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ASSESSMENT OF FLUSHING FLOW RECOMMENDATIONS IN A STEEP, ROUGH, REGULATED TRIBUTARY

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INTRODUCTION

Alteration of stream flow regime and sediment loading from water development activities can result in both short- and long-term changes in channel morphology and conveyance capacity. Subsequently, the condition of the aquatic habitat can be affected. In recent years, much research and development effort has been directed toward the determination of suitable instream flows to maintain fisheries habitat in regulated streams (Stalnaker & Arnette 1976; Wesche & Rechard 1980). However, there are several facets of the instream flow problem which have not been adequately investigated, one involving the recommendation of flushing flows to simulate the peak runoff hydrograph characteristics of most unregulated streams (Reiser et al. 1985).

Limited research has been conducted to develop methodology for determining the magnitude, timing, and duration of flushing flows needed to maintain channel integrity and associated habitat characteristics through the movement of sediment deposits. Of the 15 methodologies identified by Reiser et al. (1985), a majority were not designed specifically to assess flushing flows, but rather were approaches for studying sediment transport problems. The several formal methodologies currently available (Wesche et al. 1977; Environmental Research & Technology, Inc. 1980; Rosgen 1982) were developed in response to immediate management needs and are relatively untested in terms of accuracy and reliability.

During 1984, the Wyoming Water Research Center initiated a research project entitled, "Development of methodology to determine flushing flow requirements for channel maintenance purposes." Objectives of this project are to 1) document the rate of change of various channel characteristics resulting from aggradation/degradation processes under altered flow regimes; 2) quantify the physical and hydraulic properties needed to transport deposited sediment through natural channels; 3) test the predictive capabilities of existing sediment transport models against field data; and 4) develop methodology to predict conditions of flow needed to flush sediments to maintain given streams in prescribed hydraulic, physical and biologic conditions.

One stream selected for study in response to these objectives was the North Fork of the Little Snake River (North Fork), a steep, rough, regulated, headwater stream. Wesche et al. (1977) recommended both maintenance and flushing flow regimes for the North Fork in light of the proposed expansion of water diversion facilities in the drainage by the City of Cheyenne, Wyoming, as part of their Stage II water development program. Construction of Stage II began in 1983. During the late summer of 1984, intense rainfall in the construction area resulted in the deposition of a broad size range of sediments in that section of the North Fork where flushing recommendations had been made. At the request of the Wyoming Game and Fish Department and in cooperation with the United States Department of Agriculture Forest Service, the authors initiated a study of the North Fork. The objectives of this paper are to 1) describe the methods used to assess the extent of the 1984 sediment deposits; 2) present preliminary results summarizing the response of the deposited sediment to the 1985 spring runoff flow regime; and 3) evaluate the effectiveness of the 1977 flushing flow recommendations in relation to the 1984 sediment deposits.

DESCRIPTION OF STUDY AREA

The North Fork of the Little Snake River is a steep, rough, regulated tributary of the Little Snake River located in the Green River sub-basin of the Colorado River basin in southwest and southcentral Wyoming (Figure 1). The headwaters of the North Fork rise on the west slope of the Continental Divide at an elevation of 3050 meters (m) above sea level (msl) and flow southwesterly 20 kilometers (km) to the confluence with the Little Snake River at an elevation of 2130 m. Average gradient is 4.6 percent. A United States Geological Survey (U.S.G.S.) streamflow gaging station (#09251800) located 2.4 km below the study area was in operation from 1957 to 1965 and recorded a maximum discharge of 14.6 cubic meters per second ($m^3\ s^{-1}$) on June 7, 1957. Average discharge over the period of record was 0.73 $m^3\ s^{-1}$. Prior to initial water diversion in the mid-1960's, the North Fork hydrograph was typical of unregulated mountain streams in the central Rocky Mountain Region, with the majority of runoff occurring in the May to late-June period, as a result of the melting snowpack.

The North Fork and its tributaries support the largest known, essentially-pure, naturally-reproducing endemic population of Colorado River cutthroat trout (*Salmo clarki pleuriticus* Cope) (Binns 1977). For this reason, management of the population is a high priority for the Wyoming Game and Fish Department. Wesche et al. (1977) also report the collection of mottled sculpin (*Cottus bairdi* Girard) in the North Fork.

Transbasin diversion of water from the North Fork drainage has occurred since 1964 when the City of Cheyenne, Wyoming completed Stage I of its water development program. Approximately 9.86 x 10^6 m (8,000 acre-feet) per year have been diverted (Banner Associates, Inc. 1976). During 1983, construction began on Stage II collection facilities. When completed in 1986, a total of 28.4 x 10^6 m^3 (23,000 acre-feet) per year will be conveyed from the upper Little Snake drainage to the east slope of the Continental Divide (U.S.D.A., Forest Service, 1981).

The study area on the North Fork is located in Section 27, Township 13 North, Range 85 West at an elevation of 2615 m, within the boundaries of Medicine Bow National Forest, 2.4 km below the Stage I diversion structure. Under Stage II, this structure is being modified to increase the amount of water diverted from the North Fork proper. Within the study area boundary, a stream section 0.5 km in length, construction of a bridge and pipeline crossing was underway in the late summer of 1984 when heavy rains precipitated the sediment spill that led to the initiation of this study. Gradient through this area is 4.4 percent while the predominant natural substrate is boulders and cobbles. Wesche et al. (1977) reported a mid-July 1976 water temperature range of 12.7 to 17 °C, a total alkalinity range of 25 to 32 mg l^{-1}, a pH of 7.1, and clear water conditions for this section of the North Fork. Standing crop estimates for Colorado River cutthroat trout ranged up to 15.6 kg ha^{-1}. Instream flow recommendations developed by Wesche et al. (1977) called for a minimum flow of 0.085 m^3 s^{-1} or the natural flow, whichever is less, and a three-day annual release of 1.70 m^3 s^{-1} for flushing purposes during the spring runoff period.

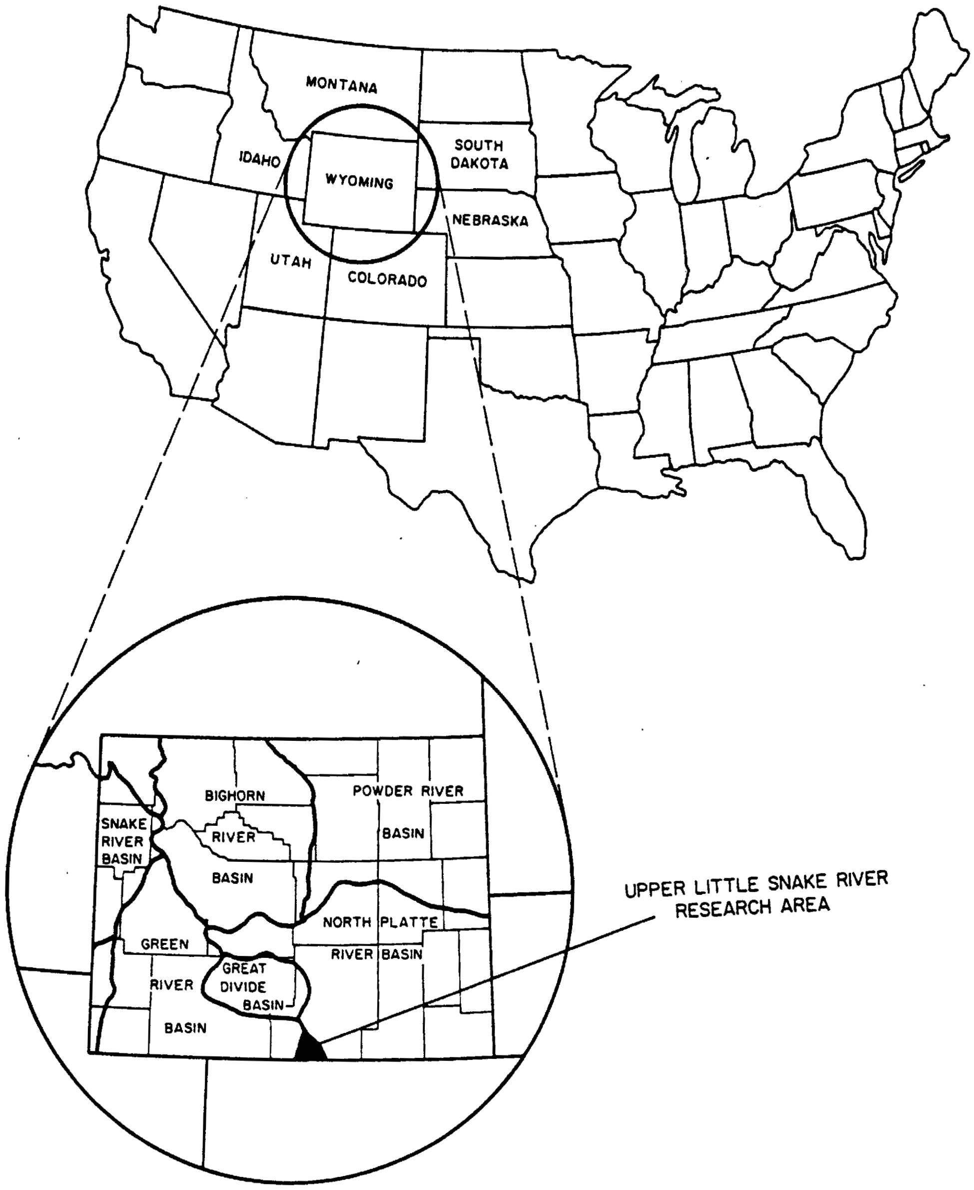

Figure 1. Map showing location of the Upper Little Snake River Research Area.

METHODS

During the Fall of 1984, four reaches were selected for study in cooperation with personnel from the Wyoming Game and Fish Department and the U.S. Forest Service (Figure 2). Reach 1, the uppermost site, was located just above the confluence of Second Creek, approximately 400 m upstream from the North Fork bridge and pipeline crossing. Reach 1 served as the control above the construction area from which the sediment spill originated. Reaches 2, 3 and 4 were located in descending order below the North Fork crossing area and were within the zone of immediate deposition from the spill. Given the intensive nature of the sampling to be conducted, study reaches were kept short in length, with Reach 2 being the longest, 15 m. Study reaches were located close to one another to avoid compounding the access problems involved with early spring sampling in a remote, high elevation area.

Two recording streamflow gage stations were installed within the study area in early May, 1985, to monitor the spring runoff hydrograph. One station was located at Reach 1 while the second was installed at Reach 3. As no tributaries entered between Reaches 2, 3, and 4, this lower station served to define the hydrograph for the three downstream reaches. Each station consisted of a stilling well constructed from a 1.2 m length of 30 cm diameter perforated plastic pipe, a Leopold and Stevens Type F water

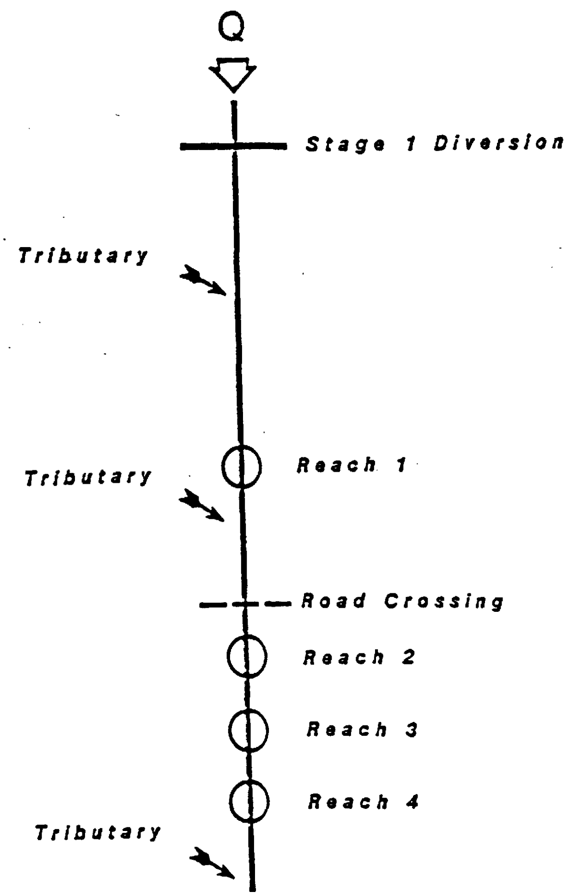

Figure 2. Study reach layout on the North Fork of the Little Snake River.

stage recorder, a steel platform on which the recorder was seated, and an outside staff gage for measuring stream stage. A rating curve for each gage station was developed following standard U.S.G.S. procedures (Buchanan & Somers 1969). Eight stage-discharge measurements were made at each station to determine the rating curves. The correlation coefficient (r) for each curve was 0.99. Recording thermographs to measure water temperature were installed in conjunction with each stream gage station. Four equally spaced cross-channel transects were established during October, 1984, within each study reach. Field data collected along these transects were used to quantify changes in response to the runoff hydrograph of 1) hydraulic characteristics, including discharge, channel width, top width, water depth, cross-sectional area, wetted perimeter, hydraulic radius, mean water velocity, bottom water velocity, and intergravel permeability; 2) bedload transport; 3) suspended sediment transport; 4) quantity and distribution of deposited sediments; and 5) quality of the deposited sediments. Given the scope of this paper, analysis will focus only on data types 4 and 5 listed above. The hydraulic and sediment transport data collected is presently undergoing analysis and will be presented in future project papers and reports.

Field sampling began in late October, 1984, was then discontinued over the winter months, and was reinitiated in early May, 1985, as spring runoff began. Sampling continued on approximately a weekly basis through early July, 1985.

The quantity of deposited sediment [kg $(m^2)^{-1}$] within each study reach at each sampling time was determined by multiplying the volume of material (m^3) by its mean density [kg $(m^3)^{-1}$] and dividing this product by the surface area (m^2). Volume was calculated as the product of mean depth of deposition (measured at approximately 80 locations within the reach using a round steel depth rod), reach length, and reach width. Mean density determinations were based upon the analysis of 12 core samples collected from each reach in October, 1984, May, 1985, and July, 1985, using a McNeil- Ahnell sampler (McNeil & Ahnell 1964). All cores were oven dried for at least 24 hours at 60 C to standardize weight measurements while the volume of each core was determined by water displacement.

The composition and quality of the deposited material within each reach over time was assessed by the following procedure:

1. As described above, 12 core samples were taken at each study reach at each of three sampling times. A total of 144 cores were collected (12 cores per reach times 4 reaches times 3 sampling times).

2. Particle size distribution by weight within each core sample was determined by dry-sieve analysis at the University of Wyoming's Division of Range Management Watershed Laboratory. A series of 10 sieves ranging in mesh size from 75 to 0.2 mm were used (Reiser & Wesche 1977).

3. The mean particle size distribution for each reach at each sampling time was determined by averaging the results from the 12 individual core samples. Distribution plots of particle size (mm) versus percentage (by weight) finer than the given sieve sizes were then developed.

4. Quality of the deposited material by reach over time was assessed by:

a) the median particle size read from the distribution plots described above;

b) the geometric mean particle size (d_g) calculated by the equation,

$$d_g = (d_1^{w_1} \times d_2^{w_2} \times \ldots d_n^{w_n}, \quad (1)$$

where d_n is the midpoint diameter of particles retained by the nth sieve and w_n is the decimal fraction by weight of particles retained on the nth sieve (Platts et al. 1983);

c) The Fredle Index (f) calculated by the equation,

$$f = \frac{d_g}{S_o} \quad (2)$$

where S_o is the sorting coefficient defined as the ratio of d75 to d25 where the particle size diameters are 75 and 25 percent finer on a weight basis of the sample (Lotspeich & Everest 1981).

RESULTS

A summary of hydraulic characteristics for each study reach is presented in Table 1. As indicated by these data, Reach 2 had the steepest gradient and subsequently the highest water velocities and shallowest water depths. Reach 4, the lowermost site, consisted primarily of pool habitat having the lowest gradient, deepest water and slowest velocities. Reaches 1 and 3 were similar in hydraulic characteristics and represented more moderate conditions.

Table 1. Mean hydraulic characteristics of the four North Fork study reaches at a low and a high discharge.

	Hydraulic Characteristics					
Reach	Discharge ($m^3\ s^{-1}$)	Top Width (m)	Cross Sectional Area (m^2)	Mean Depth (m)	Mean Velocity ($m^3\ s^{-1}$)	Water Surface Slope (percent)
#1	0.10	5.79	0.66	0.11	0.17	2.6
	1.12	6.59	1.96	0.30	0.58	---
#2	0.12	6.37	0.40	0.06	0.33	4.5
	1.83	7.19	1.90	0.27	0.97	---
#3	0.10	6.04	0.60	0.10	0.16	3.0
	2.11	7.50	2.42	0.33	0.88	---
#4	0.09	4.88	0.63	0.13	0.15	0.4
	2.86	8.55	4.45	0.53	0.68	---

Spring 1985 runoff hydrographs for the two streamflow gaging stations are presented in Figure 3. While the magnitude of the runoff was greater at the lower station due to the tributary which entered the North Fork immediately below Reach 1, timing and duration were similar. Also shown on Figure 3 is the magnitude of the flushing flow recommended by Wesche et al. (1977) for the North Fork in the vicinity of the three lower study reaches. This recommendation, 1.7 $m^3 s^{-1}$ for a duration of 3 days, was based upon field measurement of bankfull discharge and the findings of Eustis and Hillen (1954).

Three major runoff peaks occurred during 1985 which equalled or exceeded the magnitude and duration of the recommended flushing flow (Figure 3). Each peak had a maximum instantaneous discharge of 2.97 $m^3 s^{-1}$ while the maximum mean daily peaks ranged from 2.06 to 2.26 $m^3 s^{-1}$. Based upon maximum instantaneous discharge, the earliest peak lasted 3 days (May 10 to 12), the second peak extended over 8 days (May 23 to 30), and the third peak exceeded the recommended discharge on five consecutive days (June 6 to 10). A fourth peak occurred in late June during which the maximum flow approached the 1.7 $m^3 s^{-1}$ level, but only for a portion of one day.

The quantity of deposited material within each study reach at each sampling time is presented in Figure 4. Deposition was consistently lowest in Reach 1, the upstream control, and Reach 2, the uppermost study section below the construction area. Quantities in these two reaches varied from 79 to 153 kg $(m^2)^{-1}$. The high gradient through Reach 2 probably explains the relative lack of deposition in this area. Based upon the early May and July 1985 data, Reach 2 experienced a net export of 7 kg $(m^2)^{-1}$ through the spring runoff period, while Reach 1, a moderate gradient section, realized a loss of 22 kg $(m^2)^{-1}$.

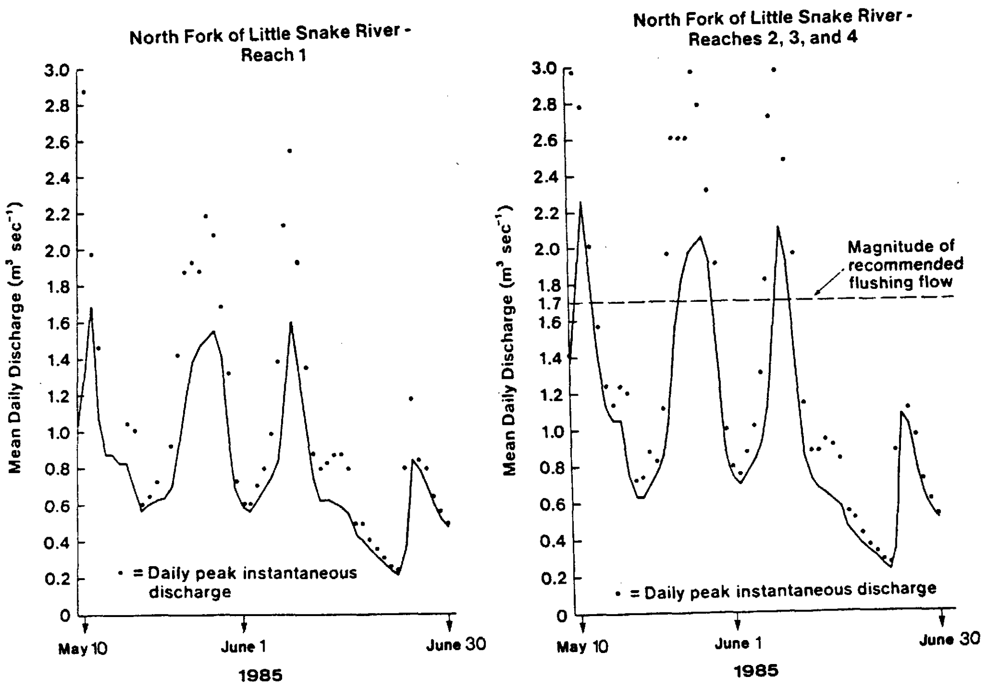

Figure 3. Spring runoff hydrographs for the two North Fork Stream gage stations.

The quantity of deposited material sampled in Reach 3 ranged from 145 to 230 kg $(m^2)^{-1}$. From early May to July 1985, a net export of 21 kg $(m^2)^{-1}$ was observed in this moderate gradient reach. The trend of the data, while greater in magnitude, paralleled that found for Reach 1, a section having similar hydraulic characteristics.

Reach 4, the lower gradient pool section, was found to have the greatest magnitude and variation of deposited material. In early May, prior to the first peak in the hydrograph, the amount of deposition present was 403 kg $(m^2)^{-1}$. The effects of the three major peak runoff events and one minor event observed during the spring of 1985 on Reach 4 are evident from Figure 4. In total, these four flushes reduced the amount of deposition to 248 kg $(m^2)^{-1}$, a net export of 155 kg $(m^2)^{-1}$.

Comparison of October 1984 and early May 1985 deposition quantities indicates considerable aggradation during the winter (Figure 4). Deposits in the moderate gradient reaches, 1 and 3, increased 52 and 20 kg $(m^2)^{-1}$, respectively, while the low gradient pool section, Reach 4, realized a net gain of 249 kg $(m^2)^{-1}$. The high gradient Reach 1 was the only study section to export material over the winter, showing a net loss of 30 kg $(m^2)^{-1}$. As the streamgage stations were not in operation during the winter and bedload transport samples could not be taken due to access limitations and heavy snow cover over the stream, the source and timing of these deposits cannot be positively identified; however, early winter thaws on the disturbed soils throughout the study area are probably responsible.

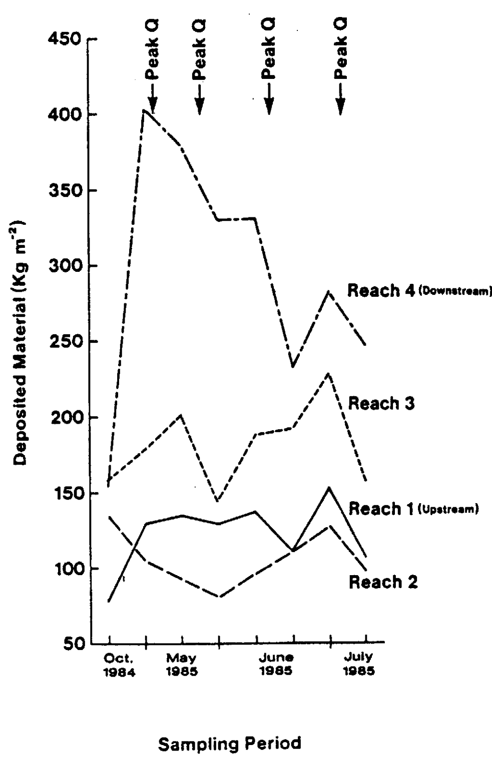

Figure 4. Comparison of deposited material in the four North Fork study reaches in relation to the spring runoff peak discharges.

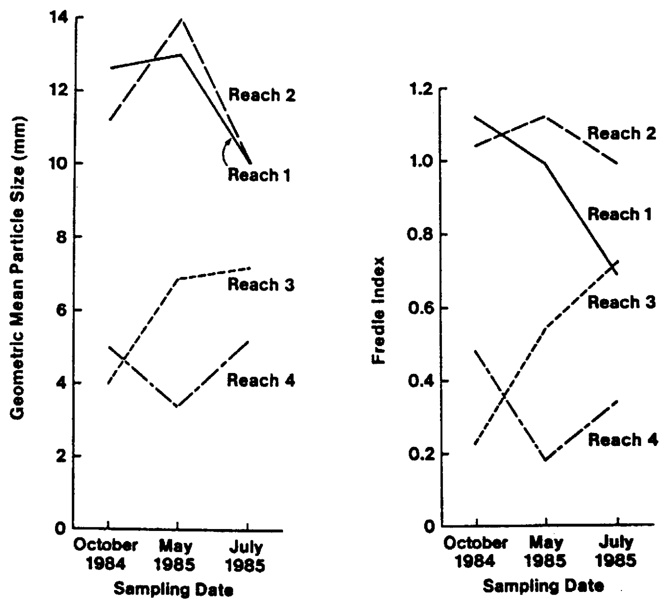

Figure 5. Quality of deposited material in the four North Fork study reaches over time.

The relative quality of deposited material in each of the study reaches over time is provided in Figure 5. As median particle size data were similar in both magnitude and variation to the geometric means, they are not presented.

The geometric mean particle size was consistently larger in Reaches 1 (range 10 to 13 mm) and 2 (10 to 14 mm) than in the lower two sections. Data for Reach 3 varied from 4.0 to 7.2 mm while the range for Reach 4 was 3.4 to 5.2 mm. Geometric means for both reaches 3 and 4 increased in response to the runoff peaks.

Fredle numbers, a spawning substrate quality index developed by Lotspeich and Everest (1981), appear to be quite low in all study reaches when compared to the preliminary relationships presented by Platts et al. (1983) between index values and percent survival-to-emergence of eggs from several salmonid species. However, the trend of our data is similar to that for geometric mean particle size and indicates improvement of deposition quality in Reaches 3 and 4 in response to the spring runoff hydrograph.

CONCLUSIONS

Based upon our analysis of the data presented, the following conclusions can be drawn:

1. Three spring runoff flushes meeting or exceeding the magnitude and duration of the recommended flushing flow for this section of the North Fork of the Little Snake River were somewhat successful in reducing the quantity of deposited material.

2. Flushing was more effective in steeper gradient reaches, while results regarding duration of the individual flushes are at present inconclusive.

3. As indicated by the Fredle Index, quality of the deposited material was very low throughout the study area.

4. Quality of deposited material showed an improving trend in response to the runoff hydrograph within the study reaches having the largest quantities of deposition.

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