decreasing gradually to lowest flows in late winter (Wesche 1973; Jesperson 1980). The mean monthly hydrograph at Gage Number 6–6204 (near the upstream end of our study area) for the 9 years before water development (1956–65) is shown in Fig. 2. A prolonged period of low flow occurred each year from August through March, with higher flows from April through July as a result of melting snow. The natural hydrograph was altered by construction of Stage I. The duration and magnitude of the low-flow period were accentuated, whereas the duration and magnitude of the high spring flow were reduced. A period of spring runoff still occurred, however, as a result of flow from the Horse Creek drainage, which was not regulated by Stage I.

A comparison of natural flows with those after water diversion indicated that during Stage I low flows were generally less than natural flow levels, and substantially more fluctuation in flows occurred (Jesperson 1980). Jesperson attributed the variability in discharge to poor reservoir management by the City of Cheyenne. He recommended that Stage II be implemented so that a constant minimum flow could be maintained throughout the year. The minimum flow he recommended (5.5 cfs) actually exceeded the mean natural low flow from November through March (Fig. 2) in Douglas Creek at Gage Number 6–6204.

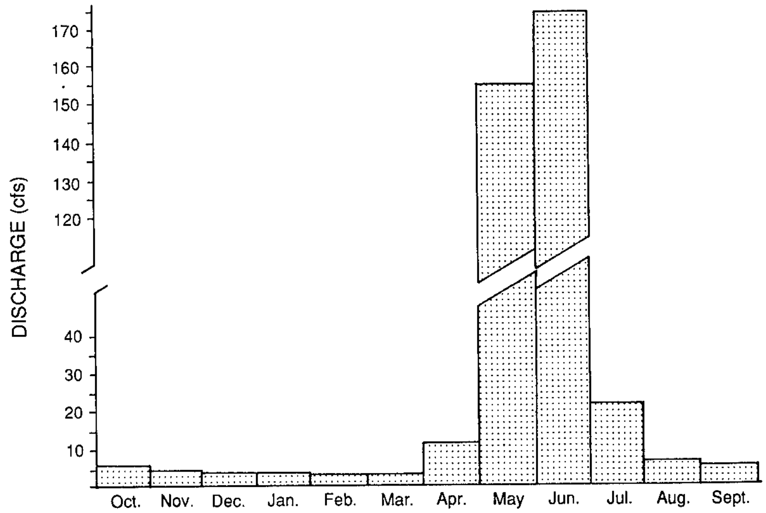

Fig. 2. Mean monthly discharge at Gage Number 6-6204 on Douglas Creek, 1956–65, before operation of Rob Roy Dam.

Methods

Design

Four reaches of Douglas Creek were defined by major changes in discharge because of the diversion of water from the creek or perennial tributaries entering the creek: (1) Rob Roy Dam to the diversion structure, (2) the diversion structure to Lake Creek, (3) Lake Creek to Pelton Creek, and (4) Pelton Creek to Devil's Gate Creek (Fig. 1). The lower 5 miles of Douglas Creek (Devil's Gate Creek to North Platte River) were not included in the present study.

Two gradient classes were specified—low (<1.0%, L) and moderate (≥1.0%, M)—in the four reaches. Kozel's (1987) work on streams in the Medicine Bow National Forest showed a relation between stream gradient, habitat, and trout standing stocks. Study sites were 2,507 to 2,836 m (8,220 to 9,300 feet) above mean sea level.

Eight study sites were sampled in 1988 and 1989; six of these sites had been sampled in the 1970's. Two sites, 1-M and 2-L (Fig. 1), not sampled in the 1970's, were added to provide one site of each gradient class within each reach.

Field Techniques

Brown trout standing stocks were estimated at least once during the 1970's in August or September, at the six sites. Sites 1-L and 2-M were sampled in 1972, Sites 3-L and 3-M in 1974 and 1975, and Sites 4-L and 4-M in 1973. We attempted to sample the same reaches in 1988 and 1989. We sampled with electroshocking and removal methods (Delury 1951). All trout ≥10.2 cm (≥4 inches) were identified, weighed, and measured. We estimated standing stocks for August and September of 1988 and 1989 with the CAPTURE computer program, model M(bh), which allows for variation in behavior because of the first capture attempt (White et al. 1982). Standing stocks were estimated in pounds per mile and pounds per surface acre of stream. The estimate in pounds per mile enabled comparison of 1970's and 1980's standing stocks without bias associated with the changes in water surface area because of the increased minimum flow.

In the 1970's, 4 to 16 transects were established at each of the six study sites. Transects were selected to represent a stream segment having similar hydraulic and morphologic characteristics. Some sites were sampled at one to five different stream discharges, but our evaluation was limited to physical habitat availability during a 1.0-cfs discharge downstream from the diversion structure. Depth was measured at 10 to 20 points along each transect, and mean velocity and substrate were also recorded during certain sampling periods. The amount of cover was measured following Wesche (1980). Complete measurements were not available for the six sites studied in the 1970's but were gathered during August and September 1988 at all eight study sites.

Three techniques were used to assess habitat in the 1970's and in 1988: (1) Physical Habitat Simulation System (PHABSIM), developed by the U.S. Fish and Wildlife Service (Milhous et al. 1984); (2) Habitat Quality Index (HQI), developed by the Wyoming Game and Fish Department (Binns and Eiserman 1979); and (3) Trout Cover

Rating (TCR), developed by the WWRC (Wesche 1980). Data from the six study sites in the 1970's were not collected specifically for application of these models. Hence model variables were sometimes estimated from file information and photographs. At some sites, data were not available to apply all three models. For example, lack of data at two sites prevented PHABSIM application, and absence of cover data at another site prevented TCR from being used.

PHABSIM analyses were performed according to Bovee (1982), Milhous et al. (1984), and PHABSIM Technical Notes published by the U.S. Fish and Wildlife Service. Hydraulic and channel morphology data from four sites in the 1970's and all eight sites in 1988 were loaded into an IFG4-formatted file for analysis using PHABSIM. We ran PHABSIM using depth, velocity, and substrate curves for adult, juvenile, fry, and spawning brown trout (Bovee 1978, 1986). Curves for all life stages except fry were developed from data collected from Douglas Creek in the 1970's (Reiser and Wesche 1977; Wesche 1980). Data for fry habitat utilization curves were obtained from B. Nehring (Colorado Division of Wildlife, Montrose, Colorado, personal communication). Habitat utilization curves used in our analyses are in the Appendix.

The Habitat Quality Index (Binns and Eiserman 1979; Binns 1982) is used to provide estimates of potential standing stocks of trout in Wyoming streams without consideration of individual species. Eight of the nine variables in the model were estimated from the 1970's data. No data were available on nitrate–nitrogen concentrations (X_4), so this variable was held constant at 0.01 mg/L for all sites. We used this concentration because it is the level reported by the Wyoming Game and Fish Department for previous HQI sampling on Douglas Creek. Similarly, there were few data available on water temperature in Douglas Creek, but the data that were examined suggested that optimum conditions exist most of the time (Wesche 1973). Therefore, we gave an optimum temperature rating (X_3) to all study sites. Measured values for all variables in the model were transformed to ratings of 0 to 4 and used in the Model II multiple regression equation to provide an estimate of potential standing stock at each study site.

The Trout Cover Rating is obtained from a dimensionless equation, the typical output of which ranges from 0 to 1 (Wesche 1980). This method is based on the measurement of linear overhead bank cover, the area of instream rubble–boulder and aquatic vegetation cover, and the proportion of the study area having depths greater than 0.45 m (1.5 feet). Preference factors are used to weight the model for either juvenile (<15.2 cm; <6 inches) or adult (≥15.2 cm; ≥6 inches) trout. The TCR has been correlated with brown trout standing stocks in southeastern Wyoming streams (Wesche et al. 1987a,1987b).

In 1988, we collected data on water temperature from three locations on Douglas Creek. Recording thermographs were placed (1) at the outlet from Rob Roy Reservoir (operated by the U.S. Forest Service), (2) downstream from the diversion structure, and (3) downstream from the confluence of Lake Creek with Douglas Creek.

Annual low flows were simulated from discharge records for Douglas Creek, data from other streams in the area, and water diversion records obtained from the City of Cheyenne. Measurements of discharge for Douglas Creek were available for Reach 1 in 1972, Reach 3 in 1974–75, and Reach 4 in 1967–73. Records of the amount of water diverted at the diversion structure separating Reaches 1 and 2 were available for 1967–88. Discharge data have not been obtained in the Douglas Creek study area since 1975. The diversion dam was constructed so that the minimum streamflow, 1 cfs from 1967 to 1985 and 5.5 cfs from 1986 to 1988, was passed through the dam before any water could be diverted. Thus, the diversion records provided a means for determining if the minimum low flows were maintained downstream from the diversion structure.

Results

Standing Stocks

Estimates of brown trout standing stocks ranged from 56 to 635 pounds/mile in the 1970's, 183 to 772 pounds/mile in 1988, and 156 to 553 pounds/mile in 1989 (Table 1). Study sites varied substantially; Site 4-M was not sampled in 1989 because the reach had become impounded by beaver (*Castor canadensis*).

At Site 1-L, brown trout standing stock was 89 pounds/mile in 1973; it was 189 pounds/mile in 1988 and 217 pounds/mile in 1989—more than a twofold increase between the 1970's and late 1980's.

At Site 2-M, brown trout standing stock was 56 pounds/mile in 1972, 307 pounds/mile in 1988, and 222 pounds/mile in 1989. Thus brown trout abundance increased four- to sixfold in this reach immediately downstream from the water diver-

Table 1. *Estimated standing stocks of brown trout* (Salmo trutta; *≥4 inches) at Douglas Creek study sites. Parenthetical figures are 95% confidence intervals.*

Site	Year		
	1970's	1988	1989
		Pounds per mile	
1-L	89(76–102)	189(177–201)	217(196–238)
1-M		772(659–885)	553(387–719)
2-L		358(325–391)	327(300–354)
2-M	56	307(358–391)	222(187–257)
3-L	328(294–362)	214(203–225)	197(148–246)
	239(216–262)		
3-M	226(209–243)	228(236–340)	173(145–201)
	281(256–306)		
4-L	635(547–724)	354(335–373)	156(120–192)
4-M	148(123–173)	183(170–196)	
		Pounds per acre	
1-L	46(39–53)	68(64–72)	78(71–85)
1-M		275(235–315)	197(138–256)
2-L		117(106–128)	107(98–116)
2-M	37	106(93–119)	77(65–89)
3-L	65(60–70)	47(45–49)	43(32–54)
	80(72–87)		
3-M	100(89–11)	65(53–77)	39(33–45)
	73(66–80)		
4-L	218(118–248)	109(103–115)	48(37–59)
4-M	30(25–35)	50(46–54)	

sion structure, where the influence of the 1.0 cfs minimum flow had been most severe.

Estimates for Reaches 3 and 4, which are more than 10.3 km (6.4 miles) downstream from the water diversion structure, indicated no change in standing stock in relation to the enhanced minimum flow. Indications of reduced brown trout abundance were evident at one site (4-L). Substantial variation in standing stock estimates between adjacent years was observed in the 1970's (Sites 3-L and 3-M), as well as in the 1980's (Sites 1-M, 2-M, 3-M, and 4-L).

Possible changes in population structure between the 1970's and 1988–89 were assessed by evaluating the length–frequencies of fish ≥10.2 cm (≥4 inches; Table 2). The proportion of brown trout ≥15.2 cm (≥6.0 inches) in the 1970's was greater than in 1988, but less than in 1989 at most sites. Substantial year-to-year variation in population structure is indicated by data from the 1970's (Sites 3-L and 3-M), as well as from 1988 and 1989. Although our data do not indicate that the change in minimum flow led to a change in population structure, an increased proportion of brown trout ≥15.2 cm (≥6 inches) was indicated between 1988 and 1989 at the five sampling sites closest to Rob Roy Dam.

We compared the number of brown trout (≥20.3cm; ≥8 inches) per mile between the 1970's and 1988–89 as another indicator of change (Table 3). A greater number of fish ≥20.3 cm (≥8 inches) were observed at Site 1-L and 3-L in 1988–89 than in the 1970's, but substantial variation between years was again noted during the 1970's (Sites 3-L and 3-M), as well as between 1988 and 1989 at several study sites (1-L, 3-L, 3-M, 4-L).

Habitat

Differences in hydrologic features at the study sites between the 1970's and 1988 included increased minimum low flows and greater average wetted widths at low flow (Table 4). Reach 2 increased fivefold in low flow and doubled in average wetted width at low flow. The differences between the 1970's and 1988 declined with progression downstream from Site 2-M, which was immedi-

Table 2. *Percent of brown trout (*Salmo trutta*) of various lengths included in the standing stock estimates at Douglas Creek study sites. Only fish ≥10.2 cm (≥4.0 inches) were included in standing stock estimates.*

Length (inches)	Site	Time 1970's	1988	1989
≤6.0	1-L	53.7	31.3	80.9
	1-M		46.2	80.0
	2-L		38.5	57.6
	2-M		35.9	51.8
	3-L	56.6	46.9	68.8
		40.1		
	3-M	61.2	42.7	42.5
		40.4		
	4-L	65.2	83.1	51.7
	4-M	37.6	49.5	
6.0–7.9	1-L	29.9	17.7	48.1
	1-M		19.1	53.0
	2-L		22.4	38.9
	2-M		16.3	34.9
	3-L	44.3	21.0	35.0
		29.3		
	3-M	56.2	28.2	30.1
		35.8		
	4-L	17.8	32.4	18.3
	4-M	23.7	30.7	
8.0–9.9	1-L	11.9	5.2	15.3
	1-M		15.6	16.5
	2-L		12.2	13.9
	2-M		12.0	13.2
	3-L	6.7	16.8	10.0
		8.4		
	3-M	4.5	12.1	9.6
		4.6		
	4-L	7.4	2.5	20.0
	4-M	6.5	11.5	
≥10.0	1-L	11.9	8.3	17.6
	1-M		11.6	10.4
	2-L		3.8	4.9
	2-M		7.6	3.6
	3-L	5.4	9.1	23.8
		2.4		
	3-M	0.6	2.4	2.7
		0.0		
	4-L	40.0	28.2	13.3
	4-M	7.5	7.3	

Table 3. *Estimated number of brown trout (*Salmo trutta*; ≥8 inches) per mile at Douglas Creek study sites.*

Site	Period 1970's	1988	1989
1-L	141	197	340
1-M		1,104	932
2-L		552	557
2-M		429	340
3-L	232	345	302
	303		
3-M	184	380	178
	138		
4-L	837	538	346
4-M	189	264	

Table 4. *Minimum low flows and average wetted stream widths at Douglas Creek study sites in the 1970's and 1988.*

Site	Minimum low flow (cfs) 1970's	1988	Average wetted width (feet) 1970's	1988
1-L	3.0	5.0	15.9	23.1
1-M		5.0		23.2
2-L		5.5		23.9
2-M	1.0	5.5	12.3	25.2
3-L	5.0	9.0	28.8	37.7
3-M	6.0	9.0	27.1	36.7
4-L	8.0	11.0	24.1	26.8
4-M	8.0	11.0	25.9	30.0

ately below the water diversion structure. Study sites in Reach 4 increased only 38% in low flow and 11 to 16% in wetted width.

Physical habitat differences between the 1970's and 1988 at the minimum flows were evaluated with PHABSIM (Table 5). Increases in weighted usable area at low flow were indicated for adult and juvenile brown trout for all four study reaches, but the relative changes were greatest in Reaches 1 and 2. Fry habitat at minimum flows declined from the 1970's to 1988, while spawning habitat increased. We estimated potential standing stocks of trout in the 1970's and 1988 with the HQI (Table 6). A threefold increase in potential standing stock between the 1970's and 1988 was estimated for Site 1-L; a sevenfold increase was estimated for Site 2-M. Declines in potential standing stock were predicted in Reaches 3 and 4. Analysis of the field measurements and ratings used in the HQI indicated that the higher potential standing stocks in Reaches 1 and 2 were related to enhanced late summer streamflows,

Table 5. *Weighted usable area for adult, juvenile, fry, and spawning life stages of brown trout (*Salmo trutta*) at Douglas Creek in the 1970's and 1988.*

	Weighted usable area (feet^2/1,000 feet)							
	Adult		Juvenile		Fry		Spawning	
Site	1970's	1988	1970's	1988	1970's	1988	1970's	1988
1-L	1,270	2,213	3,800	6,503	2,244	1,966	628	4,619
1-M		2,644		6,482			797	2,011
2-L		2,511		7,178		2,753		2,448
2-M	310	1,259	3,294	4,783	722	618	1,360	3,840
3-L		755		5,378		2,008		6,546
3-M	150	270	3,888	4,045	1,072	805	3,565	6,045
4-L		10,106		8,680		1,606		3,600
4-M	2,138	2,754	7,642	8,252	2,097	1,870	3,168	4,435

less annual variation in streamflow, fewer eroding banks, and greater water velocity (Table 7). The lower potential standing stock estimates in Reaches 3 and 4 were related to less cover and suitable substrate in 1988 than in the 1970's. The HQI ratings indicate that the amount of cover and suitable substrate has declined in Reaches 3 and 4 since the 1970's. The declines may be due partly to a small change in area of cover with a larger change in water surface area, but habitat loss because of the destruction of overhanging banks by cattle and sediment deposition in the streambed are also likely contributing factors.

The TCR indicated a decline in the quality of trout cover from the 1970's to 1988 at minimum flows in all five study sites where data were available from the 1970's (Table 8). The ratings seemed to have declined because of the decreases in overhead bank cover and the area of rubble–boulder and aquatic vegetation cover (Table 9). Some of the changes may have been because of the substantial increase in water surface area at low flow with little change in cover availability. We assessed differences in available cover by comparing the area of cover per 305 m (1,000 feet) of stream at study sites in the 1970's and 1988 (Table 10). These computations indicated that the abundance of rubble–boulder and aquatic vegetation cover declined by 10–80% between the 1970's and 1988 at the five study sites where data were available. Likewise, the availability of deep-water cover declined at Site 1-L, remained unchanged in Reach 3 (where it was totally lacking), and increased in Reach 4. These habitat losses are not a function of changes in minimum flow from the 1970's to 1988, but seem to be related primarily to sediment deposition in Reach 1 and destruction of streambanks in Reach 4.

Table 6. *Estimated potential standing stocks of trout at Douglas Creek study sites in the 1970's and 1988 based on the Habitat Quality Index.*

	Standing stock (pounds per acre)	
Site	1970's	1988
1-L	55	174
1-M		152
2-L		136
2-M	29	208
3-L	51	42
3-M	37	27
4-L	58	49
4-M	74	94

Temperature

Temperature data gathered in summer 1988 showed that on 3 days water temperature reached 19° C at the most downstream thermograph, near the mouth of Lake Creek. Maximum recorded temperatures were 15° C at the outlet from the dam and 16° C at the diversion structure. Average daily water temperatures in August at all three stations were between 9 and 12° C. Summer temperatures were considered optimum for trout (Binns and Eiserman 1979).

Discharge

Annual low-flow estimates based on past records and simulation using trends in nearby wa-

Table 7. *Field measurements and ratings for seven attributes in the Habitat Quality Index at Douglas Creek study sites in the 1970's and in 1988.*

	Field measurement		Rating	
Site	1970's	1988	1970's	1988
Late summer streamflow (%)				
1-L	18	42	2	3
1-M		42		3
2-L		60		4
2-M	10	68	1	4
3-L	18	32	2	3
3-M	20	32	2	3
4-L	25	26	2	3
4-M	25	26	2	3
Annual streamflow variation				
1-L			1	3
1-M				3
2-L				3
2-M			1	3
3-L			2	2
3-M			2	2
4-L			2	2
4-M			2	2
Cover (%)				
1-L	18	10	1	1
1-M		37		2
2-L		26		1
2-M	30	12	2	1
3-L	45	12	3	1
3-M	38	6	2	0
4-L	31	34	2	2
4-M	26	29	2	2
Eroding banks (%)				
1-L	15	4	3	3
1-M		0		4
2-L				3
2-M	15	1	3	4
Eroding banks (%) (continued)				
3-L	15	12	3	3
3-M	15	7	3	4
4-L	15	20	3	3
4-M	15	17	3	3
Substrate[a]				
1-L	A	A	4	4
1-M		O		2
2-L		O		2
2-M	O	A	2	4
3-L	F	O	3	2
3-M	O	O	2	2
4-L	F	L	2	1
4-M	O	O	2	2
Velocity (feet per second)				
1-L	0.95	1.21	2	3
1-M		2.10		4
2-L		1.15		3
2-M	0.95	1.31	2	3
3-L	0.50	0.88	2	2
3-M	0.70	0.91	2	2
4-L	0.50	0.96	2	2
4-M	1.20	1.11	3	3
Stream width (feet)				
1-L	15.9	23.1	3	3
1-M		23.2		3
2-L		23.9		3
2-M	12.3	25.2	4	3
3-L	28.8	37.7	3	3
3-M	27.1	36.7	3	3
4-L	24.1	26.8	3	3
4-M	25.9	30.0	3	3

[a] A = abundant, F = frequent, O = occasional, L = little.

tersheds indicated that annual low flows have fluctuated substantially in Reaches 1, 3, and 4 from 1967 to 1988 (Fig. 3). Annual low flow in Reach 2, immediately downstream from the diversion dam, was consistently 1 cfs from 1967 to 1986, when it was increased to 5.5 cfs. The simulations indicated that annual low flows from 1970 to 1975 ranged from 2 to 6 cfs in Reach 1, 4 to 11 cfs in Reach 3, and 6 to 14 cfs in Reach 4. During this 5-year period, annual low flows were less than those in 1986–88 for 4 years in Reaches 1, 3, and 4, and for all 5 years in Reach 2.

Discussion

Population Response

A notable increase in brown trout standing stock was indicated between the 1970's and 1988–89 in

Table 8. *Trout Cover Ratings for adult and juvenile fish at Douglas Creek study sites in the 1970's and in 1988 (the equation for small streams was used).*

	Trout cover rating			
	Adult		Juvenile	
Site	1970's	1988	1970's	1988
1-L	0.27	0.10	0.24	0.10
1-M		0.27		0.32
2-L		0.14		0.18
2-M		0.14		0.17
3-L	0.21	0.20	0.24	0.16
3-M	0.09	0.03	0.15	0.04
4-L	0.49	0.37	0.42	0.28
4-M	0.20	0.18	0.23	0.19

Reaches 1 and 2. No standing stock changes attributable to the enhanced minimum flow were seen farther downstream in Reach 3 or 4.

The Wyoming Game and Fish Department made standing stock estimates of trout in 1979 and 1986 (a few months after the enhanced minimum flow) in three of our study reaches (Table 11). The estimates in all three reaches showed higher standing stocks in 1986 than in 1979. The greatest difference, almost threefold, was in Reach 2, where we also observed the greatest difference between 1972 and 1988–89.

In the 1970's, individual study sites were sampled for 1- to 3-year periods between 1972 and 1975, 6–9 years after the 1.0-cfs minimum low flow was begun, and 11–14 years before our sampling in 1988. The data set representing conditions during the period of 1.0-cfs minimum flow through the diversion dam is limited. Only single estimates of standing stock were available at four of the six study sites during the 1970's, and where multiple estimates were available, estimates varied substantially. At Site 3-L, four standing stock estimates made in 1974 and 1975 that ranged from 7 to 75 pounds/acre (Cooper and Wesche 1976). Variation associated with sampling date was indicated among these estimates; July estimates were 7 pounds/acre in 1974 and 15 pounds/acre in 1975, whereas September estimates were 75 pounds/acre in 1974 and 52 pounds/acre in 1975. We suspected that the cause of the July to September increases was either movement of fish from tributaries into Douglas Creek as flows declined in the tributaries or upstream migration of fish from lower in Douglas Creek or the North Platte River in preparation for spawning.

Habitat Response

Our assessment of habitat in Douglas Creek indicated that the stream has been affected by human activities; habitat quality may have further degraded from the 1970's to 1988 in regard to the availability of cover for brown trout. Brown

Table 9. *Field measurements of the cover variables used in the computation of Trout Cover Ratings at Douglas Creek study sites in the 1970's and in 1988 following Wesche (1980).*

	Overhead bank[a]		Rock and vegetation[b]		Deep water[c]	
Site	1970's	1988	1970's	1988	1970's	1988
1-L	0.30	0.09	0.18	0.11	0.04	0.01
1-M		0.22		0.42		0.02
2-L		0.09		0.27		0.00
2-M		0.11		0.23		0.04
3-L	0.19	0.25	0.28	0.06	0.00	0.00
3-M	0.03	0.03	0.27	0.04	0.00	0.00
4-L	0.55	0.46	0.30	0.11	0.15	0.31
4-M	0.18	0.16	0.28	0.22	0.01	0.01

[a] Length of overhead bank cover in the study reach with a water depth of at least 0.15 m (0.50 foot) and a width of 0.09 m (0.3 foot) or greater divided by length of the thalweg through the reach.
[b] Surface area of the study reach with water depths greater than 0.15 m (0.50 foot) and a substrate size of 7.6 cm (3.0 inches) in diameter or greater (i.e., rubble and boulder) or a substrate covered with vegetation divided by total surface area of the study reach at minimum flow.
[c] Surface area of the study reach with a water depth of 0.45 m (1.5 feet) or greater divided by total surface area of the study reach at minimum flow.

Table 10. *Estimated abundance (feet^2/1,000 feet) of rubble–boulder cover, aquatic vegetation cover, and deep-water cover at Douglas Creek study sites in the 1970's and in 1988.*

Site	Rubble–boulder and aquatic vegetation cover		Deep-water cover	
	1970's	1988	1970's	1988
1-L	2,850	2,540	430	170
1-M		9,750		130
2-L		6,440		0
2-M		5,790		280
3-L	8,060	2,260	0	0
3-M	7,320	1,480	0	0
4-L	7,230	2,950	1,730	3,080
4-M	7,250	6,600	210	270

Table 11. *Estimated standing stocks (pounds per acre) of trout at three sites in Douglas Creek, 1979 and 1986, by the Wyoming Game and Fish Department.*

Reach	Year 1979	1986
1	104	114
2	37	95
3	105	147

trout habitat in Douglas Creek was affected by tie-drives and gold dredging in the late nineteenth and early twentieth centuries, as well as by water development in the last 25 years. To a smaller degree, livestock grazing, road construction, and recreation activities have further reduced habitat quality. We observed reduction in habitat quality near Site 4-L, for example, where accelerated bar formation has taken place. This aggradation of river gravels has resulted in closure of side channels to fish and reduction of bed material size. Although the cause of this channel change has not been identified, the overall result has been a reduction in available cover despite the enhanced minimum flow. Kozel (1987) studied streams in the Medicine Bow National Forest that were not affected by logging, mining, livestock grazing, or road construction. His findings indicated that unaffected streams with a basin area similar to Douglas Creek have deeper, narrower channels with more cover in the form of undercut banks and woody debris, as well as higher standing stocks of trout, than does Douglas Creek.

Lanka et al. (1987) developed models to predict trout standing stocks from knowledge of geomorphic and stream habitat features for forested streams in Wyoming. We applied their geomorphic model to Douglas Creek. Standing stocks predicted for Douglas Creek were greater than those measured in 1988, which indicates that fish abundance in Douglas Creek is lower than average compared with streams of similar size and geomorphic features. Our data from PHABSIM and HQI analyses

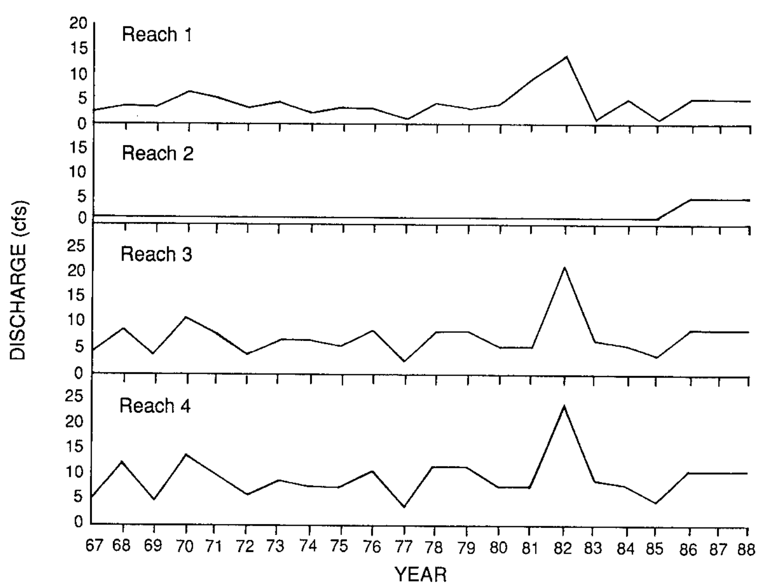

Fig. 3. Estimated annual low flows in the four study reaches of Douglas Creek, 1967–88.

indicated that the augmentation of the minimum streamflow from 1.0 to 5.5 cfs has benefited the brown trout population in Reaches 1 and 2. In Reach 1, the PHABSIM analysis indicated that, from the 3.0-cfs low flows in the 1970's to the 5.5 cfs minimum in 1988, weighted usable area for both adults and juveniles increased almost twofold, and spawning habitat (Table 5) increased more than sevenfold. The HQI analysis indicated an increase in potential standing stocks of trout by more than threefold (Table 6) as a result of enhanced late-summer streamflow, less annual streamflow variation, increased water velocity, and increased wetted width, despite reductions in cover and increases in eroding banks since the 1970's (Table 7). A more than twofold increase in brown trout abundance was observed (Table 1).

In Reach 2, the minimum flow increased from 1.0 to 5.5 cfs; PHABSIM analysis indicated a fourfold increase in adult weighted usable area, but little change in juvenile weighted usable area (Table 5). An almost threefold increase in potential standing stock was predicted by the HQI (Table 6), for the same reasons as in Reach 1 (Table 7). A four- to sixfold increase in brown trout standing stock was observed (Table 1).

In Reaches 3 and 4, both PHABSIM and HQI analyses indicated little or no change in habitat availability resulting from enhanced flows (Tables 5, 6, and 7), but the minimum flows were increased relatively less than in the two upstream reaches (Table 4). As might be expected, no change in brown trout abundance attributable to the enhanced minimum flow was observed in these two reaches (Table 1).

Both HQI and TCR analyses indicated losses in some features of habitat quality from the 1970's to 1988. Habitat quality declined because of losses of instream cover in the form of overhanging banks, rubble–boulder substrate, aquatic vegetation, and deep pools. Two processes seem to have contributed to the loss of cover—sedimentation and bank erosion. Sediment input is probably related to construction of Rob Roy Dam, and bank damage is probably related to cattle grazing. Despite the habitat losses in Reaches 1 and 2 between the 1970's and 1988, the enhanced minimum flows led to substantial increases in habitat quality for brown trout and observed increases in brown trout abundance. Cover limitations in Douglas Creek have been recognized by the U.S. Forest Service, and a 5-year habitat restoration plan has been developed (Wesche 1987) to rehabilitate Douglas Creek employing a variety of treatments, such as placement of instream and bank structures, to encourage narrowing and deepening of the channel. A total of 176 habitat improvement treatments at specific sites have been recommended (Wesche 1987).

Our work was conducted with recognition of the limitations of two of the habitat assessment models. The PHABSIM model is considered by many to be the state of the art for instream flow assessment (Orth 1987). Some authors criticize the lack of significant correlations between weighted usable area and standing stocks (Conder and Annear 1987; Scott and Shirvell 1987); others, however, say that there is such a relation (Stalnaker 1979; Orth and Maughan 1982). Reviews of both points of view can be found in Orth (1987) and Gore and Nestler (1988). The HQI model has been tested in the central Rocky Mountains and is believed to be an adequate means for assessing trout stream habitat quality and for identifying factors that limit brown trout abundance (Conder and Annear 1987; Scarnecchia and Bergersen 1987).

It is possible that standing stocks of brown trout throughout the study area are depressed, not only by cover availability but also by harvest. Public access to stream fisheries has been shown to have a negative effect on brown trout standing stocks in streams in southeastern Wyoming (Wesche et al. 1987b). Our study sites all had convenient public access.

From June to mid-September 1989, the Wyoming Game and Fish Department conducted a creel survey on Douglas Creek between Rob Roy Dam and the mouth of Lake Creek (Reaches 1 and 2). The department estimated fishing pressure at 1,874 angler days. Overall, anglers caught 6,086 fish at a rate of 2.16 fish per hour; 954 of the fish were harvested. Brown trout made up most of the catch, with 4,022 brown trout caught at 1.43 fish per hour; 462 fish were estimated to have been kept by anglers (M. Snigg, Wyoming Game and Fish Department, Laramie, Wyoming, personal communication).

Long-term Value of Increased Minimum Flow

Since augmentation of the minimum low flow, brown trout populations in Douglas Creek have increased significantly between the Rob Roy Dam and the diversion structure, as well as within the 6.4-mile reach immediately downstream from the diversion dam. Habitat quantity and quality seem to have increased substantially in these reaches because of the enhanced minimum flow initiated in 1986. We expect the brown trout population to maintain itself at present levels or continue to expand if the 5.5-cfs minimum low flow is consistently maintained. Enhanced minimum flow seems to be an effective mitigation alternative.

The PHABSIM and HQI analyses, as well as the rapid changes in brown trout abundance observed after the enhancement of minimum flow, indicated that the brown trout population response was probably because of the greater abundance of habitat for juvenile and adult fish during low flow (July–April in most years), not increased habitat for fry or spawning. Given the physical effects in the Douglas Creek watershed from past human activities, the increased minimum low flow was not the only mitigative measure needed to enhance the fishery. Additional work is needed at Douglas Creek study sites to determine if the 1988–89 population levels and the agreed upon minimum low flow will be maintained. The U.S. Forest Service initiated a habitat improvement project in 1989. The influence of this mitigation effort should be evaluated for its addition to overall brown trout habitat quality and fish abundance.

Acknowledgments

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Appendix. Habitat Utilization Curves

Habitat utilization curves used in the assessment of habitat changes with increased minimum low flow. The curves are for adult, juvenile, fry, and spawning life stages of brown trout (*Salmo trutta*). Substrate codes are as follows: 1 = organic; 2 = silt and clay; 3 = sand, 0.10–0.61 cm (0.04–0.24 inches) in diameter; 4 = fine gravel, 0.63–2.51 cm (0.25–0.99 inches); 5 = coarse gravel, 2.54–7.37 cm (1.0–2.9 inches); 6 = rubble, 7.62–30.23 cm (3.0–11.9 inches); 7 = boulders, ≥30.49 cm (≥12.0 inches); and 8 = bedrock.

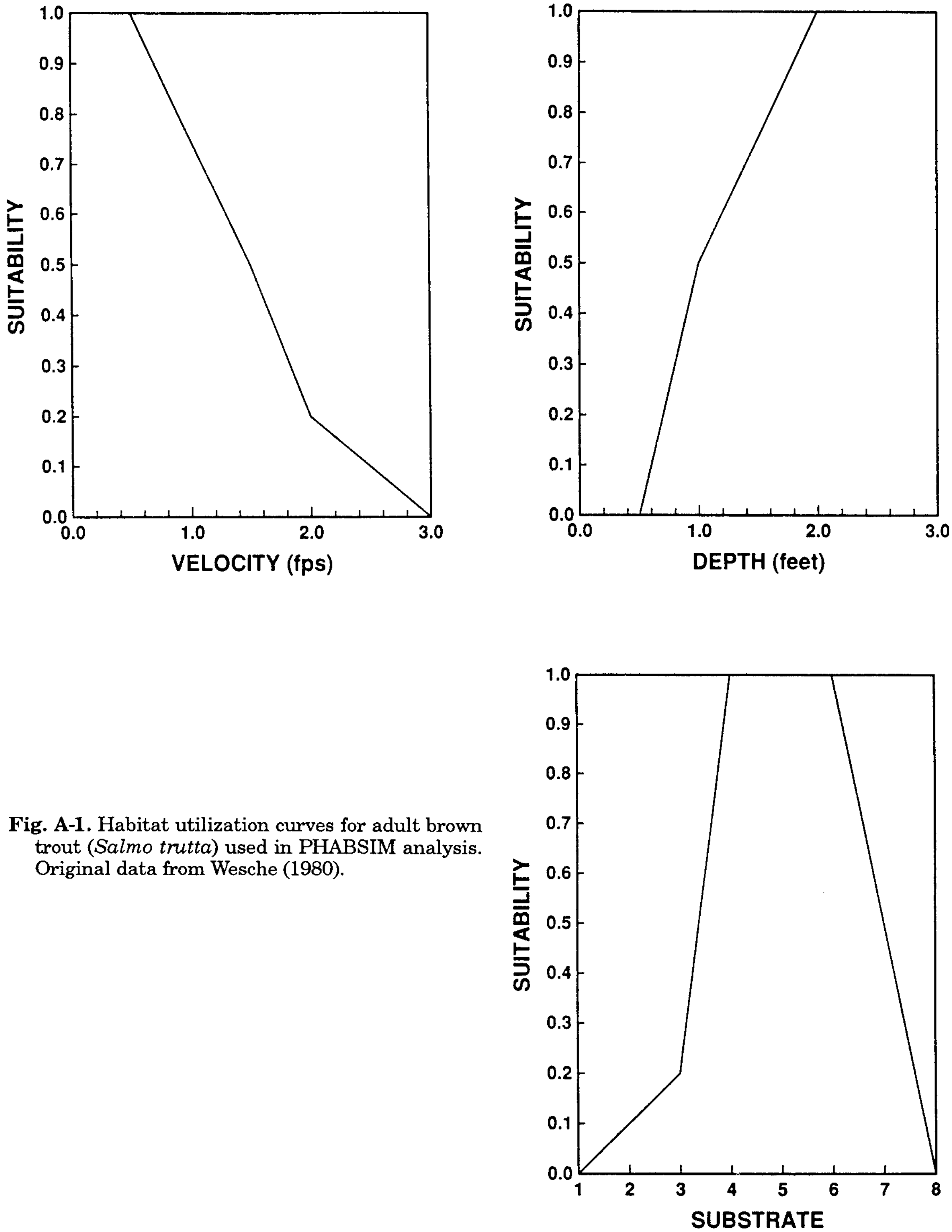

Fig. A-1. Habitat utilization curves for adult brown trout (*Salmo trutta*) used in PHABSIM analysis. Original data from Wesche (1980).

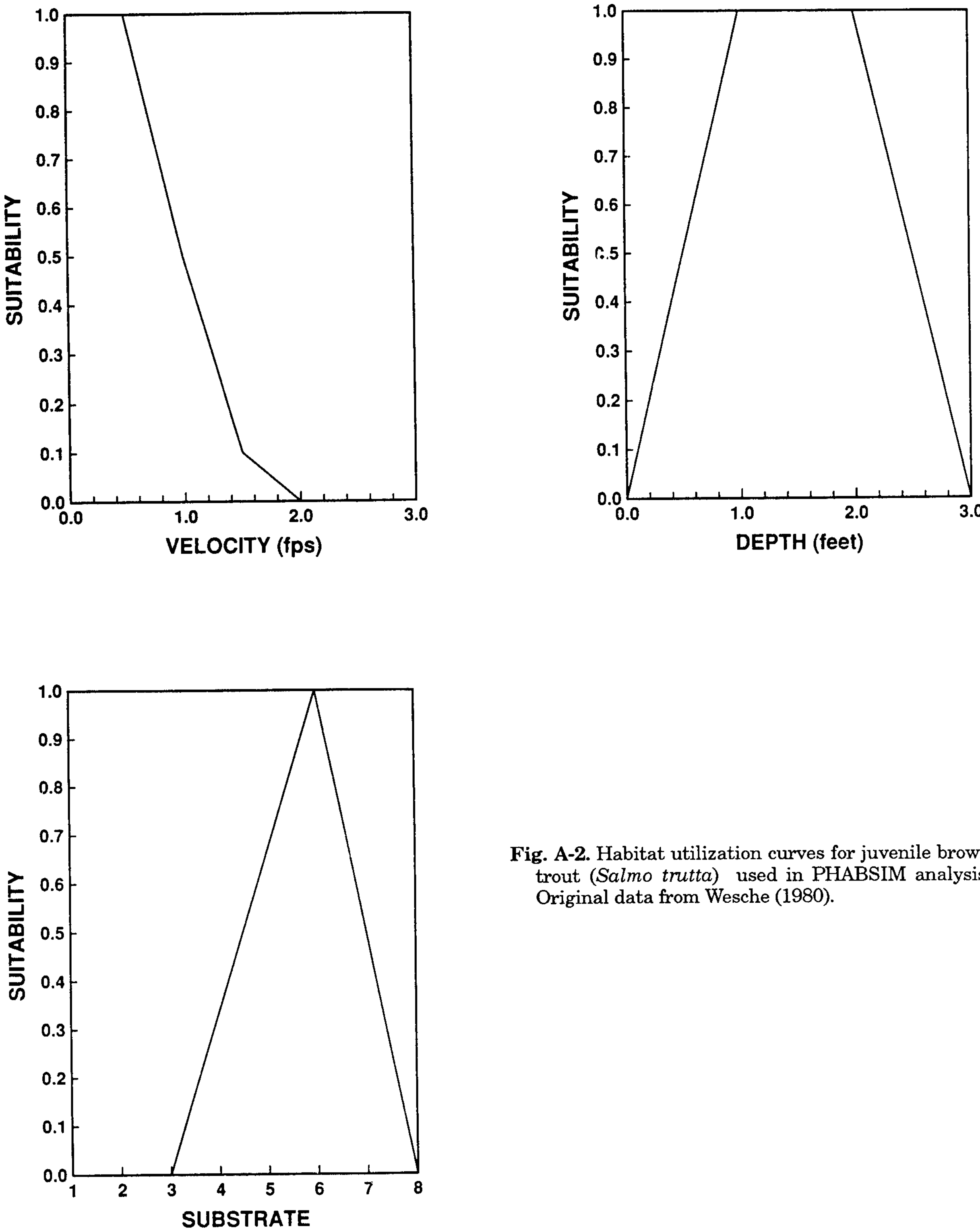

Fig. A-2. Habitat utilization curves for juvenile brown trout (*Salmo trutta*) used in PHABSIM analysis. Original data from Wesche (1980).

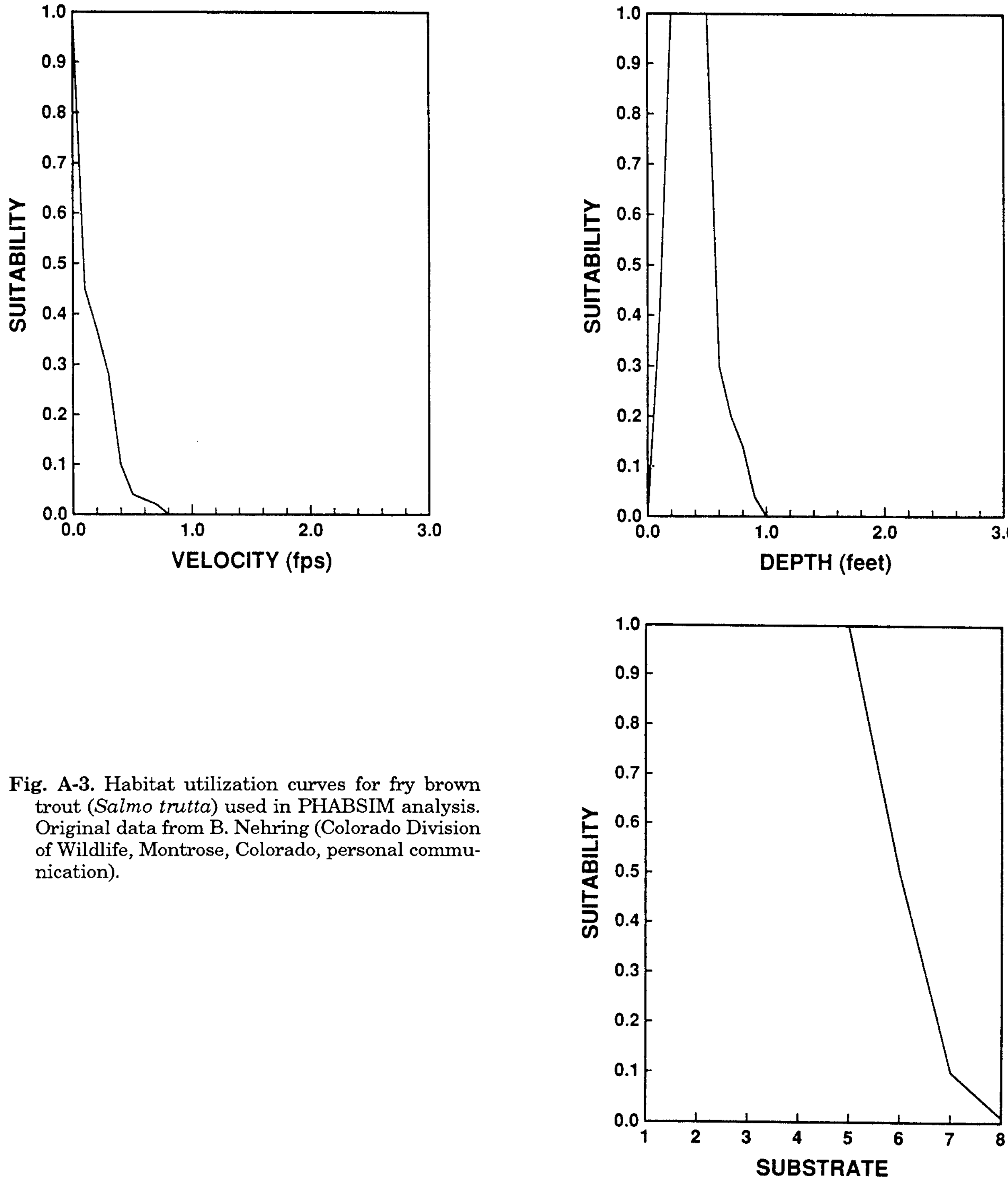

Fig. A-3. Habitat utilization curves for fry brown trout (*Salmo trutta*) used in PHABSIM analysis. Original data from B. Nehring (Colorado Division of Wildlife, Montrose, Colorado, personal communication).

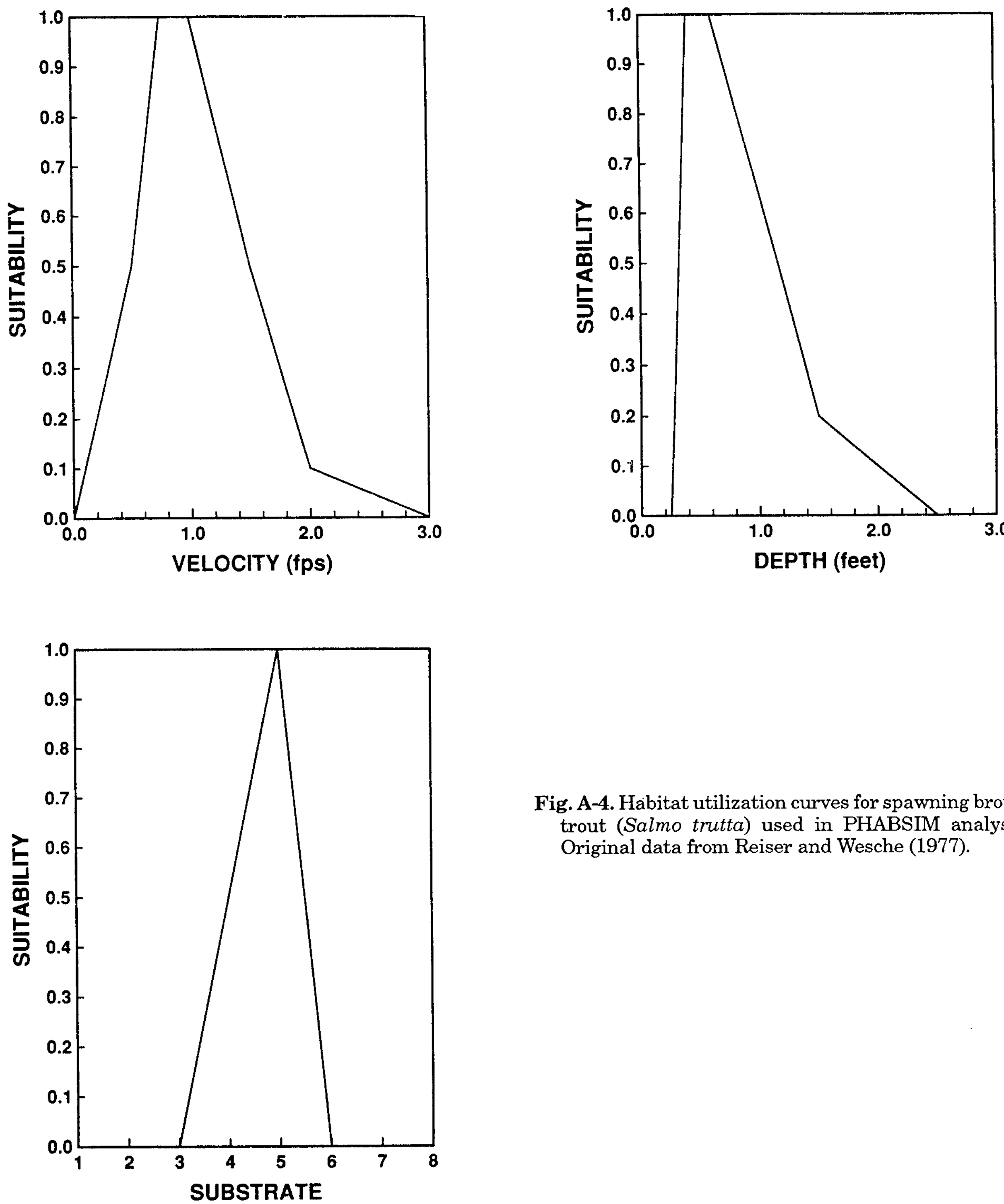

Fig. A-4. Habitat utilization curves for spawning brown trout (*Salmo trutta*) used in PHABSIM analysis. Original data from Reiser and Wesche (1977).

Wolff, Steven W., Thomas A. Wesche, Douglas D. Harris, and Wayne A. Hubert. 1990. **Brown Trout Population and Habitat Changes Associated with Increased Minimum Low Flows in Douglas Creek, Wyoming.** U.S. Fish Wildl. Serv., *Biol. Rep.* 90(11). 20 pp.

The biological significance of an increase in minimum streamflow in Douglas Creek, Wyoming, to brown trout (*Salmo trutta*) was assessed. Population and habitat data were compared between a period of minimum flow (1.0 cfs, 1972-76) and that of increased minimum flow (5.5 cfs, 1988-89). Brown trout standing stock increased two- to sixfold in different reaches of Douglas Creek between 1972 and 1988-89.

Key words: Minimum flow, standing stock, water diversion, brown trout, population, habitat.

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