STREAM CHANNEL RESPONSE TO FLOW DEPLETION

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SUMMARY AND CONCLUSIONS

Channel width, depth, width to depth ratio, cross-sectional area and conveyance capacity were measured above and below diversion structures on 20 mountain stream reaches in Wyoming and Colorado. Diversion structures ranged in age from 12 to 106 years and reduced streamflow up to 90 percent. Statistical analysis indicated no significant differences in channel dimensions above and below diversions on steep (slope > 4.0 percent) and moderate (slope 1.5 to 4.0 percent) gradient channels. Low gradient (slope < 1.5 percent) channels responded to streamflow depletion by significantly reducing their depth, area and capacity.

Based upon these findings, additional comparisons were made on low gradient reaches of foothill and basin streams. Results were similar. Channel width, depth, area and capacity were significantly reduced below diversion structures. Using regression analysis, equations were developed expressing these channel properties as a function of discharge.

Our results indicate that moderate to high gradient mountain stream channels located in the forest snowpack zone may be maintained with reduced streamflow regimes. Channel maintenance flow studies should focus on low gradient stream reaches where encroachment and aggradation are more likely to occur. The regression equations presented can be used to estimate the physical response of this channel type to flow depletion.

INTRODUCTION

The maintenance of suitable instream flows below water development projects in the western United States has been recognized as environmentally desirable and a cost that in many cases developers must be willing to incur. Currently, one aspect of instream flows which is being actively debated by water developers and resource management agencies is the need for, and the determination of, channel maintenance flow requirements. Such instream flows may simulate the natural spring runoff hydrograph and are felt to be necessary to maintain conveyance capacity by reducing channel aggradation and encroachment by riparian vegetation.

Given the quantities of project water typically required for channel maintenance purposes, basic questions are being raised regarding the quantitative response of stream channels to flow regulation. Should certain channel types respond more slowly to flow regulation, the argument can be made that the magnitude and duration of some maintenance flow regimes can be reduced or eliminated while maintaining conveyance capacity.

The two dominant factors controlling morphological characteristics of stream channels are flood frequencies and the magnitude of the sediment load (Petts 1984). Flow regulation of a stream system, whether it be by impoundment, diversion or augmentation, may cause changes in both. Consequently, the size and shape of the channel will change. For example, Williams (1978) documented the reduction in channel size of the North Platte and Platte Rivers in Nebraska in response to flow regulation upstream in Wyoming and Nebraska.

Our ability to predict change based on the degree of flow regime alteration is limited (Simons and Milhous 1981). This is illustrated by the diversity of approaches applied and conclusions drawn by 20 professional hydrologists using 3 examples of reservoir and diversion projects (Simons and Milhous 1981). Some models that have been used to estimate morphological changes in channels under altered flow regimes include the Morphological River Model (Bettess and White 1981), and the U.S. Army Corps of Engineer's HEC-6 (U.S. COE 1977). Also, empirical relations between discharge and hydraulic geometry have been derived which could be used to estimate channel response (Leopold and Maddock 1953, Leopold and Miller 1956, Simons and Milhous 1981).

The emphasis of channel response research has dealt with larger alluvial river systems (Petts 1984, Williams and Wolman 1984). Little work has been performed on higher elevation, mountain streams. Yet, these systems are currently the most directly impacted by water development in the central Rocky Mountain region.

In 1986, the Wyoming Water Research Center (WWRC) began a project, funded by the Wyoming Water Development Commission, to investigate the physical response of stream channels in the central Rocky Mountains to flow depletion. This report presents our findings.

METHODS

Preliminary mountain study stream selection was based on water-use and watershed characteristics. Final selection was made in the field to assure that localized land use (i.e., highway construction, channelization) had not affected channel morphology. The study reach on each stream consisted of two study sites, one immediately above and one immediately below a diversion structure. All study sites were located in stable, straight stream sections.

Data collected at each study site included mean bankfull width and depth, and channel slope. Based on these field data, cross-sectional area, conveyance capacity and width-depth ratio were calculated for each site. At each site a Channel Stability Evaluation was made following Pfankuch (1975). Characterization of the riparian zone by density and species composition was also recorded. Each stream section was classified as an A (slope > 4%), B (slope 1.5 to 4%), or C (slope < 1.5%) channel following Rosgen (1985).

The hydrologic record for each study reach was developed by one of two methods. For those study reaches where suitable streamflow records were available, flood frequency analysis using the log-Pearson Type III method was performed to determine the discharge having a recurrence interval of two years. This discharge, termed Q_{P2}, is often considered to be the channel forming flow based upon its magnitude and availability. For reaches where flow records were unavailable, the basin characteristics method of Lowham (1976) was used to estimate Q_{P2}. Diversion records were then analyzed to determine the percent of flow reduction experienced at the downstream site within each reach.

Following preliminary analysis of the mountain stream reaches, additional low gradient (C type channel) study reaches on several foothill and basin streams in Wyoming were selected and measured. Measurements made were the same as for the mountain streams. Where large diversion structures were present, measurements were again made at sites immediately upstream and downstream. Where numerous small diversions were present through a longer reach, sites were selected beginning at the upper end of the reach and progressed downstream to assess cumulative effects of flow depletion.

RESULTS

Field measurements of channel characteristics were made at 39 study sites on 19 streams in southern Wyoming and northern Colorado. From this group, 20 comparisons above and below diversion structures were made. Site elevations ranged from 7,480 to 10,060 ft above sea level. Diversion structures ranged in age from 12 to 106 years and depleted streamflows from 17 to 90 percent. Channel stability at all study sites was rated as good or fair. Descriptions of the mountain study sties are provided in Table A-1 of the Appendix.

The response of 20 mountain stream reaches to flow depletion are summarized in Table 1. For the higher gradient study reaches (A and B types), paired t-tests comparing channel characteristics above and below diversion structures indicated no significant differences for width, depth, width-to-depth ratio, cross-sectional area or conveyance capacity. These steeper channels had maintained their physical dimensions despite an average length of diversion exceeding 35 years and an estimated average flow reduction of 70 percent.

Low gradient C channels responded more to flow depletion than did the A and B types. Mean channel depth, cross-sectional area and conveyance capacity were significantly reduced below diversion structures that averaged 66 years of age and depleted flow by 46 percent. Increased sediment deposition (aggradation) and encroachment by streamside vegetation were observed at most of these study sites. Watershed characteristics undoubtedly contributed to this response. As

Table 1. Comparison of channel characteristics above and below diversion structures on 20 mountain stream reaches, by channel type, using paired t-tests.

	CHANNEL TYPE					
	A		B		C	
	Above	Below	Above	Below	Above	Below
Number of Pairs Sampled	7		7		6	
Mean Width (ft)	10.5	10.0	15.4	15.5	21.5	18.3
Mean Depth (ft)	1.29	1.31	1.30	1.33	1.90	1.43[1]
Width to Depth Ratio	8.6	7.9	11.0	10.4	11.4	12.4
Mean Cross-Sectional Area (ft^2)	13.5	13.9	23.9	25.1	43.1	28.0[1]
Conveyance Capacity (cfs)	133	141	166	197	253	83[1]

[1]Significant difference between means at $\alpha = .05$

shown on Table 2, the C channel types were generally located lower within their respective watersheds, the result being a more favorable climate for vegetation establishment, a reduced rate of incoming accretion flow from snowmelt runoff, an increased sediment supply, and a reduction in sediment transport capability.

Qualitative comparisons of riparian vegetation density and type were made above and below each of the mountain diversion structures, Trends in vegetation response to flow depletion are summarized in Table 3. Results were somewhat varied. In the majority of cases (75 percent) however, no change or an increasing trend in plant density was observed below diversion structures. Of the 15 cases where a decrease in plant density was noted, 9 (60 percent) occurred in the C channel type where the riparian area was increasing due to channel encroachment.

Low Gradient Streams

Based upon the observations made of mountain stream response to flow depletion, measurements were made on additional low gradient channels. Foothill and basin streams investigated were the Laramie River, New Fork River, Owl Creek and Gooseberry Creek, as described in Table A-2 (Appendix). With the inclusion of these streams, the number of paired observations for C channels was increased to 15. The results of statistical analysis comparing channel characteristics above and below diversion structures are presented in Table 4.

Results using this larger sample were similar to those for the mountain streams. Mean channel width was significantly reduced by 26 percent, mean depth by 14 percent, mean cross-sectional area by 32 percent, and mean conveyance capacity by 55 percent. Flow depleted

Table 2. Watershed characteristics above the 20 mountain stream reaches.

	CHANNEL TYPE		
	A	B	C
Mean Elevation of Sites (ft)	9,566	8,973	8,605
Mean Drainage Area (sq. mile)	3.6	10.9	20.6
Average Main Channel Length (miles)	3.0	4.9	7.0
Mean Basin Elevation (ft)	10,669	9,979	9,968
Average Main Channel Slope (%)	11.3	9.4	5.9

Table 3. Trends in riparian vegetation response to flow depletion in twenty mountain stream reaches.

	VEGETATION TYPE (NUMBER OF STREAMS)		
Vegetation Response[1]	Canopy	Shrub	Grass
+	3	6	2
-	4	5	6
0	13	9	12
Total	20	20	20

[1]
+ indicates increase in plant density below diversion.

- indicates decrease in plant density below diversion.

0 indicates no change in plant density below diversion.

Table 4. Comparison of channel characteristics above and below diversion structures for C channel types (n = 15).

	LOCATION	
	Above Diversion	Below Diversion
Mean Width (ft)	32.3	23.8[1]
Mean Depth (ft)	2.2	1.9[1]
Width to Depth Ratio	14.4	12.5
Mean Cross-Sectional Area (ft)	86.4	58.4[1]
Conveyance Capacity (cfs)	274.0	122.6[1]

[1]Significant difference between means at $\alpha = .05$

sites also had a reduced width to depth ratio, although this difference was not statistically significant. Clearly, our sample of C channels was responding to flow depletion by reducing channel dimensions.

Based upon these findings, attempts were made to develop statistical relations that could be used to estimate the response of C channel types to flow depletion. Both multiple and single regression approaches were followed. Best results were obtained using power fit regression with Q_{P2} (that flood flow having a recurrence interval of two years) as the independent variable and the various channel dimensions as the dependent variables. The form of the equation is

$$Y = aQ_{P2}{}^{b}$$

where, Y = channel characteristic

a = coefficient

b = exponent

Table 5 summarizes the coefficients, exponents and correlation coefficients for mean width, depth, area and capacity.

The regression equations presented above can be used to estimate the physical response of a low gradient stream channel in Wyoming to water development. For example, suppose that a planned diversion structure will reduce the Q_{P2} of a stream reach by 75 percent. If we use the subscripts p and a to denote percent and altered conditions, the following relationship can be developed for estimating the new channel depth (D_a):

$$\frac{D_a}{D_p} = (Q_a/Q_p)^b = (0.25)^{0.338} = 0.63$$

$$D_a = 0.63\ D_p$$

Table 5. Power fit regression relations between channel characteristics (dependent variable) and Q_{P2} (independent variable) for C-type channels (n = 21).

	Coefficient a	Exponent b	Correlation Coefficient r
Mean Width (ft)	3.015	0.395	0.77[1]
Mean Depth (ft)	0.303	0.338	0.87[1]
Mean Cross-Sectional Area (ft^2)	0.914	0.732	0.85[1]
Conveyance Capacity (cfs)	4.999	0.628	0.78[1]

[1]Significant at α = .05.

Thus if D_p is 2.0 ft, we would estimate D_a to be 1.81 ft. A similar approach could be followed to estimate relative change for other channel characteristics.

We attempted multiple regression analysis incorporating age of diversion structure as an independent variable. The predictive ability of the resultant equations however, was no greater than that for the relationships presented above. Obviously, stream channels do not respond immediately to flow depletion. A number of years must pass for a new equilibrium condition to be achieved. However, given the distribution of ages for the diversion structures at our study reaches (only one diversion was less than 50 years old), we can only assume that most of our depleted sites had reached equilibrium. As a result, the age variable explained little of the variation observed in channel dimensions.

DISCUSSION

The need for channel maintenance flow releases is a complex issue. Like most water management problems, it is complicated by political boundaries, the limited responsibilities of individual management agencies, the often times singular management and development objectives within agencies, and our lack of understanding of natural systems response to man-induced changes. The goal of our study has been to address one portion of this latter constraint, the response of mountain stream channels to flow depletion.

Our observations indicate that all mountain channels do not physically respond in the same manner to streamflow depletion. High elevation, steeper gradient channels, where stream power is high, sediment loadings low and growing seasons short, appear able to maintain their channel dimensions with reduced flow regimes over extended time periods. Lower gradient, C channel types should be the primary focus of channel maintenance flow investigations. Knowledge of the relations between stream energy, sediment transport capability and sediment loadings in this channel type is essential to the determination of proper maintenance flow regimes.

Channel maintenance flow regimes can be a powerful management tool. However, before studies are undertaken and recommendations made, management goals need to be clarified. If the objective is to maintain total conveyance capacity of the channel, prevention of aggradation and encroachment must be considered. Should fish habitat quality be of primary concern, limited channel encroachment may be beneficial to narrow and deepen the channel for rearing purposes. Also, deposition of fine gravels moving through the system may be beneficial for spawning. If enhancement of riparian areas is a primary objective, river regulation to promote aggradation and encroachment may be one possible approach.

Based upon our findings, each stream proposed for development in a mountain watershed should be considered individually from the standpoint of channel maintenance. Channel profiles should be developed, streams stratified by channel type, and critical reaches identified. Dependent upon management and development goals, various channel maintenance flow regime scenarios should then be evaluated, the objective being to maximize resource potential and water use efficiency.

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APPENDIX

Table A-1. Description of mountain stream study sites.

Stream & Site	Date of Diversion	Reduction[1] In Q_{P2} (%)	Mean Width (ft)	Mean Depth (ft)	Mean Cross-Section Area (ft^2)	Estimated Conveyance Capacity (cfs)
Laramie River - Above Poudre Tunnel	1920		25.2	2.5	63.0	266
Laramie River - Below Poudre Tunnel		23	27.3	2.0	54.6	67
North Fork Encampment - Above Wolfard Canal	1890		25.0	2.0	50.0	237
North Fork Encampment - Below Wolfard Canal		44	26.2	2.0	52.4	364
Cow Creek - Above Pilson Ditches	1882		19.8	2.5	49.5	421
Cow Creek - Below Pilson Ditches		17	21.3	1.5	32.0	181
N. Fork Little Snake - Above Cheyenne Div.	1963		10.1	1.0	10.1	36
N. Fork Little Snake - Below Cheyenne Div.		68	10.5	1.0	10.5	59
N. Fork Little Snake - Below Cheyenne Div.		68	6.1	1.0	6.1	22
South Brush Creek - Above Supply Canal	1920		27.9	2.0	55.8	602
South Brush Creek - Below Supply Canal		21	30.4	2.0	60.8	656
North Brush Creek - Above Supply Canal	1888		29.8	2.0	59.6	291
North Brush Creek - Below Supply Canal		72	19.5	1.5	29.2	44
Vasquez Creek - Above Diversion	1936		26.4	1.9	50.2	335
Vasquez Creek - Below Diversion		70	17.6	1.3	22.9	82
Fraser River - Above Diversion	1936		17.6	1.5	26.4	167
Fraser River - Below Diversion		28	18.1	1.3	23.5	102
Fool Creek - Above Diversion	1956		5.0	0.8	4.0	18
Fool Creek - Below Diversion		90	6.2	0.8	5.0	36
St. Louis Creek - Above Diversion	1956		19.2	1.3	25.0	154
St. Louis Creek - Below Diversion		67	21.6	1.4	30.2	193

Table A-1 (continued). Description of mountain stream study sites.

Stream & Site	Date of Diversion	Reduction[1] In Q_{P2} (%)	Mean Width (ft)	Mean Depth (ft)	Mean Cross-Section Area (ft^2)	Estimated Conveyance Capacity (cfs)
East St. Louis Creek - Above Diversion	1956		7.6	1.9	14.4	178
East St. Louis Creek - Below Diversion		89	8.2	1.2	9.8	78
West St. Louis Creek - Above Diversion	1956		7.3	0.9	6.6	37
West St. Louis Creek - Below Diversion		90	5.8	0.9	5.2	21
Little Cabin Creek - Above Diversion	1975		2.2	0.8	1.8	10
Little Cabin Creek - Below Diversion		79	2.0	0.7	1.4	6
Cabin Creek - Above Diversion	1975		16.1	1.1	17.7	87
Cabin Creek - Below Diversion		76	11.9	1.3	15.5	82
North Fork Ranch Creek - Above Diversion	1949		10.1	0.9	9.1	28
North Fork Ranch Creek - Below Diversion		66	9.0	0.8	7.2	54
Middle Fork Ranch Creek - Above Diversion	1949		15.7	1.2	18.8	195
Middle Fork Ranch Creek - Below Diversion		66	13.8	2.0	27.6	312
South Fork Ranch Creek - Above Diversion	1949		9.7	1.4	13.6	110
South Fork Ranch Creek - Below Diversion		66	9.4	1.5	14.1	142
Ranch Creek - Above Diversion	1949		11.0	1.6	17.6	262
Ranch Creek - Below Diversion		66	10.0	1.6	16.0	200
Chapman Gulch - Above Diversion	1972		14.1	1.2	16.9	142
Chapman Gulch - Below Diversion		90	13.5	1.3	17.6	167

[1]Flood flow having a recurrence interval of two years.

Table A-2. Description of foothill and basin stream study sites.

Stream & Site	Date of Diversion	Reduction[1] In Q_{P2} (%)	Mean Width (ft)	Mean Depth (ft)	Mean Cross-Section Area (ft^2)	Estimated Conveyance Capacity (cfs)
Laramie River - Above Pioneer Canal	879		65.6	4.5	295.2	630
Laramie River - Below Pioneer Canal		14	68.4	4.5	307.8	659
Laramie River - Near Laramie, WY		35	48.9	4.0	195.6	190
New Fork River - Barlow Ranch	1903		45.8	2.3	105.3	282
New Fork River - Noble Ranch		27	30.7	2.0	61.4	204
New Fork River - Leopold Cabin		92	16.5	1.2	19.8	67
New Fork River - Murdock Ranch		79	33.5	1.3	43.6	76
New Fork River - Below Duck Creek		+18[2]	42.9	2.4	103.0	287
Owl Creek - Below Confluence of North and South Forks	1900		26.4	1.6	42.2	190
Owl Creek - at County Bridge		-	16.1	2.0	32.2	84
Owl Creek - near mouth		-	13.2	1.6	21.1	34
Gooseberry Creek - near Highway 431 Bridge	1910		17.0	1.4	23.8	51
Gooseberry Creek - at Killifish Exclosure		-	12.3	1.4	17.2	8
Gooseberry Creek - near Larkin Lane Bridge		-	7.6	1.4	10.6	20

[1] Flood flow having a two-year recurrence interval.

[2] + indicates percent increase in Q_{P2} over reference site.