ADJUSTMENT OF MOUNTAIN STREAM CHANNELS TO FLOW REGIME ALTERATION, PRELIMINARY ANALYSIS

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Adjustment of Mountain Stream Channels To Flow Regime Alteration, Preliminary Analysis

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Abstract

One aspect of instream flow regimes being actively debated is the need for channel maintenance or flushing flows. However, little quantitative information exists as to how different types of channels, particularly higher elevation, mountain stream systems, respond to changes in the flow regime resulting from water development activities. This paper discusses the effect flow diversion has had on higher elevation stream systems located in Wyoming and Colorado.

Introduction

Over the past 20 years, 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 natural resource management agencies is the need for, and the determination of, flushing and channel maintenance flow requirements. Such instream flows simulate the natural spring runoff hydrograph and are felt to be necessary to maintain conveyance capacity of stream channels by reducing aggradation and encroachment of riparian vegetation, and to remove accumulated fine sediments from critical fish habitats.

Given the quantities of project water typically required for flushing/channel maintenance purposes and the associated costs of this water, 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 flushing regimes can

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be reduced while still maintaining conveyance capacity and aquatic habitat quality.

In 1986, the Wyoming Water Research Center began a project to investigate the response of higher elevation stream channels in the central Rocky Mountains to flow depletion or augmentation resulting from water development. This project is not scheduled to be completed until late 1988, though this paper summarizes part of the project (diversions on mountain streams) and discusses some results to date.

Pertinent Literature

Although a vast amount of work has been done on changes in channel morphology due to flow regulation, the majority of that work has dealt with large rivers and/or alluvial systems (Petts 1984, Williams and Wolman 1984). One example, Williams (1978) documented the reduction in channel size of the North Platte and Platte Rivers in Nebraska in response to decreases in peak discharges caused by flow regulation upstream in Wyoming and Nebraska. Very little work has been performed on higher elevation, mountain streams, yet these are the systems that are currently most directly impacted by water development in the central Rocky Mountain region.

Rosgen (1985) developed a stream classification system which categorizes various stream channels by certain morphological characteristics. Delineation criteria used in classifying channels include: 1) stream gradient, 2) sinuosity, 3) width/depth ratio, 4) channel materials, 5) entrenchment, 6) confinement, and 7) soil/landform features. The primary criterion in this classification system, stream gradient, places stream channels into three classes (A, B, or C). A channels are high gradient having slopes greater than 4 percent. B channels are moderate gradient with slopes from 1.5 to 4 percent. Low gradient channels, or C types, are channels with slopes less than 1.5 percent.

The two dominant forces in defining the morphological characteristics of a stream channel are flood frequencies and magnitude of the sediment load (Petts 1984). Flow regulation of a stream system, whether it be by impoundment, diversion or augmentation, will inevitably cause changes in both. Consequently, the size and shape of the channel will change. However, our ability to predict change based on the degree of flow regime alteration is very 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). Again, however, these models have been applied primarily to large, alluvial river systems. Some empirical relationships based on discharge have been derived for various stream types and systems (Leopold and Maddock 1953, Leopold and Miller 1956, Simons and Milhous 1981).

Converse to the idea of attempting to predict channel changes under altered flow regimes is the determination of flushing flow requirements (Reiser et al. 1985). Reiser et al. (1987) reviewed and summarized information on existing methodologies used for recommending flushing flows and set guidelines that were determined to be necessary in the development of any formal methodology, with an emphasis on the maintenance of aquatic habitat quality in regulated systems. An example of the application of these guidelines is presented in Wesche et al. (1987).

Methods

Work began in July, 1986 with the determination of potential sites. Selection of a particular stream for actual sampling was done on-site and was based on land-use and other watershed characteristics so as to keep all sites as similar as possible. Field sampling of sites was done in the summer and fall of 1986 and 1987, and consisted of sampling stream reaches immediately above and below a diversion structure. Data collected at each reach included mean bankfull channel width and depth, and channel slope. Samples of the streambed and bank were collected and analyzed to determine particle size distribution. Characterization of the riparian zone by species composition was also recorded. Several photographs (black and white prints, and color slides) were taken at each site as well. All study reaches were located in the first stable, straight reach above/below the diversion structure which occurred out of the area of construction impact.

Based on the field data, conveyance capacity using mean channel width and depth, and channel slope was calculated for each site. For all calculations of conveyance capacity, Manning's n was held constant. Hydrologic and drainage basin data is currently being gathered and analyzed for all study reaches. Timing of water diversion is similar at all sites, with the majority of diversion taking place during peak snowmelt run-off periods. Channel stability of study reaches is also being assessed using the Stream Reach Inventory/Channel Stability Evaluation (Pfankuch 1975).

Results to Date

As mentioned earlier, analysis of the channel response data collected on mountain streams is not yet completed. We anticipate a project completion report will be available late in 1988. Therefore, the results presented here should be considered as preliminary and as such, will be restricted to general data trends.

Field measurements of channel width and depth were made at 39 study sites on 19 streams in northern Colorado and southern Wyoming. Site elevations ranged from approximately 2250 to 3000 m above mean sea level, while surveyed water surface slopes varied from less than 1.0 up to 9.8 percent. The diversion structures on the study streams ranged in age from over 100 years down to less than 25 years and depleted streamflow by 5 to almost 100 percent of the average annual water yield. As many of the study streams are ungaged, synthesis of discharge records is now underway. Applying Rosgen's (1985) channel typing system, 11 of the 39 sites were classified as A channels, 14 as B channels, and 14 as C.

A comparison of channel characteristics above and below the diversion structure on each stream is presented in Table 1. Response variables considered to date in our analysis include channel width, channel depth, the ratio of width to depth, cross-sectional area and channel conveyance capacity. The response of these parameters to flow depletion has been highly variable. Conveyance capacity has shown the greatest variability, ranging from a reduction of 85 percent below the diversion on North Brush Creek to an increase of 101 percent below the Fool Creek structure. Channel width was the most constant of the variables, showing a 40 percent reduction at a low gradient site below the North Fork of the Little Snake River diversion and a 24 percent widening on Fool Creek. Cross-sectional area, depth and the ratio of width to depth were intermediate in response.

TABLE 1. Summary of channel response to flow depletion for mountain streams.

Site	Width	Depth	Area	W/D	C.C.
N.F. ENCAMPMENT RIVER					
Above Wolfard Canal	7.62	0.61	4.65	12.50	6.70
Below Wolfard Canal	7.99	0.61	4.87	13.10	10.30
COW CREEK					
Above Pilson Ditches	6.04	0.76	4.60	7.92	11.92
Below Pilson Ditches	6.49	0.46	2.97	14.20	5.11
N.F. LITTLE SNAKE					
Above Diversion	3.08	0.30	0.94	10.10	1.02
Below Diversion (steep)	3.20	0.30	0.98	10.50	1.67
Below Diversion (flat)	1.86	0.30	0.57	6.10	0.64
S. BRUSH CREEK					
Above Supply Canal	8.50	0.61	5.18	13.95	17.03
Below Supply Canal	9.27	0.61	5.65	15.20	18.56
N. BRUSH CREEK					
Above Highline Ditch	9.08	0.61	5.54	14.90	8.25
Below Highline Ditch	5.94	0.46	2.72	13.00	1.26
VASQUEZ CREEK					
Above Vasquez Diversion	8.05	0.57	4.61	14.04	9.49
Below Vasquez Diversion	5.36	0.40	2.13	13.54	2.31
FRASER RIVER					
Above Diversion	5.36	0.46	2.45	11.73	4.74
Below Diversion	5.52	0.39	2.17	14.03	2.89

TABLE 1. (cont.)

Site	Width	Depth	Area	W/D	C.C.
FOOL CREEK					
Above Diversion	1.52	0.25	0.38	6.10	0.50
Below Diversion	1.89	0.26	0.49	7.29	1.01
EAST ST. LOUIS CREEK					
Above Diversion	2.32	0.57	1.32	4.06	5.03
Below Diversion	2.50	0.35	0.88	7.13	2.21
ST. LOUIS CREEK					
Above Diversion	5.85	0.41	2.39	14.33	4.36
Below Diversion	6.58	0.44	2.87	15.10	5.49
WEST ST. LOUIS CREEK					
Above Diversion	2.23	0.26	0.58	8.49	1.04
Below Diversion	1.77	0.26	0.46	6.82	0.60
LITTLE CABIN CREEK					
Above Diversion	0.67	0.25	0.17	2.65	0.28
Below Diversion	0.61	0.22	0.13	2.82	0.17
CABIN CREEK					
Above Diversion	4.91	0.34	1.69	14.25	2.48
Below Diversion	3.63	0.38	1.39	9.44	2.34
N.F. RANCH CREEK					
Above Diversion	3.08	0.28	0.87	10.86	0.80
Below Diversion	2.74	0.26	0.70	10.71	1.53
M.F. RANCH CREEK					
Above Diversion	4.79	0.37	1.76	12.98	5.53
Below Diversion	4.21	0.61	2.55	6.93	8.83
S.F. RANCH CREEK					
Above Diversion	2.96	0.41	1.22	7.19	3.14
Below Diversion	2.87	0.47	1.34	6.14	4.04
RANCH CREEK					
Above Diversion	3.35	0.48	1.60	7.01	7.43
Below Diversion	3.05	0.48	1.46	6.37	5.66
LAKE FORK					
Above Homestake Tunnel	6.40	0.46	2.93	14.00	3.80
Below Homestake Tunnel	6.95	0.55	3.81	12.67	5.54
CHAPMAN GULCH					
Above Diversion	4.30	0.37	1.58	11.65	4.03
Below Diversion	4.11	0.39	1.59	10.63	4.72

*Width = Mean channel width (meters).
Depth = Mean channel depth (meters).
Area = Cross-sectional area of channel (square meters).
W/D = Width-Depth ratio.
C.C. = Conveyance capacity (cubic meters per second).

The general trends of the data from Table 1 are presented in Table 2. As shown, channel shrinkage was found to occur below approximately 50 percent of the diversion structures. This phenomenon was not observed at the remaining half of the study streams. It is apparent that additional analysis, taking into consideration such factors as channel slope, sediment yield, elevation, vegetation, and magnitude and duration of streamflow depletion, is needed to begin to explain the observed responses. This effort is now well underway.

TABLE 2. Trends in channel response of twenty mountain streams in Wyoming and Colorado to flow depletion.*

Channel Response**	Response Variable (Number of Streams) Width	Depth	W/D	Area	C.C.
+	9	7	9	9	10
-	11	8	11	11	10
0	0	5	0	0	0
TOTAL	20	20	20	20	20

* Width = Mean channel width.
Depth = Mean channel depth.
W/D = Width-Depth ratio.
Area = Cross-sectional area of channel.
C.C. = Conveyance capacity.

** + indicates variable increased below diversion.
\- indicates variable decreased below diversion.
\- indicates no difference in variable above and below diversion.

Conclusions

While data analysis is not yet complete and any conclusions drawn at this time must be considered preliminary, it is quite apparent that the physical response of mountain stream channels to flow depletion is highly variable. Certain of our study streams were reduced in size due to the processes of vegetative encroachment and channel aggradation, while others exhibited no such loss of conveyance capacity. Further analysis is needed to explain this variation.

The channel maintenance issue is a complex one. Before instream flow regimes are prescribed below water development projects to preserve channel capacity and competence, it would appear that consideration should be given to the type of stream channel involved, the sediment loadings to the system, the transporting capability of the flow regime in relation to these loadings, and the factors which govern the establishment and growth of streamside vegetation. We hope that when completed, the results of this study will help to provide some of the insight needed.

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