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STREAM CHANNEL AND HABITAT CHANGES DUE TO FLOW AUGMENTATION

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ABSTRACT

A previously ephemeral stream is being used to convey water and create fish habitat as part of mitigation for impacts of a transbasin water diversion project. This stream, the South Fork of Middle Crow Creek, is located in the Medicine Bow National Forest, Wyoming. After two years of increased flow to the 8·8 km study reach, the amount of stream channel had increased 32 per cent and the total area of beaver ponds had more than doubled. Brook trout (*Salvelinus fontinalis*) stocked into the beaver ponds are surviving and growing. Factors limiting fishery development in the augmented stream include interrupted flow, discontinuous channels, and summer water temperatures exceeding 25°C. Analysis using the Physical Habitat Simulation System indicated that a flow of $0{\cdot}07\ m^3 s^{-1}$ would maximize the amount of weighted usable area for brook trout under the channel conditions present in 1987.

KEY WORDS Flow augmentation Channel changes Mitigation Trout habitat

INTRODUCTION

Transbasin water diversion is a common method for municipalities in the semiarid western United States to obtain water supplies. Such projects reduce or eliminate streamflow in areas below the point of diversion, adversely affecting or eliminating aquatic and riparian resources. A strategy for fisheries mitigation is the use of ephemeral streams as conveyance channels for all or a portion of the diverted water. If flow releases are controlled and uninterrupted, a perennial stream is created and new aquatic and riparian habitat can develop, but any biota adapted to the ephemeral system will probably be eliminated (Williams and Hynes, 1976, 1977). To date such a strategy to convey water and enhance fishery resources has received little attention. However, the City of Cheyenne, Wyoming, is currently pursuing such a strategy to mitigate the adverse impacts of a transbasin diversion project on trout habitat.

During the early 1960s, the city constructed a transbasin diversion and conveyance system to bring water from the Snowy Range to Cheyenne. Water is conveyed 97 km by pipeline across the Laramie Plains to the Sherman Mountains west of Cheyenne where the water is stored in Granite Springs and Crystal Lake reservoirs and released to the city via Crow Creek. This system, termed Stage I, provides the city with $9{\cdot}1 \times 10^6\ m^3$ of water annually. To procure additional municipal water, construction of Stage II began in 1982 which will provide the city with $28{\cdot}6 \times 10^6\ m^3$ of water per year. The city was subsequently required to mitigate habitat impacts from Stage II by providing controlled year-round releases of water into an ephemeral drainage, the South Fork of Middle Crow Creek (SFMCC) and one of its tributaries, in order to create additional sport fisheries beginning in 1985.

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To the best of our knowledge, this study is unique. Few other studies known to us have dealt with channel or habitat changes due to flow augmentation (Kellerhals *et al.*, 1979; Bergman and Sullivan, 1963), and we know of no studies that have dealt with controlled flow releases into ephemeral stream channels for fisheries mitigation. The area where the project is taking place is located on national forest land and receives substantial fishing pressure. The primary goal of this mitigation attempt is to create additional fishing opportunity. The objective of this study was to measure and evaluate the type, quantity, and quality of habitat for brook trout (*Salvelinus fontinalis*) that formed in the SFMCC from 1985 to 1987 as a result of augmented flow.

DESCRIPTION OF STUDY AREA

The SFMCC is within the North Platte River Basin of southeast Wyoming, 45 km west of Cheyenne. The upper section of the drainage is within the Pole Mountain Recreation Area of the Medicine Bow National Forest (Figure 1). The headwaters rise on the east slope of the Sherman Mountains, 2506 m a.s.l. The stream extends in an easterly direction for 16 km to its confluence with the Middle Fork of Crow Creek between Granite Springs and Crystal lake reservoirs. Our study area drains 8·3 km^2 along 8·8 km of valley bottom (Figure 2).

The SFMCC was an intermittent stream that flowed primarily during spring snowmelt and after intense summer rainfall. Scattered springs and seeps provided small areas of surface flow during non-runoff periods. Active channel development was restricted to several reaches where headcutting occurred. The upper 40 per cent of the watershed was a steep, narrow, wooded, geologically controlled valley with occasional low-gradient sections. The lower 60 per cent consisted primarily of a wide, low-gradient valley with numerous meadows. These meadows generally resulted from the past activity of beaver (*Castor canadensis*).

Before flow augmentation, no fish were seen within the study area, but brook trout did inhabit the SFMCC downstream, near the confluence with the Middle Fork of Crow Creek. A total of 1700 fingerling brook trout were stocked in several beaver ponds in the lower section of the study area in June 1986 and 1987.

METHODS

Six Parshall flumes were installed in 1985 and 1986 to monitor the hydrologic response of the watershed to the increased flow; all flumes were equipped with water stage recorders for continuous monitoring. A thermograph was installed in the lower channelized sections of the study area in 1987 to monitor stream temperature.

Evaluation of fish habitat development on the SFMCC was divided into two categories, measurement of stream habitat and measurement of ponded habitat, and began in July 1985 as part of a baseline survey on the SFMCC.

Stream habitat

Ten General Habitat (GH) sites were established in reaches with well-developed channel and were sampled annually during August in 1985–1987 (Figure 2). The purposes of the GH sites were to estimate the amount and rate of change of channel features and to estimate the suitability of the stream sections for sustaining adult brook trout. Each GH site consisted of three channel cross-sections permanently marked with steel stakes (headstakes) on the right and left banks. Cross-sections were placed 5 to 7 channel widths apart, thus the length of the entire reach was equal to 10 to 14 channel widths. A permanent benchmark was established at each site to ensure that the elevations of the headstakes did not change during the course of the study.

Sampling at GH sites consisted of attaching a measuring tape across the top of a cross-section and measuring tape height, water depth, and water velocity at 10–15 points along each transect. Channel width, wetted width, dominant substrate, and cover (Wesche *et al.*, 1987a) were measured at each cross-section.

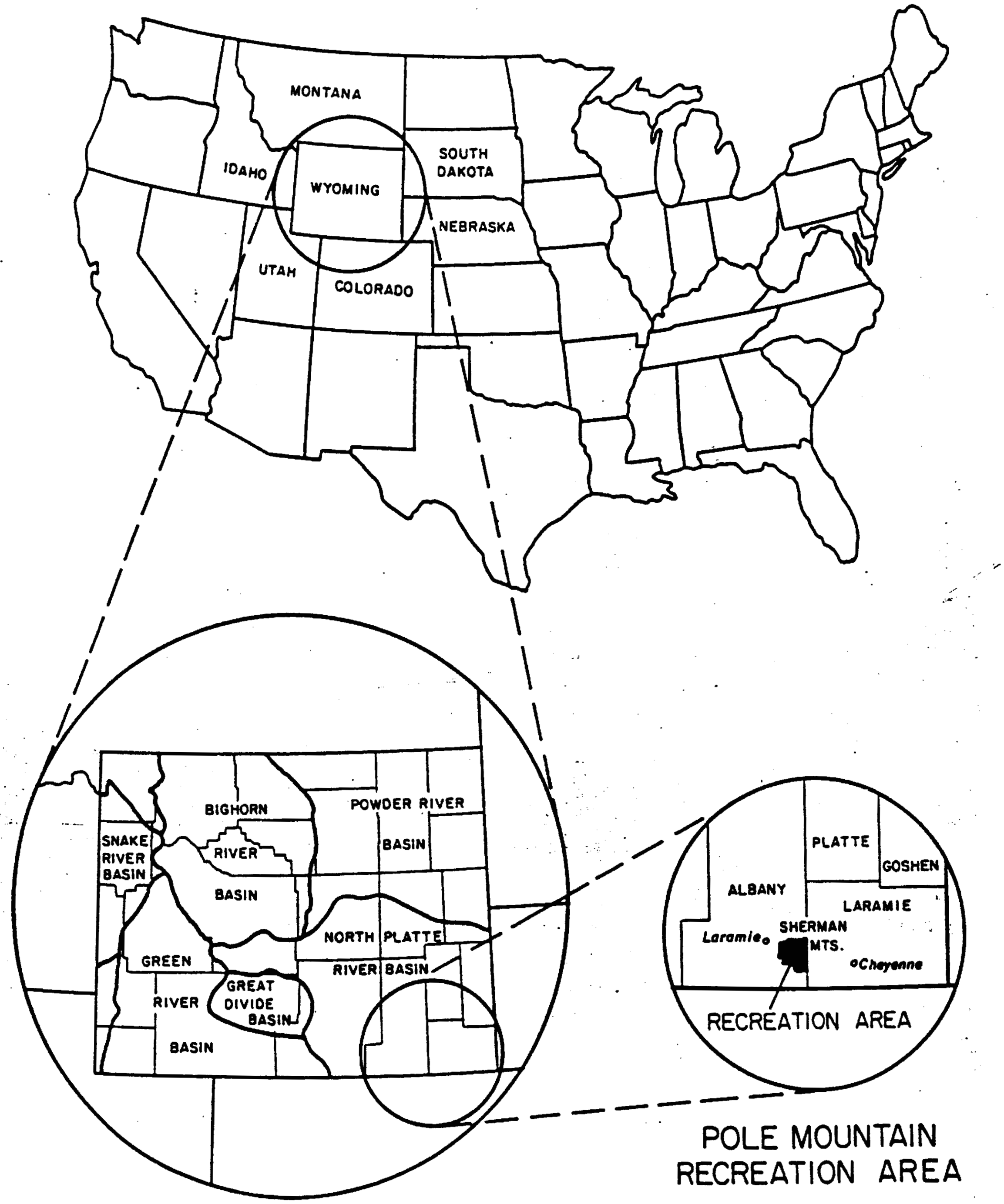

Figure 1. Location of the Pole Mountain Recreation Area

Wesche (1980) developed criteria for water velocity, water depth, and substrate for use in assessing habitat suitability for brook trout in southeastern Wyoming streams (Table I). To assess the habitat suitability of the SFMCC at each GH site, and to evaluate channel changes over time, we calculated mean velocity, mean depth, and dominant substrate type at each cross-section of each GH site in 1985 and 1987. We then determined how many of the measured variables at GH sites were within Wesche's criteria.

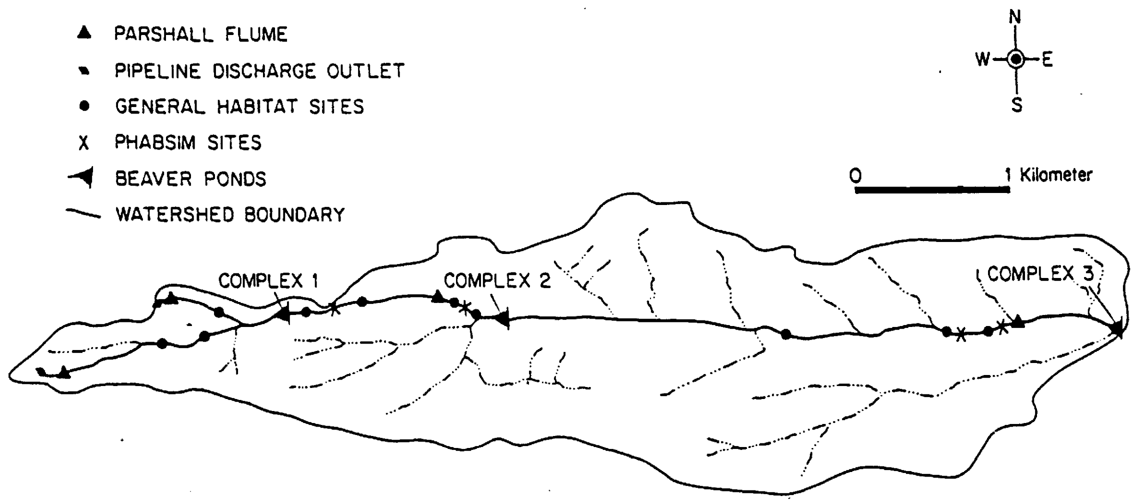

Figure 2. Map of the South Fork of Middle Crow Creek Study Area

During the time of this study very few brook trout, presumably from either stocked populations in the beaver ponds or wild populations from downstream, were ever found inhabiting the stream sections of the SFMCC, so we used a predictive model to estimate the potential standing stock of brook trout in the stream sections. The model we used was the Habitat Quality Index (HQI) of Binns and Eiserman (1979). The HQI was developed to predict the potential standing crop of trout in Wyoming streams. The HQI was applied to two, 100 m stream reaches on the SFMCC, one low-gradient (0·2 per cent) and one moderate gradient (1·7 per cent), in August 1986 and 1987.

We developed habitat–discharge relations for four sites (Figure 2) on the SFMCC, using the Physical Habitat Simulation System (PHABSIM) developed by the U.S. Fish and Wildlife Service (Bovee, 1982; Milhous *et al.*, 1984). We performed habitat analysis for both adult and spawning brook trout. Habitat use curves for PHABSIM were developed from data collected over many years by the Wyoming Water Research Center from brook trout populations in similar nearby streams.

Ponded habitat

The quantity and quality of beaver pond habitat was measured in September 1985, 1986, and 1987. Surveys were made to determine the location, number, and size of existing ponds. Ponds >0·04 ha (surface area) were mapped using standard transit-stadia survey techniques to determine surface area, water surface elevation, and mean depth. Smaller ponds (<0·04 ha) were noted as to location and size was visually estimated.

To evaluate the habitat quality of the beaver ponds, comparisons were made to other ponds in the area with similar morphological characteristics for which actual standing stocks were known (Winkle, 1988). To determine the survival of the stocked brook trout in the beaver ponds, we sampled the largest pond in

Table I. Stream habitat suitability criteria for brook trout (from Wesche, 1980)

Parameter	Criteria
Water velocity ($m\ s^{-1}$)	0·0–0·50
Water depth (m)	>0·1
Dominant substrate (% gravel and rubble)	>50

each of the three complexes (Figure 2) with two gill nets (10 × 1 m, four panels with meshes of 0·6, 1·3, 1·9, and 2·5 cm bar measure). The nets were set over one night in September 1987. Total lengths and number of fish caught were recorded.

RESULTS

Water was first released into the SFMCC in August 1985 when 0·028 $m^3 s^{-1}$ was discharged into both the main and tributary channels. Based on the project description, future releases could be as high as 0·142 $m^3 s^{-1}$ in the main channel and 0·085 $m^3 s^{-1}$ in the tributary. Mean monthly flows at the Parshall flumes ranged from zero (when discharges were zero) to 0·05 $m^3 s^{-1}$. The duration of periods without augmented flows ranged from 2 to 31 days, and totalled 121 days (15 per cent) during the first 27 months of project operation.

Stream habitat

After flow augmentation began in 1985, 32 per cent more stream channel (600 m) developed, though only about a third (2560 m) of the study area has a distinct channel. Almost all of the 600 m of new channel developed by downcutting. In 1987, surveys indicated that in several of the meadow areas without defined channels, the water was becoming more confined (i.e. decreased top width, increased velocity, increased depth)—a precursor to channel development.

The GH sites were 3·5 to 12·0 m long and from 2484 to 2378 m a.s.l. In 1987, mean channel cross-sectional areas within the 10 sites ranged from 0·62 to 2·10 m^2, and mean depths ranged from 0·30 to 0·53 m. Both mean cross-sectional area (Table II) and mean channel depth increased ($p < 0.0001$) from 1985 to 1987, and at about the same proportions.

The evaluation of habitat suitability at the GH sites is shown in Table III. Of the 90 measurements made on velocity, depth, and substrate, 39 (43 per cent) fell within the suitable ranges in 1985; the number increased to 72 (80 per cent) by 1987. The greatest change took place in the substrate criterion (i.e. >50 per cent gravel and rubble), which increased from 3 in 1985 to 27 out of a possible 30 by 1987.

Because the habitat quality ratings used in the HQI did not change at the moderate gradient site between 1986 and 1987, standing stock predictions were identical for both years. These ratings yielded an estimate of 100 kg ha^{-1}. At the low gradient site, the HQI yielded standing stock predictions of 23 kg ha^{-1} in 1986 and 41 kg ha^{-1} in 1987. The increase in the estimates from 1986 to 1987 was due to an increase in the amount of cover in the reach. The principal reason for such a large difference in predicted standing stocks between the moderate gradient and the low gradient site was due to high water temperatures

Table II. Per cent change in cross-sectional area of General Habitat sites from 1985 to 1987

Site	Transect 1	Transect 2	Transect 3
1	+8·7	+6·5	+13·1
2	+12·2	+4·1	+5·2
3	+25·9	—*	+20·0
4	−6·2	−7·0	+2·2
5	+3·1	−3·5	+1·3
6	+0·1	−4·9	+2·2
7	−2·8	+3·6	+1·9
8	+11·1	+9·4	+3·3
9	+1·9	+18·3	—*
10	+24·6	+15·7	+11·3

*Missing data.

Table III. General habitat site transects with parameters that fell within suitability criteria (Table I) in 1985 or 1987

Site	Transect	Velocity 1985	Velocity 1987	Depth 1985	Depth 1987	Substrate 1985	Substrate 1987
1	1					X	X
	2	X	X				X
	3	X			X		X
2	1	X	X	X	X		X
	2	X	X		X		X
	3	X	X				X
3	1					X	X
	2	X	X		X		X
	3		X		X		X
4	1	X	X	X	X		X
	2		X			X	X
	3	X	X	X	X		X
5	1	X	X		X		X
	2	X	X				X
	3	X	X	X	X		
6	1	X	X	X	X		X
	2	X	X	X	X		X
	3	X	X	X	X		X
7	1	X	X	X	X		X
	2	X	X	X	X		
	3	X	X	X	X		X
8	1	X	X	X	X		X
	2	X	X	X	X		X
	3	X	X		X		X
9	1		X				
	2	X	X				X
	3		X				X
10	1	X	X				X
	2	X	X				X
	3	X	X				X

measured in the low gradient reach. Late-summer stream temperature in the low gradient section of the SFMCC exceeded 25°—beyond the suitable temperature range for brook trout.

According to the PHABSIM analysis, the amount of adult habitat (reported as weighted usable area) in the SFMCC was largest at a discharge of $0{\cdot}12\,m^3\,s^{-1}$, and the amount of spawning habitat was largest at a discharge of $0{\cdot}02\,m^3\,s^{-1}$. The combination of adult and spawning habitat was largest at a discharge of $0{\cdot}07\,m^3\,s^{-1}$ (Figure 3).

Ponded habitat

All beaver ponds in the study area were located within three pond complexes (Figure 2). The amount of beaver pond habitat increased in both 1986 and 1987 due to increases in both the number of ponds and

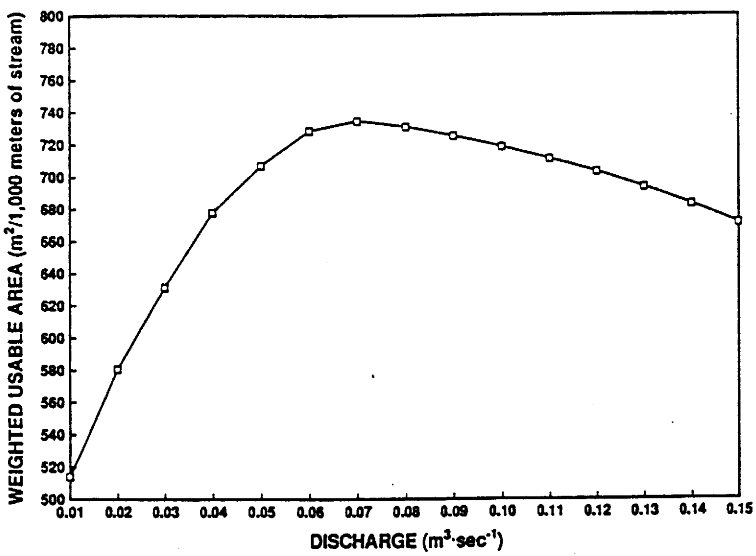

Figure 3. Habitat–discharge relation for the South Fork of Middle Crow Creek (habitat reported as Weighted Usable Area)

the size of existing ponds. The eight beaver ponds found in 1985 had surface areas totalling 0·61 ha. In 1986, 14 beaver ponds with surface areas totalling 1·10 ha were located on the stream, and in 1987 there were a total of 24 ponds covering 1·25 ha. This was an increase of 300 per cent in the number of ponds and more than 100 per cent in the total surface area.

Although standing stocks of brook trout in the beaver ponds on the SFMCC are not known, records from the Wyoming Game and Fish Department indicated that similar ponds in the Pole Mountain Recreation Area have standing stocks of 5 to 66 kg ha^{-1} (Winkle, 1988). However, the SFMCC ponds are unique in having a relatively high and stable flow of water. Stable water levels in beaver ponds of this area are correlated with high brook trout standing stock (Winkle, 1988). The augmented and constant flow on the SFMCC should stabilize water levels in the beaver ponds and possibly result in relatively high standing stocks.

Of the three ponds sampled with gill nets, only those in complexes 2 and 3 yielded brook trout (Figure 2). Fish caught in complex 2 were of two distinct size classes (modal values = 190 mm and 300 mm), although only two fish were in the larger size class. Only one size class (190 mm) was taken in complex 3. This indicated that some fish survived after both the 1986 and 1987 stocking in complex 2, but only after the 1987 stocking in complex 3.

DISCUSSION

Stream habitat

Stream habitat on the SFMCC is increasing in quantity and quality after two years of augmented flows. The total length of developed channel increased 32 per cent, but with more channel still to develop. Overall, 67 per cent of the stream reach is without a well-developed channel, mostly in the lower gradient sections. A channel will probably develop in the lower gradient, meadow sections of the drainage when root masses of meadow vegetation deteriorate, allowing erosive processes to become effective. Based on habitat analysis using transect measurements (GH sites) many of the channelized sections are suitable for brook trout, and the amount of stream channel suitable for brook trout is increasing.

Information obtained from the Wyoming Game and Fish Department show that measured standing stocks of brook trout in other streams in the Pole Mountain Recreation Area range from 1·2 to nearly 50 kg ha^{-1} (M. Snigg, Wyoming Game and Fish Department, Laramie, personal communication). These are much lower than the standing stock predictions made using the HQI for the SFMCC. HQI estimates by the Wyoming Game and Fish Department, on many of the same streams that standing stocks were measured, ranged from 15 to over 250 kg ha^{-1}. The HQI, developed by Binns and Eiserman (1979), has performed well for some authors (Conder and Annear, 1987), but not for others (Scarnecchia and Bergersen, 1987). We believe that the standing stock predictions made by the HQI for the SFMCC are reasonable estimates. The HQI gives a prediction of potential standing stock. The large differences between measured standing stocks and HQI predictions could be a result of fishermen harvest, which has been shown to correlate highly with measured standing stocks (Wesche *et al.*, 1987b).

To date, three factors have been identified as potentially limiting to the development of a stream fishery on the SFMCC: discontinuous channels, high summer water temperatures, and interrupted flow. Because the developed channel is not continuous, it occurs in short sections, the availability of most of the stream to brook trout is limited to stocked fish. However, the channel is expected to continue to develop and should eventually be continuous throughout the system.

Summer water temperature is a problem in the lower reaches of the study area. Water flows through large meadows lacking defined channels where it warms considerably before running into the downstream sections. Maximum suitable water temperature for adult brook trout is reported to be 25°C (MacCrimmon and Campbell, 1969), but in August 1987 stream temperatures exceeded 28°C on several occasions. Water temperature is assumed only to be a temporary limiting factor because using a stream temperature model developed by the U.S. Fish and Wildlife Service (J. Bartholow, Fort Collins, Colorado, personal communication), we predicted that the maximum stream temperature on the SFMCC will not exceed 18°C if the entire valley length develops a defined channel. Thus, if a channel does develop along the entire length of the study area, water temperature should no longer be a limiting factor. Also, if the temperature rating in the HQI is adjusted to reflect the predicted 18°C maximum stream temperature, the standing stock estimate at the low gradient site increases to 225 kg ha^{-1}, indicating the potential for a much more productive fishery.

The augmented flow into the SFMCC has been shut off on several occasions. When this occurred, stream channels in the upper sections of the study area became dry (no surface flow) within 1–3 days. Due to groundwater storage, surface flow remained for a longer period in the lower reaches, but was reduced significantly.

The results of the PHABSIM analysis are important from the perspective of water developers. Based on this simulation model, the discharge that would maximize brook trout habitat on the SFMCC is about one quarter of what could be required for release by the City of Cheyenne. This could significantly reduce the amount of water lost to the city during conveyance. However, it should be noted that as the SFMCC channel changes over time, the optimum discharge for fish habitat may also change.

We used PHABSIM as an index to assess the change in available habitat for brook trout with changes in flow in the SFMCC. A large amount of support and criticism exists for the use of PHABSIM (Orth, 1987). Many authors criticize the lack of any significant relationships between weighted usable area and standing stocks (Conder and Annear, 1987; Scott and Shirvell, 1987), while others state that there is such a relationship (Stalnaker, 1979; Orth and Maughan, 1982). In either event we felt that PHABSIM was the best tool available to address the needs of this study.

Ponded habitat

Beaver pond habitat on the SFMCC increased substantially from 1985 to 1987. This increase was important because beaver pond habitat supports most of the brook trout fishery in the Pole Mountain Recreation Area (M. Snigg, Wyoming Game and Fish Department, Laramie, personal communication). The limiting factor to the pond habitat was the interrupted flow. When augmented flow was discontinued on the SFMCC, even for 31 days, all of the beaver ponds maintained water. However, water levels in most ponds decreased and water temperature became elevated.

CONCLUSION

Obtaining the *uninterrupted* flow called for in the plans of the SFMCC mitigation project will ultimately determine the success or failure of the fishery development on the SFMCC. The frequency and duration of interrupted discharge during the first two years indicated that a productive fishery will not develop if current water management policies are maintained.

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