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EXECUTIVE SUMMARY

The purpose of this study was to assess 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 a substantial increase of the required minimum flow in 1986 from 1.0 to 5.5 cubic feet/second (cfs) after 23 years at 1.0 cfs. Population and habitat data obtained during the period when minimum flow was 1.0 cfs (1972-1976) were compared to data collected after the minimum flow was increased to 5.5 cfs (1988-1989).

More than a two-fold increase in brown trout abundance was measured between 1973 and 1988-1989 in a reach between Rob Roy Dam and the point of water diversion. Within this reach discharge was occasionally as low as 3.0 cfs prior to 1986, but the low flow was not as severe as downstream of the water diversion.

A four- to six-fold increase in brown trout abundance was indicated between 1972 and 1988-1989 in a 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 five times greater.

At sites more than 6.4 mi downstream from the water diversion structure, where the impact of reduced flow had

been less due to addition of water from tributary streams, no measurable changes related to the enhanced minimum flow were identified.

INTRODUCTION

The purpose of this study was to assess the biological significance of an increase in minimum low flow to brown trout (*Salmo trutta*) using a case study of Douglas Creek on the Medicine Bow National Forest, Wyoming. Douglas Creek is a regulated stream that underwent a substantial increase in the required minimum flow to 5.5 cubic feet/second (cfs) in 1986 after 23 years of minimum flows at 1.0 cfs. Availability of population and habitat data gathered through studies conducted by the Wyoming Water Research Center (WWRC) during the period of the 1.0 cfs minimum flow presented a unique opportunity to evaluate the biological significance of increased minimum flows for brown trout in the system.

Instream flows as mitigation to protect fish and other aquatic organisms have been widely prescribed for streams which have experienced water development (Wesche and Rechard 1980). Two major assumptions underlie the success of any flow recommendation. The first assumption is that flow releases have some biological significance to the organisms of concern, while the second is that project operators will comply with the required flow releases. Raley et al. (1988) found that compliance with instream flow agreements was poor among sites in Colorado, Montana, and Wyoming where stream flow data were available to enable an assessment. Availability of projects where flows are monitored and compliance has occurred was a major factor limiting the ability to evaluate the biological significance of instream flow agreements. Douglas Creek was one of a very 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). Numerous studies comparing methodologies for instream flow and habitat assessment are available, including Osborn and Allman (1976), Stalnaker and Arnette (1976), Wesche and Rechard (1980), E.A. Engineering, Science, and Technology (1986), and Fausch et al. (1988). Because of the relation between physical habitat in a stream and discharge, both instream flow models and habitat assessment models have developed along similar paths with the same model used for both purposes in many cases. Despite the large amount of work, minimal evidence has been reported that links a biological response of fish populations to changes in minimum instream flow.

The goal of this study was to investigate the response of the brown trout population in Douglas Creek to an increase in the minimum flow release (to 5.5 cfs), after a 23-year period of a 1.0 cfs minimum low flow. Our specific 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 it to data obtained during the 1.0 cfs minimum flow period;

2) Describe the physical habitat in Douglas Creek at a 1.0 and 5.5 cfs minimum low flow;

3) Determine possible mechanisms through which the enhanced minimum flow in the Douglas Creek may have improved the brown trout fishery.

DESCRIPTION OF STUDY AREA

Douglas Creek is located on the Medicine Bow National Forest in southeastern Wyoming (Figure 1). The headwaters are on the southeast slope of the Snowy Range at 10,400 ft above mean sea level. The stream flows in a southwesterly direction 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, which gradually give way to sagebrush and grassland hills at the lower elevations. The brown trout is the most common fish species inhabiting Douglas Creek; other species occurring in the drainage include brook trout (*Salvelinus fontinalis*), white sucker (*Catostomus commersoni*), longnose sucker (*Catastomus catastomus*), longnose dace (*Rhinichthys cataractae*), and creek chub (*Semotilus atromaculatis*) (Baxter and Simon 1970).

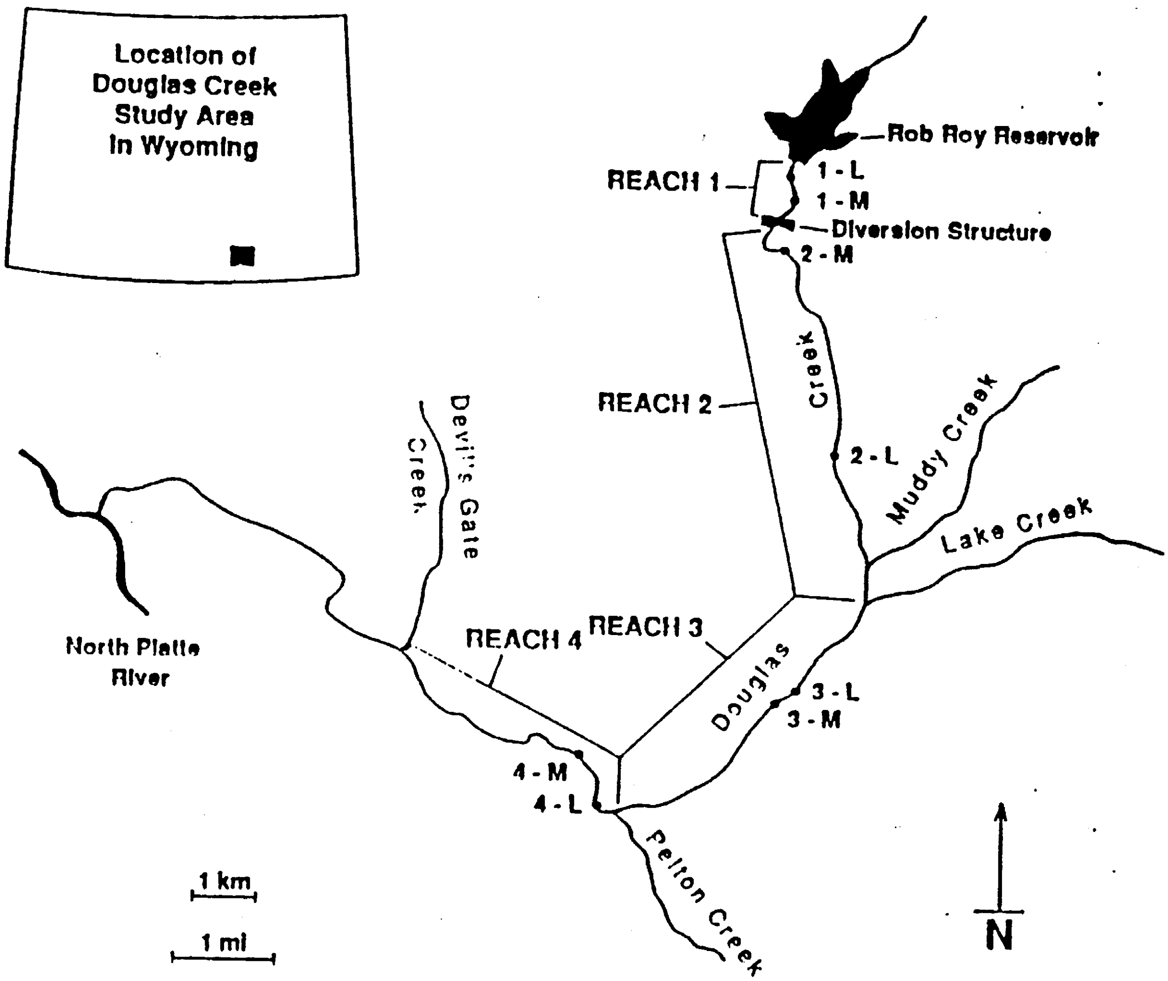

Figure 1. Map of the Douglas Creek study area, Medicine Bow National Forest, Wyoming.

The sport fishery in Douglas Creek is dominated by brown trout. Wesche (1973) reported that the trout stock was comprised of 76% brown trout and 22% brook trout at a study site 0.55 mi downstream from Rob Roy Dam in 1972. Jespersen (!980) reported that 87% of the trout population in Douglas Creek downstream from Rob Roy Dam was made up of brown trout.

The brown trout in Douglas Creek are relatively small and appear to grow slowly. The average total length of brown trout sampled by Jesperson (1980) was 6.0 in and the largest fish was 14.7 in. Similar sizes were observed by Wesche (1979) and during studies by the Wyoming Game and Fish Department in 1979 (Donald Miller, Wyoming Game and Fish Department, Laramie, personal communication). Length frequency data from Wesche (1974) and Jesperson (1980) indicate that brown trout reach a total length of 2 in by the end of their first summer of life and 4-5 in by the end of their second summer. Maximum age using scales has been estimated to be 5 years by Wesche (1972), but it is expected that the use of otoliths would yield higher age estimates (Kozel and Hubert 1987).

Douglas Creek has been altered by both railroad tie dries and gold dredging operations (Thoybony et al. 1986). Tie driving was the practice of using streams and rivers to transport logs to areas where they could be used. The majority of this timer was used as railroad cross-ties and shaped into ties prior to transport, hence the name tiedrive. Timber was usually harvested in the winter and stacked on stream banks until spring. Once spring runoff began and flows were at or near their peak, logs were floated downstream. In order 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 known for gold. Large steam shovels were used to excavate the stream bed 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, ranging up to 3.6 times wider than would be expected for a natural stream with a similar drainage area (Robert 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 totally absent. Also, overhead bank cover is generally lacking.

Douglas Creek was also influenced by water development when construction of Rob Roy Reservoir was completed in 1963. The reservoir, located at an elevation of 9,320 ft, was part of a system used to store (storage 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 mi where it could be diverted by a small dam into a pipeline for transport to Cheyenne. Termed, Stage I, this system 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. Downstream from the diversion structure, Douglas Creek flows 22 miles before emptying into the North Platte River.

The City of Cheyenne anticipated the need for additional municipal water so enlargement of the project, Stage II, was proposed. It included increasing the storage capacity of Rob Roy Reservoir to 35,400 acre-feet in order to provide Cheyenne with 23,200 acre-feet of water per year.

As a result, 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) conducted a study as a fisheries biologist employed by the U.S. Forest Service on the Medicine Bow National Forest.

Wesche (1973) evaluated the minimum stream flow for trout in Douglas Creek following construction of Rob Roy Reservoir. His primary study area was 0.55 mi downstream from Rob Roy Reservoir corresponding to Site 1-L in our study. A stream gage (Number 6-6204) located 1.2 mi further downstream and operated from 1955 to 1971 showed a maximum discharge of 865 cfs (June 5, 1957) and a minimum discharge of 1.3 cfs (March 1-31, 1958). The average daily flow (adf) over 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 water depth, velocity, wetted width, wetted perimeter, hydraulic radius and cross-sectional area at 16 transects over the 680-ft study reach. Potential trout cover, undercut banks and rubble-boulder areas, was also measure over the range of flows. Wesche recommended a minimum flow of 25% adf (7.8 cfs). He found that the greatest rate of decrease from the hydrologic parameters, the water surface area, and the available trout cover occurred at flow reduction between 25 and 12.5% adf.

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

In addition to a minimum bypass flow of 5.5 cfs, Jesperson (1980) recommended a flushing flow of 130 cfs for 72 hours coinciding with natural peak runoff each spring. These recommendations were subsequently incorporated in the U.S. Forest Service use permit for Stage II of the Cheyenne water project. A minimum bypass 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 during Stage I through the study area, controlled to quite some degree by Rob Roy Dam, followed a rather natural regime with high flows of several hundred cubic feet per second in June decreasing gradually to lowest flows during 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-year period prior to water development (1956-1965) is shown in Figure 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 low flow period was accentuated, both in duration and magnitude, while the duration and magnitude of the high spring flow was reduced. However, a period of spring runoff still occurred as a result of flow from the Horse Creek drainage which was not regulated by Stage I.

A comparison of natural flows to those which occurred with water diversion indicated that during Stage I the low flows were generally less than the natural 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

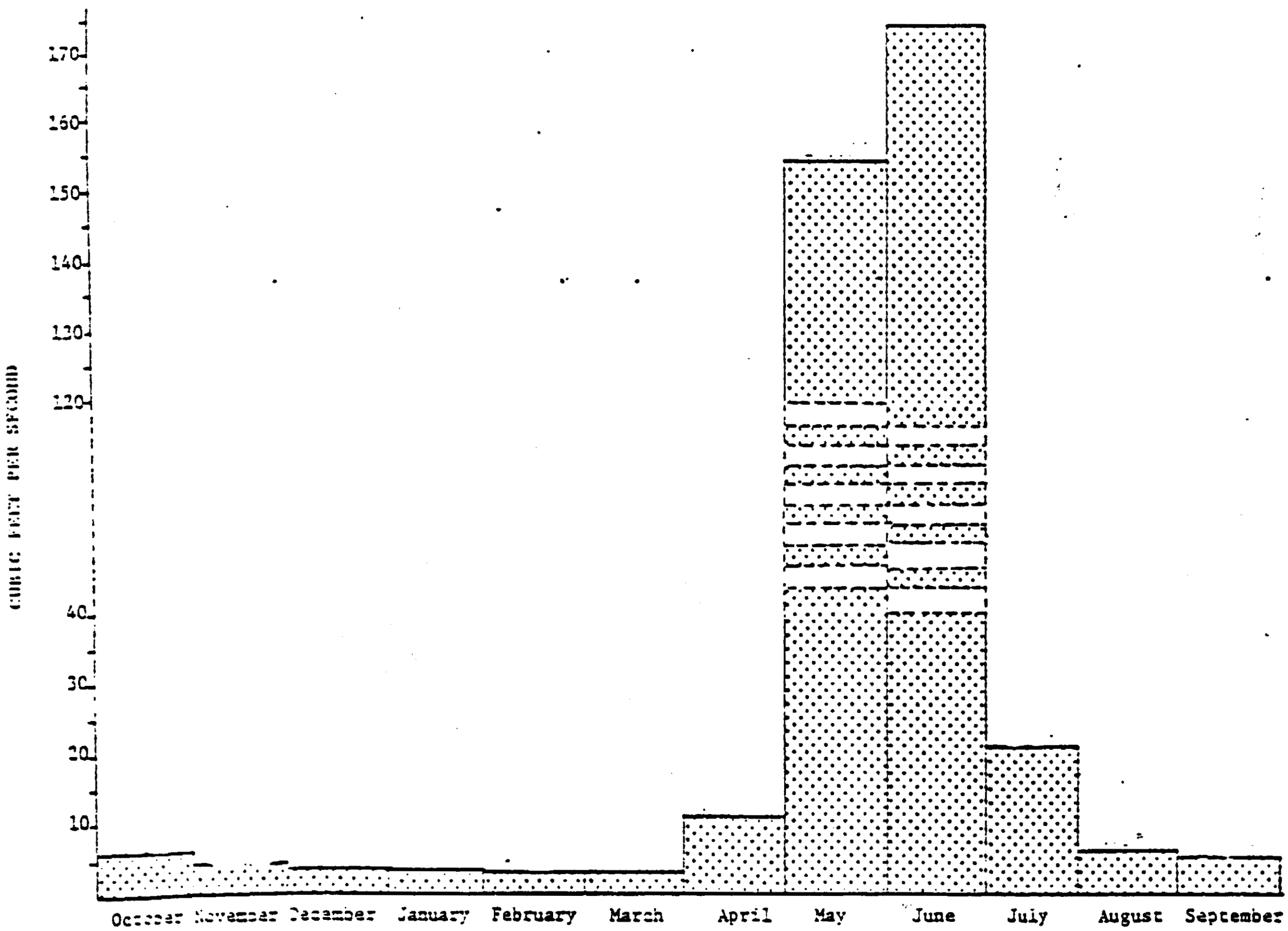

Figure 2. Mean monthly discharge at Gage Number 6-6204 on Douglas Creek, 1956-1965, prior to operation of Rob Roy Dam.

recommended that Stage II be implemented so that a constant minimum flow be maintained throughout the year. The minimum flow that he recommends (5.5 cfs) actually exceeded the mean natural low flow experienced from November through March (Figure 2) in Douglas Creek at Gage Number 6-6204.

METHODS

Design

Four reaches of Douglas Creek were identified based on hydrologic features. Reaches were defined by major changes in discharge due to diversion of water from the creek or to perennial tributaries entering the creek (Figure 1). These reaches were: 1) Rob Roy Dam to the diversion structure (1.0 mi), 2) the diversion structure to Lake Creek (6.4 mi), 3) Lake Creek to Pelton Creek (4.7 mi), and 4) Pelton Creek to Devils Gate Creek (5.2). The four reaches extend over 17.4 mi of Douglas Creek (Figure 1). The lower 5 miles of Douglas Creek (Devils Gate Creek to North Platte River) were not included in this study. Two gradient classes were identified, low (< 1.0%, L) and moderate (1.0%, M), within the four study reaches. Kozel's (1987) work on streams in the Medicine Bow National Forest showed a relationship between stream gradient, habitat, and trout standing stocks. Study sites were at 8,220 to 9,300 ft above mean sea level.

Eight study sites were sampled in 1986 and 1988; six of these 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.

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; Site 3-L in 1974 and 1975; Site 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. Sampling was accomplished by electroshocking using removal methods (Delury 1951). All trout equal to or greater than 4 in total length were identified, weighed, and measured. Standing stocks were computed, along with 95% confidence limits, using the CAPTURE computer program, model M(bh), which allows for variation in behavior due to the first capture attempt (White et al. 1982). Standing stocks were estimated during August and September of 1988 and 1989. Standing stocks were computed as both pounds per mile and pounds per surface acre of stream. The estimate in pounds per mile enabled comparison of 1970's and 1980's estimates without bias associated with the changes in water surface area associated with increased minimum flow.

During the 1970's four 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 during a 1.0 cfs discharge downstream from the diversion structure. Water depth was measured at 10 to 20 points along each transect, while mean water velocity and substrate were also recorded during certain sampling periods. The amount of cover was measured following Wesche (1980). A complete set of measurements was not available for all six sites studied in the 1970's, but a complete set was gathered during August and September 1988 at our 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). The data from the six study sites in the 1970's were not collected specifically for application of these models; model variables were sometimes estimated from file information and photographs. At some sites, data were not available to apply all three models. For example, the lack of data at three sites prevented PHABSIM application, and the absence of cover data at another site prevented the TCR from being used.

PHABSIM analyses were done 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. PHABSIM was run using depth, velocity and substrate curves for adult, juvenile, fry and spawning brown trout (Bovee 1978 and 1986). Curves for all life stages except fry were developed with data collected from Douglas Creek during the 1970's (Wesche 1980; Reiser and Wesche 1977). Data for fry habitat utilization curves were obtained from Barry Nehring, Colorado Division of Wildlife, Denver, Colorado. Habitat utilization curves used in our analyses are in Appendix A.

The Habitat Quality Index was developed by the Wyoming Game and Fish Department (Binns and Eiserman 1979; Binns 1982) and 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/1 for all sites. This concentration was chosen because it is the level reported by the Wyoming Game and Fish Department for previous HQI sampling on Douglas Creek. Similarly, there were little data available on water temperature in Douglas Creek, both the data that were examined suggested that optimum conditions exist most of the time (Wesche 1973). Therefore, an optimum temperature rating (X_3) was given to all study sites. Measured values for all variables in the model were transformed to ratings of 0 to 4 and inserted into the Model II multiple regression equation to provide an estimate of potential standing stock at each study site.

The Trout Cover Rating (TCR) results from a dimensionless equation whose typical output ranges from 0.0 to 1.0 (Wesche 1980). The 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 water depths greater than 1.5 ft. Preference factors are used to weight the model for either juvenile (< 6 inches) or adult ($\geq$ 6 inches) trout. The TCR has been found to be correlated with brown trout standing stock in streams of southeastern Wyoming (Wesche et al. 1987).

During 1988, data on water temperature were collected from three locations on Douglas Creek. Recording thermographs were located at the outlet from Rob Roy Reservoir (operated by the U.S. Forest Service), just downstream from the diversion structure, and 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 general 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 1974-1975, and

Reach 4 in 1967-1973. Records of the amount of water diverted at the diversion structure separating Reach 1 and 2 were available for 1967-1988. No records of discharge at any point in the Douglas Creek study area have been obtained since 1975. The diversion dam was constructed so that the minimum stream flow, 1 cfs from 1967 to 1985 and 5.5 cfs from 1986 to 1988, was passed through the dams before 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

Brown trout standing stock estimates ranged from 56 to 635 lb/mi in the 1970's, from 68 to 772 lb/mi in 1988, and from 78 to 553 lb/mi in 1989. Substantial variation was found among study sites (Table 1).

At Site 1-L the brown trout standing stock was estimated to be 89 lb/mi in 1973, but 189 and 217 lb/mi in 1988 and 1989, respectively. A more than two-fold increase in brown trout abundance between the 1970's and late 1980's was indicated within the reach between Rob Roy Dam and the water diversion structure.

At Site 2-M, there was an estimated 56 lb/mi of brown trout in 1972, while the estimated standing stock was 307 and 222 lb/mi in 1988 and 1989, respectively. A four- to six-

Table 1. Estimated standing stocks brown trout ($\geq$ 4 inches total length) at Douglas Creek study sites. 95% confidence intervals in parentheses.

Unit of measure	Site	Time period 1970's	1988	1989
Pounds/ 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/ 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)	

fold increase in brown trout abundance was indicated in this reach immediately downstream from the water diversion structure where the influence of the 1.0 cfs minimum flow had been most severe.

Abundance estimates in made Reaches 3 and 4, more than 6.4 mi downstream from the water diversion structure, indicated no change in relation to the enhanced minimum flow. There was indication of reduced brown trout abundance 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-L, 3-M and 4-L).

Possible changes in population structure between the 1970's and 1988-1989 were assessed by evaluating the length frequencies of fish $\geq$ 4 in total length (Table 2). The proportion of brown trout $\geq$ 6.0 in 1988 was less than in the 1970's at most sites, but in 1989 it was greater than in the 1970's at most sites. Substantial year-to-year variation in population structure is indicated by data from the 1970's (Site 3-L and 3-M), as well as from 1988 and 1989. Our data do not indicate that the change in minimum flow has led to a change in population structure, but an increased proportion of larger-size brown trout was indicated between 1988 and 1989 at the five sampling sites closest to Rob Roy Dam.

Table 2. Proportion of brown trout included in the standing stock estimates ($\geq$ 4 inches total length) at Douglas Creek study sites within specific length increments.

Length increment (in)	Site	Time period 1970's	1988	1989
$\geq$ 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	46.9	68.8
		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

Table 2. Continued.

	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	

The standing stock of fish $\geq$ 8 in was compared between the 1970's and 1988-1989 as another measure of possible changes (Table 3). A greater proportion of fish $\geq$ 8 in was observed between the 1970's and 1988-1989 at Sites 1-L and 3-L, 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 had a five-fold increase in low flow and a doubling of the average wetted width at low flow. The differences between the 1970's and 1988 declined with progression downstream from Site 2-M immediately below the water diversion structure. Study sites in Reach 4 experienced only a 38% increase in low flow and an 11-16% increase in wetted width.

Physical habitat differences between the 1970's and 1988 at the minimum flows were evaluated using PHABSIM (Table 5). Increases in WUA at low flow were indicated for both adult and juvenile brown trout over all four study reaches; but the relative changes were greatest in Reaches 1 and 2. Physical habitat for fry at minimum flows declined from the 1970's to 1988, while there was an increase in spawning habitat.

Table 3. Estimated number of brown trout per mile of 8 inches or more total length at Douglas Creek study site.

	Time period		
Site	1970's	1988	1989
1-L	141	197	340
1-M		1104	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.

	Minimum low flow (cfs)		Average wetted width (ft)	
Site	1970's	1988	1970's	1988
1-L	3.0	5.0	15.9	23.1
1-M		5.0		23.2
2-L		5.0		23.9
2-M	1.0	5.0	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

Table 5. Weighted usable area for adult, juvenile, fry and spawning life stages of brown trout at Douglas Creek she 1970's and in 1988.

	Weighted usable area (ft^2/1000 ft)							
	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

Potential standing stocks of trout in the 1970's and 1988 were estimated using the HQI (Table 6). A three-fold increase in potential standing stock between the 1970's and 1988 was estimated at Site 1-L, while a seven-fold increase was estimated at 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 stream flows, less annual variation in stream flow, 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 partly due to a small change in area of cover with a larger change in water surface area, but habitat losses due to destruction of overhanging banks by cattle and sediment deposition in the streambed are also a likely contributing factor.

The TCR indicated a decline in the quality of tout cover from the 1970's to 1988 at minimum flows among all five study sites where data were available from the 1970's (Table 8). The rating appeared to have declined due to decreases in overhead bank cover, as well as the area of rubble-boulder and aquatic vegetation cover (Table 9). Some of the changes

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

	Standing stock (pounds/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

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	
Attribute	Site	1970's	1988	1970's	1988
Late summer stream flow (%)	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 stream flow 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

Table 7. Continued.

	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				
	2-M	15	1	3	4
	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[1]	1-L	A	A	4	4
	1-M		0		2
	2-L		0		2
	2-M	0	A	2	4
	3-L	F	0	3	2
	3-M	0	0	2	2
	4-L	F	L	2	1
	4-M	0	0	2	2
Water Velocity (ft/second)	1-L	0.95	1.21	2	3
	1-M		2.10		4

Table 7. Continued.

	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 (ft)	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

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

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

	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

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[1]		Rubble-boulder[2] and aquatic vegetation		Deep water[3]	
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

[1] Length of overhead bank cover in the study reach having a water depth of at least 0.50 feet and a width of 0.3 feet or greater divided by length of the thalweg through the reach.

[2] Surface area of the study reach having water depths greater than 0.50 feet and substrate size of 3.0 inches in diameter or greater (i.e., rubble and boulder) or a

Table 9. Continued.

substrate covered with aquatic vegetation divided by total surface area of the study reach) at minimum flow.

[3] Surface area of the study reach having a water depth of 1.5 feet or greater divided by total surface are of the study reach at minimum flow.

may have been due to the substantial increase in water surface area at low flow with little change in cover availability. Differences in available cover were assessed by comparing the area of cover per 100 ft 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 to 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 at Reach 4. The causes of the habitat loss are not a function of changes in minimum flow from the 1970's to 1988, but appear to be related primarily to sediment deposition in Reach 1 and destruction of streambanks in Reach 4.

Temperature

Temperature data gathered during the summer of 1988 showed that on 3 days the water temperature reached 70° F at the most downstream thermograph near the mouth of Lake Creek. Maximum recorded temperatures at the outlet from the dam and at the diversion structure were 61° and 63° F, respectively. Average daily water temperatures in August at all three stations were between 50° and 55° F.

Table 10. Estimated abundance (ft 2/1000 ft) of rubble-boulder, aquatic vegetation cover and deep-water cover at Douglas Creek study sites in the 1970's and in 1988 using the definition's of Wesche (1980).

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

Discharge

Annual low flow estimates based on past records and simulation using trends in nearby watersheds indicated that annual low flows have fluctuated substantially in Reaches 1, 3, and 4 from 1967 to 1988 (Figure 3). Annual low flow in Reach 2 immediately downstream from the diversion dam was consistently 1.0 cfs from 1967 to 1986 when it was increased to 5.5 cfs. The simulations indicated that annual low flows in the 1970 to 1975 period ranged from 2 to 6 cfs in Reach 1, from 4 to 11 cfs in Reach 3 and from 6 to 14 cfs in Reach 4. During this 5-year period, annual low flows were less than those experienced in 1986-1988 for 4 years in Reaches 1, 3, and 4, and for all 5 years in Reach 2.

DISCUSSION

Population Response

A substantial increase in the brown trout standing stock was indicated between the 1970's and 1988-1989 in Reach 1, between Rob Roy Dam and the diversion dam, and Reach 2, immediately downstream from the diversion dam. No identifiable changes attributable to the enhance minimum flow were seen further downstream in Reaches 3 or 4.

Trout standing stock estimates were made by the Wyoming Game and Fish Department in 1979 and a few months following the enhanced minimum flow in 1986 within three of our study reaches (Table 11). The estimates in all three reaches

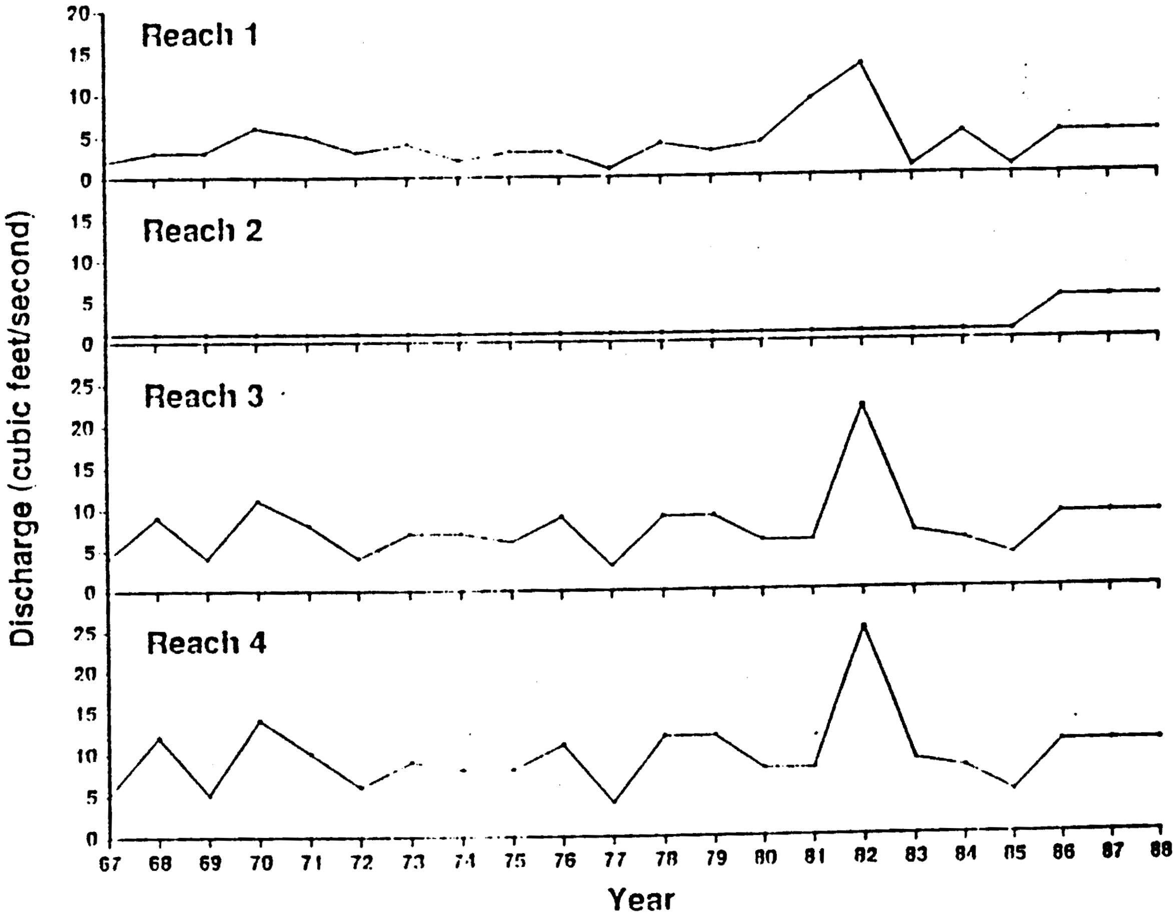

Figure 3. Estimated annual low flows within the four study reaches of Douglas Creek, 1976-1988.

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

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

showed higher standing stocks in 1986 than in 1979. The greatest difference, almost three-fold, was in Reach 2, where we also observed the greatest difference between 1972 and 1988-1989.

Sampling in the 1970's was conducted at individual study sites 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 prior to our sampling in 1988. The data set representing conditions during the period of a 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 occurred there was substantial variation among estimates. At Site 3-L there were four standing stock estimates made in 1974 and 1975 that ranged from 7 to 75 lb/acre (Cooper and Wesche 1976). Variation associated with sampling date was indicated among these estimates; July estimates were 7 and 15 lb/acre in 1974 and 1975, respectively, while September estimates were 75 and 52 lb/acre in 1974 and 1975, respectively . We suspect the cause of the July to September increases was due either to 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 impacted by human activities and that the quality of habitat may have degraded further from the 1970's to 1988 relative to the availability of cover for brown trout. The habitat for brown trout in Douglas Creek was impacted by tie drives and gold dredging in the late 19th and early 20th Centuries, as well as by water development over the last 25 years. To a smaller degree livestock grazing, road construction and human recreation activities have further reduced habitat quality. Evidence of the reduction in habitat quality has been observed by the authors in the vicinity of Site 4-L, for example, where bar formation appears to be accelerating. This aggradation of river gravels has resulted in the closure of side channels to fish and the reduction of bed material size. While the cause of this channel change cannot be defined, 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 unimpacted by logging, mining, livestock grazing or road construction. His findings indicate that unimpacted 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 both geomorphic and stream habitat features for forested streams in Wyoming. Using their geomorphic model for forested streams, the predicted standing stocks in Douglas Creek should be greater than those measured in 1988, indicating that fish abundance is lower than average for streams of similar size and geomorphic features. These models indicated that standing stocks of trout at the study sites in Douglas Creek are lower than would be expected for streams of similar size and geomorphology in Wyoming.

Our data analysis using PHABSIM and HQI indicated that the augmentation of the minimum stream flow from 1.0 to 5.5 cfs has benefitted the brown trout population between Rob Roy Dam and the diversion structure (Reach 1), as well as 6.5 mi downstream from the diversion to the mouth of Lake Creek (Reach 2). Within Reach 1, the PHABSIM analysis indicated that from the 3.0 cfs low flows experienced in the 1970's to the 5.5 cfs minimum in 1988, there was an almost two-fold increase in WUA for both adults and juveniles, as well as more than a seven-fold increase in spawning habitat (Table 5). The HQI indicated an increase in potential standing stocks of trout by more than three-fold (Table 6) as a result of enhanced later summer stream flow, less annual stream flow 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 two-fold increase in brown trout abundance was observed (Table 1).

In Reach 2, downstream from the water diversion, the minimum flow increased from 1.0 to 5.5 cfs. Within this reach the PHABSIM analysis indicated a four-fold increase in adult WUA, but little change in juvenile WUA (Table 5). An almost three-fold increase in potential standing stock in this reach was predicted by the HQI (Table 6) due to enhanced late summer stream flow, less annual stream flow variation, increased water velocity, and increased stream width in spite of losses in cover and increases in eroding banks since the 1970's (Table 7). A four- to six-fold increase in brown trout standing stock was observed in this reach (Table 1).

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

Both the HQI and TCR indicated losses in habitat quality from the 1970's to 1988. The habitat quality declined due to losses of instream cover in the form of overhanging banks, rubble-boulder substrate, aquatic vegetation, and deep pools. Two mechanisms appear to have contributed to the loss of cover, increased sedimentation as well as bank sloughing and erosion. Sediment input is likely due to construction of Rob Roy Dam and bank damage is probably related to cattle grazing. Despite the habitat losses that occurred in Reaches 1 and 2 between the 1970's and 1988, the enhanced minimum flows lead 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 habitat restoration plan for Douglas Creek has been developed (Wesche 1987). The U.S. Forest Service is implementing a 5-year plan to rehabilitate Douglas Creek using a variety of treatments, including 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 limitation of the three habitat assessment models used. Currently, PHABSIM is considered by many to be the state of the art for instream flow assessment (Orth 1987). However, many authors criticize the lack of significant correlations between WUA and standing stocks (Conder and Annear 1987, Scott and Shirvell 1987), while others state that there is such a relation (Stalnaker 1979, Orth and Maughan 1982). Reviews covering both points of view can be found in Orth (1987) and Gore and Nestler (1988). The HQI 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 relation to brown trout standing stocks among streams in southeastern Wyoming (Wesche et al. 1987a). All of our study sites 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 of this study). They estimated the fishing pressure to have been 1,874 fisherman days. Overall, fisherman caught 6,086 fish at a rate of 2.16 fish/hour with 954 of the fish harvested. Brown trout made up the majority of the fishery with 4,022 brown trout caught at 1.43 fish/hour, with 462 estimated to have been kept by fisherman (Michael Snigg, Wyoming Game and Fish department, Laramie, personal communication).

Long Term Value of Increased Minimum Flow

Based on data collected in the 1970's and in 1988-1989, the brown trout populations in Douglas Creek have increased significantly since augmentation of the minimum low flow between Rob Roy Dam and the diversion structure, as well as within the 6.4-mi reach immediately downstream from diversion dam. Habitat quantity and quality appear to have increased substantially within these reaches due to the enhanced minimum flow initiated in 1986. We would expect that the brown trout population will maintain itself at current levels or continue to expand if the 5.5 cfs minimum low flow is consistently maintained. The data from the 1970's, as well as our "post effect" data, provide evidence that habitat quality has been improved and the enhanced minimum flow can be considered as an effective mitigation alternative.

Both the PHABSIM and HQI analysis, as well as the rapid changes in brown trout abundance observed after the enhancement of minimum flow, indicate that the brown trout population response was probably due to greater abundance of habitat for juvenile and adult fish during low flow (July-April most years), not increased habitat for fry or spawning. Given the physical impacts to the Douglas Creek watershed by past human activities, the increased minimum low flow was not the only mitigative measure needed to maximize the fishery value of Douglas Creek. Additional work is needed at Douglas Creek study sites to determine if the 1988-1989 population levels will be maintained and if the agreed upon minimum low flow will be maintained. Since the U.S. Forest Service initiated a substantial habitat improvement project in 1989, the influence of this mitigation effort should be assessed relative to its addition to overall brown trout habitat quality and fish abundance.

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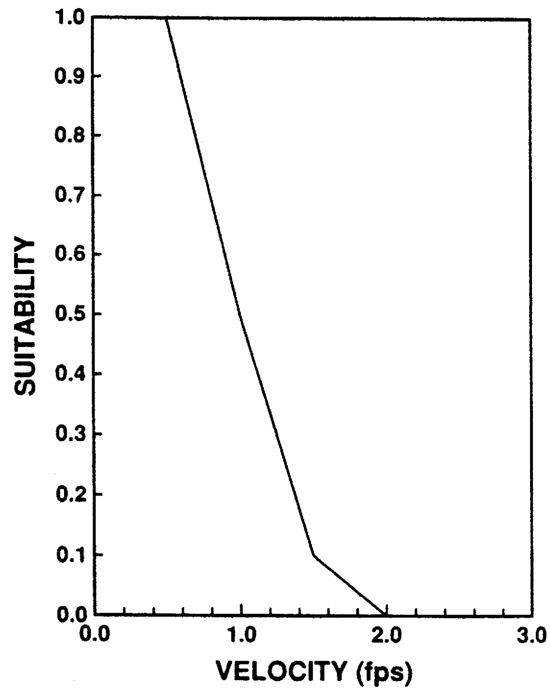
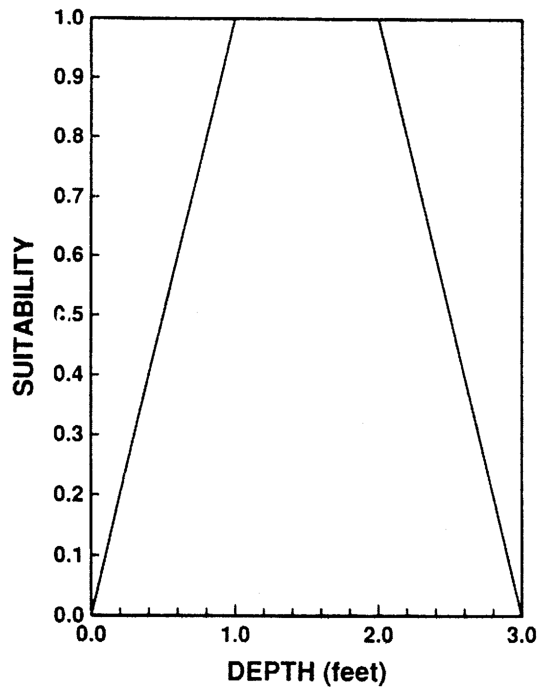
Appendix A. Habitat utilization curves used in the assessment of habitat changes with increased minimum low flow. The curves are for adult, juvenile, fry and spawning life stages of brown trout. Substrate codes are: 1 = organic, 2 = silt and clay, 3 = sand (0.04-0.24 inches diameter), 4 = fine gravel (0.25-0.99 inches), 5 = course gravel (1.0-2.9 inches), 6 = rubble (3.0-11.9 inches), 7 = boulder (12.0 inches), and 8 = bedrock.





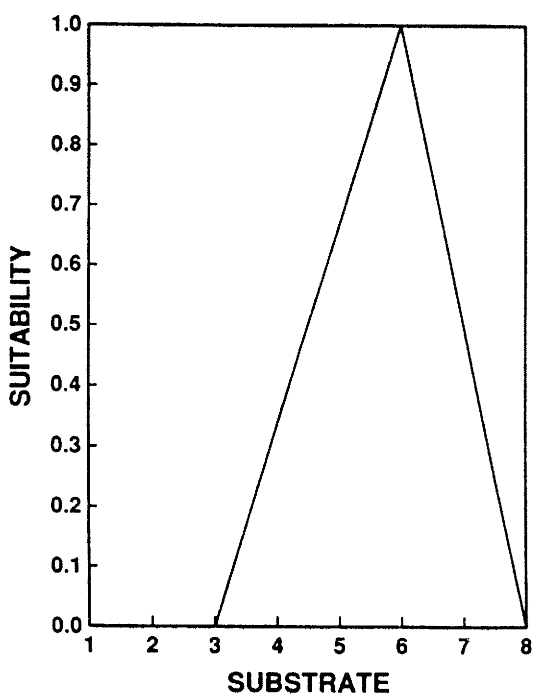
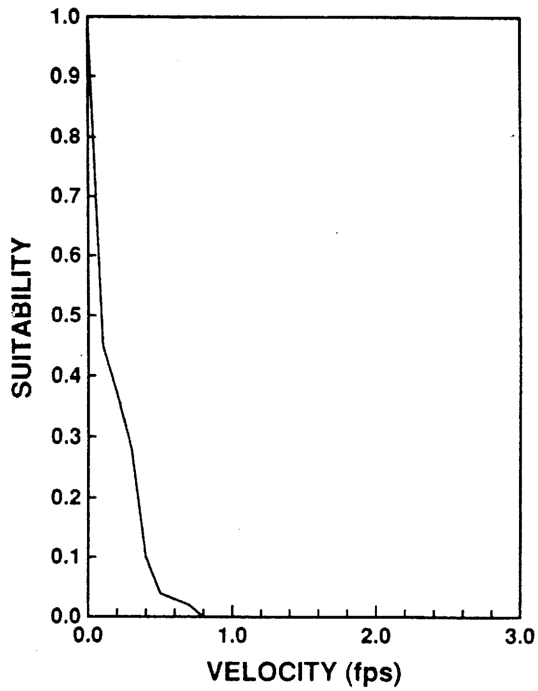
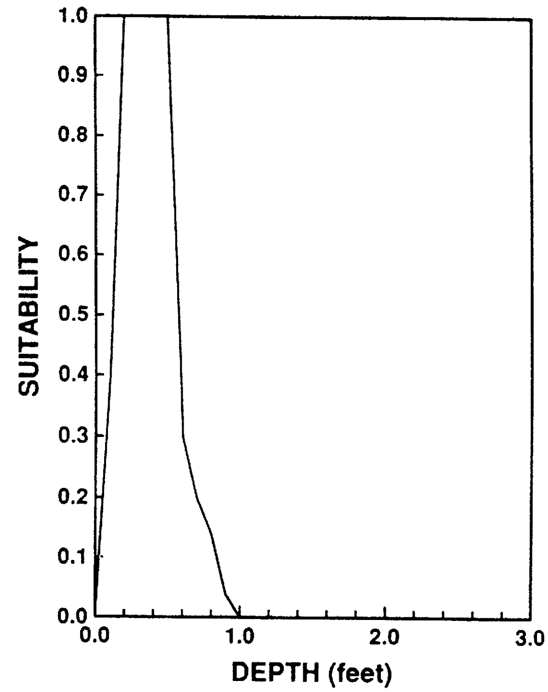


Fig. A-2. Habitat utilization curves for juvenile brown trout (*Salmo trutta*) used in PHABSIM analysis. Original data from Wesche (1980).





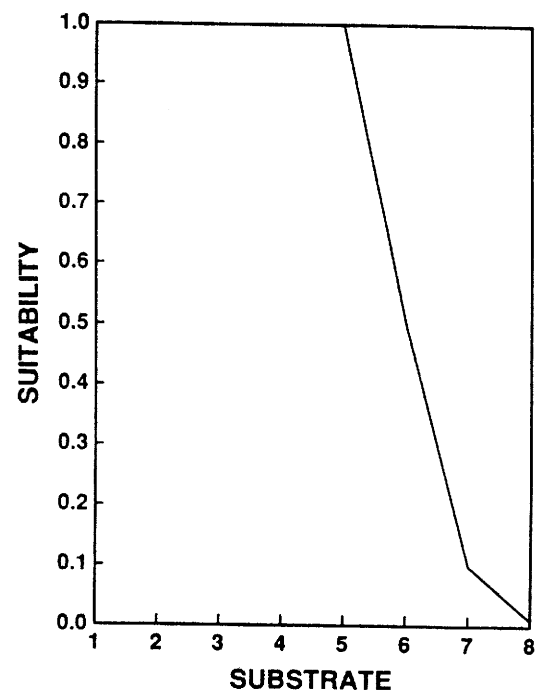


Fig. A-3. Habitat utilization curves for fry brown trout (*Salmo trutta*) used in PHABSIM analysis. Original data from B. Nehring (Colorado Division of Wildlife, Montrose, Colorado, personal communication).

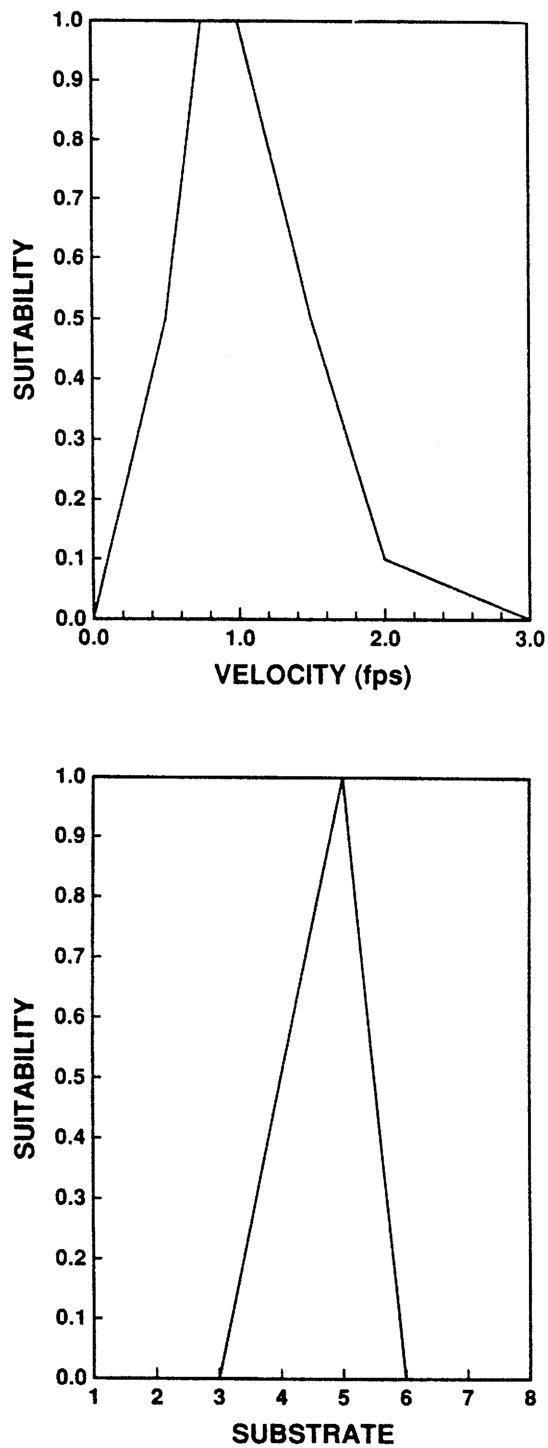


Fig. A-4. Habitat utilization curves for spawning brown trout (*Salmo trutta*) used in PHABSIM analysis. Original data from Reiser and Wesche (1977).

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.

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