BROWN TROUT POPULATION AND HABITAT RESPONSE TO ENHANCED MINIMUM FLOW IN DOUGLAS CREEK, WYOMING

Douglas D. Harris Wayne A. Hubert
Thomas A. Wesche

1991
Journal Article WWRC-91-17

In

Rivers

Volume 2, Number 4

Submitted by

Douglas D. Harris
Wayne A. Hubert
U.S. Fish and Wildlife Service
Wyoming Cooperative Fish and
Wildlife Research Unit

Thomas A. Wesche
Wyoming Water Resources Center
and
Department of Range Management

University of Wyoming
Laramie, Wyoming

Brown Trout Population and Habitat Response to Enhanced Minimum Flow in Douglas Creek, Wyoming

Douglas D. Harris
Wayne A. Hubert
U.S. Fish and Wildlife Service
Wyoming Cooperative Fish and Wildlife Research Unit[1]
University of Wyoming
Laramie, Wyoming 82071

Thomas A. Wesche
Department of Range Management and
Wyoming Water Research Center
University of Wyoming
Laramie, Wyoming 82071

ABSTRACT: We assessed the biological significance of an increase in minimum flow to brown trout (*Salmo trutta*) in Douglas Creek, Wyoming. Douglas Creek is a regulated stream that underwent an increase in the required minimum flow in 1986 to 5.5 ft^3/second after 23 years of minimum flow at 1.0 ft^3/second. We compared population and habitat data obtained during the period when minimum flow was 1.0 ft^3/second (1972–1976) with data collected after the minimum flow was 5.5 ft^3/second (1988–1990). An increase in brown trout standing stock in excess of natural fluctuation was observed at one site within 7.4 mi of Rob Roy Dam with more deep water for juvenile and adult fish at the site. At a second site within 7.4 mi of Rob Roy Dam, the standing stock estimates remained within the range of natural variation, but instream cover was probably limiting at that site. There was no evidence of enhanced standing stocks at sites more than 7.4 mi downstream from Rob Roy Dam where the effect of the low minimum flow was reduced because of the addition of water from tributary streams. The assumption that enhanced minimum instream flow for fisheries should result in the production of more or larger fish was not supported at most of the study sites in Douglas Creek.

KEY WORDS: Brown trout, diversion, habitat, instream flow, minimum low flow.

INTRODUCTION

Enhanced minimum instream flow for fisheries should result in the production of more or larger fish. This is an assumption often made for instream flow recommendations, but a literature search revealed no previous assessment of the significance of enhanced minimum flows to fish populations (Wolff et al. 1990). Most research on minimum flows has focused on development of instream flow and habitat assessment models (Orth 1987). Many studies comparing methodologies for instream flow and habitat assessment are

[1] The unit is jointly supported by the University of Wyoming, Wyoming Game and Fish Department, and the U.S. Fish and Wildlife Service.

available, including Orsborn and Allman (1976), Stalnaker and Arnette (1976), Wesche and Rechard (1980), and Fausch et al. (1988).

A unique opportunity to assess the significance of an enhanced minimum instream flow to a fish population occurred in Douglas Creek, Wyoming, in the Medicine Bow National Forest. Raley et al. (1988) found that compliance with instream flow agreements was poor at sites in Colorado, Montana, and Wyoming. The failure of water development projects to comply with instream flow agreements added to the lack of assessment of the biological significance of instream flows. However, Raley et al. (1988) indicated that the City of Cheyenne, Wyoming, had complied with the instream flow agreement with the U.S. Forest Service on Douglas Creek. Also, data collected prior to enhancement of the minimum instream flow in 1986, describing brown trout (*Salmo trutta*) standing stocks and habitat, were available for six reaches. These data permitted assessment of the response of the brown trout population in Douglas Creek to the enhanced minimum flow. Our objectives were to compare the brown trout standing stock estimates at sites in Douglas Creek during a prolonged period of 1.0 ft^3/second minimum flow with estimates at the same sites 2–4 years after initiation of a 5.5 ft^3/second minimum flow and to describe the physical changes in habitat at minimum flows.

STUDY AREA AND SITES

Douglas Creek is located in the Medicine Bow National Forest in southeastern Wyoming. The headwaters are on the southwest slope of the Snowy Range at 10,400 ft above mean sea level. The stream flows southwesterly for 29 mi and enters the North Platte River at an elevation of 7,500 ft just north of the Colorado–Wyoming border. The upper Douglas Creek drainage consists primarily of coniferous forests that gradually give way to sagebrush and grassland hills at lower elevations. Brown trout is the most common fish species in Douglas Creek. Other species in the drainage are brook trout (*Salvelinus fontinalis*), white sucker (*Catostomus commersoni*), longnose sucker (*Catostomus catostomus*), longnose dace (*Rhinichthys cataractae*), and creek chub (*Semotilus atromaculatus*). The sport fishery in Douglas Creek is dominated by brown trout. Wesche (1973) reported the trout stock to be 76% brown trout and 22% brook trout.

Douglas Creek was altered by the floating of large numbers of railroad ties down the channel during spring high water and by gold dredging (Thybony et al. 1985). As a result, the channel is unnaturally wide and shallow in many areas, instream cover in the form of large boulders, woody debris, or deep pools is rare, and overhead bank cover is generally lacking.

Douglas Creek was influenced by water development with completion of Rob Roy Reservoir in 1963. The reservoir, at an elevation of 9,320 ft, was part of a system to store and convey water to Cheyenne, Wyoming. Water released from the reservoir flowed in the stream channel for 1.0 mi, after which it was diverted into a pipeline for transport to Cheyenne. A minimum instream flow of 1.0 ft^3/second downstream from the diversion was required by a U.S. Forest Service use permit for the project.

The City of Cheyenne expanded the size of Rob Roy Reservoir in 1986 and a minimum flow of 5.5 ft^3/second was required by the U.S. Forest Service for a use permit. The minimum flow was achieved by a 5.0 ft^3/second minimum discharge from the diversion dam on Douglas Creek and a 0.5 ft^3/second minimum flow from a diversion structure on Horse Creek, which flows into Douglas Creek immediately downstream from the small dam on Douglas Creek.

The flow pattern through the study area for the 23 years when a 1.0 ft^3/second minimum flow occurred followed a natural regime with high flows of >170 ft^3/second in June decreasing gradually to lowest flows in late winter. 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 the construction of Rob Roy Reservoir. The duration and magnitude of the low-flow period were accentuated, where-

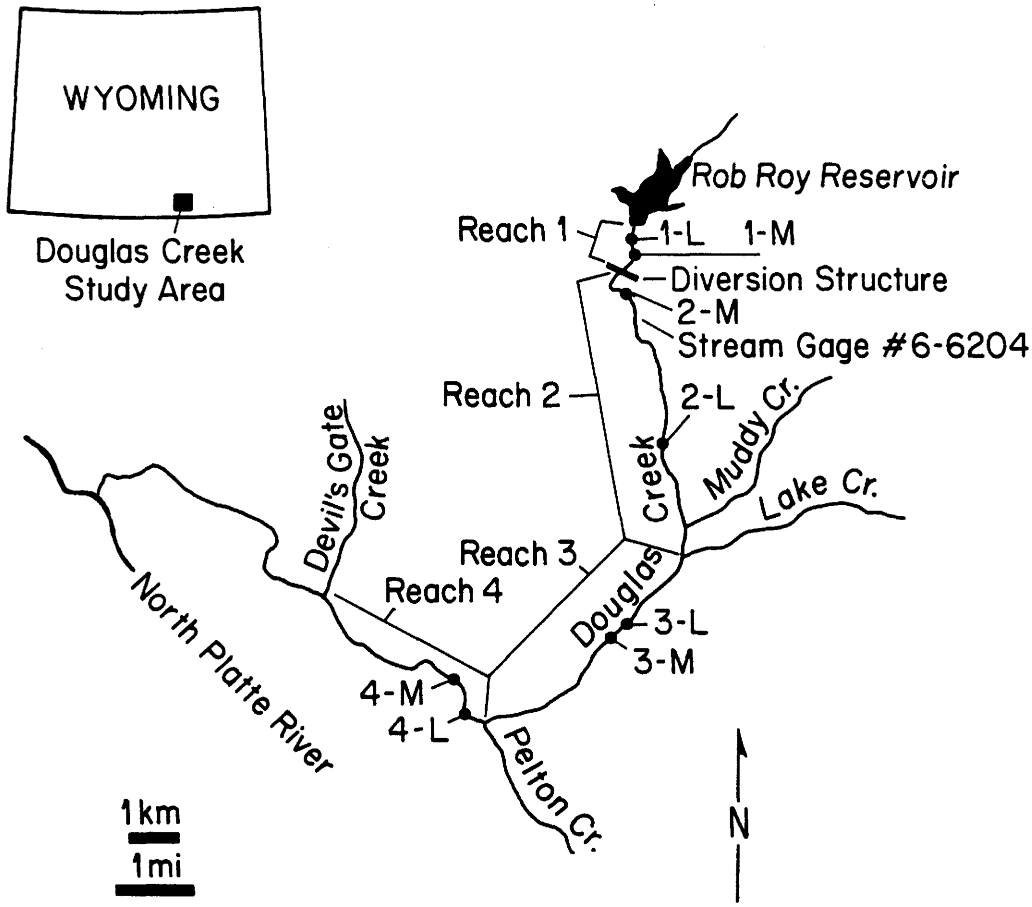

FIGURE 1. *Map of the Douglas Creek study area, Medicine Bow National Forest, Wyoming. The eight study sites are labeled with a number representing one of four reaches and a letter representing channel gradient (L, <1.0%, M, ≥1.0%).*

as the duration and magnitude of the high spring flow were reduced. A period of spring runoff still occurred as a result of natural flow from the Horse Creek drainage, which was not regulated until 1986.

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 the mouth of Lake Creek, (3) Lake Creek to Pelton Creek, and (4) Pelton Creek to Devil's Gate Creek (Figure 1). Sites of two gradient classes—low (L, <1.0% channel slope) and moderate (M, ≥1.0%)—were identified in each reach from topographic maps. Eight study sites were sampled in 1988–1990; six of these sites had been sampled in the 1970's. Two sites, 1-M and 2-L (Figure 1), not sampled in the 1970's, were added to provide one site of each gradient class within each reach.

METHODS

Field Techniques

Brown trout standing stocks were estimated in August or September at Sites 1-L and 2-M in 1972, Sites 3-L and 3-M in 1974 and 1975, and Sites 4-L and 4-M in 1973. Removal techniques with two or three electrofishing passes were used to estimate fish abundance in the 1970's and in our study (Delury 1951). All brown trout ≥4 in were weighed and measured. The CAPTURE computer program, model M(bh), which allows for variation in behavior caused by the first capture attempt was used to estimate population size in each reach (White et al. 1982). Field data were available for all sites sampled in the 1970's to enable computation of population estimates using CAPTURE with the exception of Site 2-M where only the standing stock estimate was available. We sampled each site annually from 1988 through 1990, except Site 4-M, which was sampled only in 1988 because it was subsequently impounded by beavers (*Castor canadensis*). Estimation of standing stocks in pounds per mile allowed comparison of the brown trout population before and after enhanced minimum flow without bias from increased stream width. Standing stock was estimated as the quotient of the estimated biomass in the stream reach and the length of the reach.

To determine if changes in standing stock between the 1970's and 1988–1990 were due to natural variation or response to enhanced minimum flow, the maximum and average relative fluctuation (Platts and Nelson 1988) of standing stocks were calculated for each site. The maximum relative fluctuation was calculated as:

$$M_S = [(X_{max} - X_{min})/(X_{min})] \times 100$$

where

M_S = maximum relative fluctuation,
X_{max} = largest standing stock estimate, and
X_{min} = smallest standing stock estimate.

The average relative fluctuation was calculated as:

$$A_S = [(X_{max} - X_{min})/(X_{avg})] \times 100$$

where

A_S = mean relative fluctuation,
X_{max} = largest standing stock estimate,
X_{min} = smallest standing stock estimate, and
X_{avg} = mean standing stock estimate.

The maximum and mean relative fluctuations were calculated such that positive fluctuations indicated increases and negative fluctuations indicated decreases in standing stock since the enhanced minimum flow. The fluctuations at each site were compared to natural variation that has been reported for brown trout (Platts and Nelson 1988). Based on these comparisons, we determined at which sites the standing stocks may have changed in response to enhanced minimum flow and at which sites the standing stocks exhibited variation within natural ranges.

In the 1970's, 4–16 transects were established at each of the six sites. Transects were selected to represent stream segments with similar hydraulic and morphologic characteristics. Physical habitat availability during 1.0 ft^3/second discharge from the diversion structure was measured at each site. Depth, water velocity, and substrate were recorded at 10–20 points along each transect. All eight sites were sampled following the same procedures during August or September 1988 and 1990 at minimum flow of 5.5 ft^3/second.

Two techniques were used to compare habitat in the 1970's when a 1.0 ft^3/second minimum flow occurred to 1988 and 1990 when a 5.5 ft^3/second flow had been initiated: the Physical Habitat Simulation (PHABSIM) system developed by the U.S. Fish and Wildlife Service (Milhous et al. 1984) and the Habitat Quality Index (HQI) developed by the Wyoming Game and Fish Department (Binns and Eiserman 1979). Data from the six 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 both models.

The PHABSIM analyses were performed according to Bovee (1982), Milhous et al. (1984), and PHABSIM Technical Notes prepared by the U.S. Fish and Wildlife Service. Hydraulic and channel morphology data from four sites in the 1970's, all eight sites in 1988, and seven sites in 1990 were loaded into an IFG4-formatted file for analysis with the PHABSIM. We executed the PHABSIM with 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 (Reiser and Wesche 1977, Wesche 1980). Data for fry curves were obtained from B. Nehring (Colorado Division of

Wildlife, Montrose, Colorado, personal communication). Habitat utilization curves for our analyses are given in Wolff et al. (1990).

The HQI provides estimates of potential standing stocks of trout in streams without consideration of individual species (Binns and Eiserman 1979). Eight of the nine variables in the model were estimated from the 1970's data. Because no data were available on nitrate-nitrogen concentrations (X_4) at the study sites, this variable was held constant at 0.01 mg/L among all sites. We used this concentration because it was the level reported by the Wyoming Game and Fish Department for previous HQI sampling on Douglas Creek. We monitored water temperature with recording thermographs during the summer at three locations to determine the temperature rating (X_3). 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 site at minimum low flow.

Annual low flows were simulated from discharge records for Douglas Creek, data from other streams in the area, and water diversion records from the City of Cheyenne. Measurements of discharge for Douglas Creek were available for Reach 1 in 1972, Reach 3 in 1974–1975, and Reach 4 in 1967–1973. Records of the amount of water diverted at the diversion structure separating Reaches 1 and 2 were available for 1967–1990. The diversion structure was constructed so that the minimum streamflow, 1.0 ft³/second from 1965 to 1985 and 5.5 ft³/second from 1986 to 1990, passed through the dams before any water was diverted. Thus, the diversion records provided a means for determining if the minimum low flows were maintained downstream from the diversion structure.

RESULTS

Flow Regime

The enhanced minimum flow (a change from 1.0 to 5.5 ft³/second) resulted in differential changes in the low flow regimes in the four study reaches (Table 1). In the two upstream reaches, the actual low flows were 5.0 and 5.5 ft³/second, the same as the required minimum flows, which represented a 400–450% increase in low flow from the 1970's. More than 7.4 mi downstream from Rob Roy Dam in Reach 3, where the discharges from Muddy Creek and Lake Creek contributed to the overall flow in Douglas Creek, the magnitude of the increase in minimum low flow was 33%. Similarly, in Reach 4 downstream from Pelton Creek, the minimum low flow was only 16% greater than that in the 1970's.

TABLE 1

Low flows in Douglas Creek before and after the enhanced minimum flow from the water diversion structures

Reach	Low flows (ft³/second)		Percent increase
	Before	After	
1	1.0	5.0	400
2	1.0	5.5	450
3	6.0	8.0	33
4	8.0	10.0	16

Standing Stocks

Standing stock estimates before the enhanced minimum flow were available for Sites 1-L, 2-M, 3-L, 3-M, 4-L, and 4-M (Table 2). These estimates were evaluated relative to estimates at the same sites in 1988, 1989, and 1990. The maximum and mean relative fluctuations of standing stock exceeded the natural variation for brown trout populations reported by Platts and Nelson (1988) only at Site 2-M. The increase in Site 2-M indicated a response of the brown trout stock to the enhanced minimum flow. At Site 4-L the maximum and mean relative fluctuations indicated a decline in standing stock since the 1970's.

Habitat

PHABSIM. Data were available at Sites 1-L, 2-M, 3-M, and 4-M from the 1970's for calculation of weighted usable area (WUA) at 1.0 ft³/second low flow. These WUA's

TABLE 2

Estimated standing stocks (pounds/mile) of brown trout at the Douglas Creek study sites before and after the enhanced minimum low flow. 95% confidence intervals are given in parentheses

Site	1970's	1988	1989	1990
1-L	89 (76–102)	189 (177–210)	217 (196–238)	213 (194–232)
1-M	—[a]	772 (659–885)	553 (387–719)	818 (711–925)
2-L	—	307 (269–345)	222 (187–257)	243 (190–296)
2-M	56[b]	358 (325–391)	327 (300–354)	517 (477–556)
3-L	226 (209–243) 281 (256–306)	214 (203–225)	197 (148–246)	261 (247–275)
3-M	328 (294–362) 239 (216–262)	288 (236–340)	173 (145–201)	233 (213–253)
4-L	635 (547–742)	354 (335–373)	156 (120–192)	380 (149–611)
4-M	148 (123–173)	183 (170–196)[c]		

[a] — indicates site not measured.
[b] Data not available to compute confidence intervals.
[c] Site was not sampled in subsequent years due to its impoundment by beaver.

were compared to estimates made in the 1980's at a minimum flow of 5.5 ft^3/second (Table 3). The 1988 and 1990 estimates of WUA for spawning, juveniles, and adults were greater in 1988 and 1990 at all four sites, but the greatest increases were at the two upstream sites, Site 1-L and Site 2-M, where the minimum low flow had increased by 400% and 450%, respectively.

HQI. Data were available from the 1970's to compute the HQI at six sites (Table 4). Potential standing stocks of trout were 5–20 times greater at Sites 1-L and 2-M in 1988 and 1990 than in the 1970's, but little difference was observed at sites further downstream. The greater estimates of potential standing stocks at Sites 1-L and 2-M were due to higher late summer streamflows, fewer eroding banks, higher water velocity, and greater stream width (Table 5).

DISCUSSION

Increases in standing stocks of brown trout that exceeded the range of natural fluctuation were observed only at one site (Site 2-M) in the upper 7.4 mi of the study area. At this site, the minimum low flow was increased by 450% between the first sampling in 1972 and the 1988–1990 sampling. Despite a 400% increase in the minimum low flow at another site (Site 1-L) in the upper 7.5 km of the study area, the variation in brown trout standing stock estimates between 1972 and 1988–1990 was within the range of natural fluctuation at that site. At sites more than 7.5 km downstream from Rob Roy Dam where the increases in low flows were only 16–33%, increases in standing stocks outside the range of natural fluctuations were not observed, but at one site (Site 4-L) a decrease in excess of natural fluctuation was indicated (Figure 2).

The increase in minimum low flow appeared to produce detectable changes in habitat at sites within the first 7.5 km below Rob Roy Dam based on both the PHABSIM (Table 3) and the HQI (Table 4). The PHABSIM analysis indicated greater WUA for juveniles and adults and more spawning habitat. The greater potential standing stocks predicted by the HQI were due to higher late summer flows, faster water velocities, fewer eroding banks, and greater stream width. Greater late summer flows, faster water velocities, and greater stream widths were all directly the result of enhanced minimum flows. The presence of fewer eroding banks also may have been a response to alteration of the flow regime since construction of Rob Roy Dam. The reduction of the magnitude of the spring runoff may have enabled vegetation to become established on banks previously

TABLE 3
Weighted usable area ($ft^2/1,000$ ft) for brown trout at low flow before and after the enhanced minimum low flow in Douglas Creek based on the Physical Habitat Simulation system

Site	1970's	1988	1990
Spawning			
1-L	628	4,619	3,992
1-M	—[a]	2,011	1,902
2-L	—	2,448	2,894
2-M	1,360	3,840	1,517
3-L	—	6,546	7,731
3-M	3,565	6,045	5,298
4-L	—	3,600	3,888
4-M	3,168	4,435	—
Fry			
1-L	2,244	1,966	2,042
1-M	—	797	1,224
2-L	—	2,793	2,151
2-M	722	618	2,318
3-L	—	2,008	4,182
3-M	1,072	805	2,409
4-L	—	1,606	2,138
4-M	2,097	1,870	—
Juvenile			
1-L	3,800	6,503	7,606
1-M	—	6,482	4,835
2-L	—	7,178	9,099
2-M	3,294	4,783	4,405
3-L	—	5,378	9,426
3-M	3,888	4,045	8,918
4-L	—	8,680	7,214
4-M	7,642	8,252	—
Adult			
1-L	1,270	2,213	3,445
1-M	—	2,644	2,573
2-L	—	2,511	4,483
2-M	310	1,259	2,046
3-L	—	755	1,790
3-M	150	270	1,501
4-L	—	10,106	8,147
4-M	2,138	2,754	—

[a] — indicates site not measured.

TABLE 4
Predictions of potential trout standing stocks (pounds/mile) in Douglas Creek using the Habitat Quality Index

Site	1970's	1988	1990
1-L	75	487	364
1-M	—[a]	427	477
2-L	—	388	453
2-M	43	715	814
3-L	203	192	307
3-M	101	236	433
4-L	169	159	170
4-M	232	342	—

[a] — indicates site not measured.

damaged by anthropogenic activities. The mechanism that seemed to have contributed to greater standing stocks of brown trout at Site 2-M, where a 450% increase in minimum low flow occurred, was greater availability of pools with deeper water. Such pools increased the living space for juvenile and adult fish (Chapman 1966).

At Site 1-L there was no apparent change in brown trout abundance despite a 400% increase in the minimum low flow. The HQI analysis indicated that despite increases in habitat quality stemming from greater late summer streamflow, less annual streamflow variation, fewer eroding banks, faster water velocities, and enhanced stream width, there was no increase in available cover. Very little instream cover was available at this site (Table 5). It is likely that the availability of cover limited brown trout abundance and cover was not increased by the enhanced minimum flow.

The apparent decrease in standing stocks of brown trout at Site 4-L seemed to be related to deterioration of habitat since the 1970's. The HQI indicated a reduction in the abundance of cover and submerged aquatic vegetation, and an increase in the number of eroding banks, between the 1970's and 1988 and 1990. Substantial cattle grazing was evident in the riparian area during the 1988 and 1990 sampling periods. The increase in minimum low flow enhanced the late summer streamflow attribute in the HQI, but little difference in potential standing stock was predicted because of the reduction in quality of other habitat features. At both Site 1-L and Site 4-L, cover limitations seem to have had more influence on brown trout abundance than did the enhanced minimum low flow.

Previous studies have inferred that minimum low flows influence trout standing stocks. For example, White et al. (1976) found greater standing stocks of trout in midwestern streams with more stable and higher baseflows. They found that augmented low flows increased pool space,

TABLE 5
Ratings for the attributes used in the Habitat Quality Index at the study sites in Douglas Creek

Attribute	Site	1970's	1988	1990
Late summer streamflow	1-L	1	3	3
	1-M	—[a]	3	3
	2-L	—	4	4
	2-M	1	4	4
	3-L	2	3	3
	3-M	2	3	3
	4-L	2	3	3
	4-M	2	3	—
Annual stream-flow variation	1-L	1	3	3
	1-M	—	3	3
	2-L	—	3	3
	2-M	1	3	3
	3-L	2	2	2
	3-M	2	2	2
	4-L	2	2	2
	4-M	2	2	—
Cover	1-L	1	1	1
	1-M	—	2	2
	2-L	—	1	1
	2-M	2	2	1
	3-L	3	1	0
	3-M	2	0	0
	4-L	2	2	0
	4-M	2	2	—
Eroding banks	1-L	3	4	4
	1-M	—	4	4
	2-L	—	4	4
	2-M	3	4	4
	3-L	3	3	3
	3-M	3	4	4
	4-L	3	3	2
	4-M	3	3	—
Substrate	1-L	4	4	4
	1-M	—	2	3
	2-L	—	2	2
	2-M	2	4	4
	3-L	3	2	2
	3-M	2	2	2
	4-L	2	1	1
	4-M	2	2	—
Water velocity	1-L	2	3	2
	1-M	—	4	4
	2-L	—	3	4
	2-M	2	3	3
	3-L	2	2	4
	3-M	2	2	4
	4-L	2	2	2
	4-M	3	3	—
Stream width	1-L	3	3	4
	1-M	—	3	4
	2-L	—	3	4
	2-M	4	3	4
	3-L	3	3	3
	3-M	3	3	3
	4-L	3	3	2
	4-M	3	3	—

[a] — indicates site not measured.

improved water temperature, increased stream edge, produced more instream hiding cover, created a greater food supply, and enhanced reproduction. They also suggested that during the winter, low flow was the most significant hydrologic variable limiting trout survival. Smith (1976)

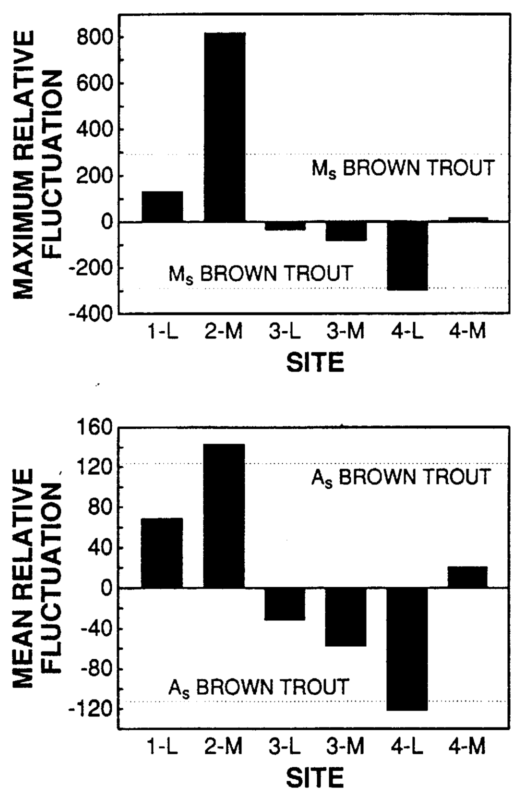

FIGURE 2. ***Maximum and mean relative fluctuations of brown trout standing stocks at the Douglas Creek study sites. Dashed lines represent the natural variation in maximum (M_s) and mean (A_s) reported in Platts and Nelson (1988). Fluctuations in standing stocks in excess of natural variation are attributed to changes in habitat quality in Douglas Creek.***

described the reduction of salmonid standing stocks in response to a 90% loss of instream flow in the Trinity River, California. The loss of flow resulted in higher water temperature and increased sediment deposition in spawning areas and pools.

Our observations on Douglas Creek suggest that increases in minimum streamflows may have variable effects on brown trout populations at different locations in a stream. Changes in brown trout abundance may not occur with enhanced minimum flows if other habitat features, such as cover, are limiting. Furthermore, deterioration of habitat due to other causes may offset the benefits derived by enhanced minimum flow, as was observed at Site 4-L. Additionally, inaccurate sampling techniques and natural variation in abundance may mask the ability to detect changes in brown trout standing stocks resulting from relatively small (16–33% in this study) increases in minimum streamflow.

Our findings fail to support the assumption that enhanced minimum instream flow for fisheries should result in the production of more or larger fish. In situations where factors other than minimum low flow are limiting populations, enhanced fish production is unlikely to be observed.

ACKNOWLEDGMENTS

We thank G. Eaglin, R. Gipson, A. Miller, J. Rhoades, R. Wilkison, and S. Wolff for field assistance, and R. Beiswenger, J. Roelle, and C. Stalnaker for critical comments. The work was funded by the U.S. Fish and Wildlife Service National Ecology Research Center.

REFERENCES

Binns, N. A., and F. M. Eiserman. 1979. Quantification of fluvial trout habitat in Wyoming. *Transactions of the American Fisheries Society* 108(3):215–228.

Bovee, K. D. 1978. Probability-of-use criteria for the family Salmonidae. Instream Flow Information Paper No. 4. Washington, DC: U.S. Fish and Wildlife Service (FWS/OBS-78/07).

———. 1982. A guide to stream habitat analysis using the Instream Flow Incremental Methodology. Instream Flow Information Paper No. 12. Washington, DC: U.S. Fish and Wildlife Service (FWS/OBS-82/26).

———. 1986. Development and evaluation of habitat suitability criteria for use in the Instream Flow Incremental Methodology. Washington, DC: U.S. Fish and Wildlife Service (Biological Report 86[7]).

Chapman, D. 1966. Food and space as regulators of salmonid populations in streams. *The American Naturalist* 100:345–357.

Delury, D. B. 1951. On the planning of experiments for the estimation of fish populations. *Journal of the Fisheries Research Board of Canada* 8(4):281–307.

Fausch, K. D., C. L. Hawkes, and M. G. Parsons. 1988. Models that predict standing crop of stream fish from habitat variables: 1950–85. Washington, DC: U.S. Forest Service (General Technical Report PNW-GTR-213).

Milhous, R. T., D. L. Wegner, and T. Waddle. 1984. User's guide to the Physical Habitat Simulation (PHABSIM) system. Instream Flow Information Paper No. 11. Washington, DC: U.S. Fish and Wildlife Service (FWS/OBS-81/43).

Orsborn, J. F., and C. H. Allman, editors. 1976. *Instream flow needs,* Volume II. Bethesda, MD: American Fisheries Society.

Orth, D. J. 1987. Ecological considerations in the development and application of instream flow habitat models. *Regulated Rivers: Research and Management* 1(2):171–181.

Platts, W. S., and R. L. Nelson. 1988. Fluctuations in trout populations and their implications for land-use evaluation. *North American Journal of Fisheries Management* 8(3):333–345.

Raley, C., W. A. Hubert, and S. Anderson. 1988. Maintenance of flows downstream from water development projects in Colorado, Montana, and Wyoming. Washington, DC: U.S. Fish and Wildlife Service (Biological Report 88[27]).

Reiser, D. W., and T. A. Wesche. 1977. Determination of physical and hydraulic preferences of brown and brook trout in the selection of spawning locations. Laramie: University of Wyoming, Water Resources Research Institute (Publication 64).

Smith, F. E. 1976. Water development impact on fish resources and associated values of the Trinity River, California. Pages 98-111 *in* J. F. Orsborn and C. H. Allman, editors. *Instream flow needs,* Volume II. Bethesda, MD: American Fisheries Society.

Stalnaker, C. B., and J. L. Arnette. 1976. Methodologies and determination of stream resource flow requirements, an assessment. Washington, DC: U.S. Fish and Wildlife Service (FWS/OBS-79/36).

Thybony, S., R. Rosenberg, and E. Rosenberg. 1985. *The Medicine Bows.* Laramie, WY: University Press.

Wesche, T. A. 1973. Parametric determination of minimum streamflow for trout. Laramie: University of Wyoming, Water Resources Research Institute (Publication 37).

———. 1980. The WRRI trout cover rating method. Laramie: University of Wyoming, Water Resources Research Institute (Publication 78).

———, and P. A. Rechard. 1980. A summary of instream flow methods for fisheries and related research needs. Laramie: University of Wyoming, Water Resources Research Institute (Eisenhower Consortium Bulletin 9).

White, G. C., D. R. Anderson, K. P. Burnham, and D. L. Otis. 1982. Capture-recapture and removal methods for sampling closed populations. Los Alamos National Laboratory (LA-8787-NERP).

White, R. J., E. A. Hansen, and G. R. Alexander. 1976. Relationship of trout abundance to stream flow in midwestern streams. Pages 597–615 *in* J. F. Orsborn and C. H. Allman, editors. *Instream flow needs,* Volume II. Bethesda, MD: American Fisheries Society.

Wolff, S. W., T. A. Wesche, D. D. Harris, and W. A. Hubert. 1990. Brown trout population and habitat changes associated with increased minimum low flows in Douglas Creek, Wyoming. Washington, DC: U.S. Fish and Wildlife Service (Biological Report 90[11]).

Received: 28 June 1991
Accepted: 18 November 1991
Discussion open until: 30 September 1992