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

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ABSTRACT

The effectiveness of flushing flow recommendations for the North Fork of the Little Snake River was assessed in response to sediment deposition which occurred in 1984 as a result of construction activity in the watershed. Results indicate that three spring runoff flushes meeting or exceeding the magnitude and duration of the recommended flushing flow were somewhat successful in reducing the quantity of deposited material. Quality of deposited material, in terms of trout habitat, was very low but showed an improving trend in response to the runoff hydrograph in stream areas most severely effected. Methodology for quantitatively assessing the effectiveness of flushing flows is presented.

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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 and Arnette, 1976; Wesche and Rechard, 1980). However, there are several facets of the instream flow problem which have not been adequately investigated, one of which involves 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 (e.g. Wesche et al., 1977; Environmental Research and 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. The headwaters of the North Fork rise on the west slope of the Continental Divide at an elevation of 10,000 feet above mean sea level (msl) and flow southwesterly 12.4 miles to the confluence with the Little Snake River at an elevation of 6,990 feet. Average gradient is 4.6 percent. A United States Geological Survey (U.S.G.S.) streamflow gaging station (#09251800) located 1.5 miles below the study area was in operation from 1957 to 1965 and recorded a maximum discharge of 516 cubic feet per second (cfs) on June 7, 1957. Average discharge over the period of record was 25.8 cfs. 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).

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 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 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 8,580 feet above msl, within the boundaries of Medicine Bow National Forest, 1.5 miles 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 0.3 miles 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 55 to 63°F, a total alkalinity range of 25 to 32 ppm, 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 14.0 pounds per surface acre. Instream flow recommendations developed by Wesche et al. (1977) called for a minimum flow of 3.0 cfs or the natural flow, whichever is less, and a three-day annual release of 60 cfs for flushing purposes during the spring runoff period.

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. Reach 1, the uppermost site, was located just above the confluence of Second Creek, approximately 1,300 feet upstream from the North Fork bridge and pipeline crossing. Reach 1 served as the control station 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, 50 feet. Also, 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 4 feet. length of 12-inch diameter perforated plastic pipe, a Leopold and Stevens Type F water 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 and 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 within each study reach was determined by the following procedure:

1. Along each transect at each sampling time, the depth of deposited material (Dd) was measured at 1.0 foot intervals to the nearest 0.05 foot by gently driving a 0.5 inch diameter round steel depth rod into the substrate until it came into contact with the underlying boulders and cobbles.
2. Mean Dd for each transect was determined by summing the individual depth measurements and dividing by the number of measurements taken along the transect (usually about 20 measurements).

3. The mean Dd for each of the four transects in a reach were then summed and divided by four to obtain the mean Dd for the reach at that sampling time.
4. Multiplying the mean reach Dd (feet) by the mean channel width (feet) and by the length of the reach (feet) yielded the volume of deposited material ($feet^3$) in the reach at that time.
5. To determine the density of the deposited material ($pounds/feet^3$), three core samples were collected along each transect in October 1984, early May 1985 and early July 1985 using a McNeil-Ahnell sampler (McNeil and Ahnell, 1964). To standardize weight measurements, all core samples were oven-dried for at least 24 hours at 140°F before weighing. Volume measurements for each sample were made by water displacement technique. The mean density of each reach was calculated by dividing total weight of the 12 cores for that reach by their total volume.
6. Total weight of deposited material within each reach at each sampling time was determined by multiplying the volume of deposited material by the mean density.
7. To allow comparison of study reaches having different surface areas, the total weight was divided by reach area to obtain pounds of deposited material per square foot.

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 3.0 to 0.008 inches were used (Reiser and 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 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,

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

   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,

   $$f = \frac{d_g}{S_o},$$

   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 and 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.

Spring 1985 runoff hydrographs for the two streamflow gaging stations are presented in Figure 1. 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 1 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, 60 cfs 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 1). Each peak had a maximum instantaneous discharge of 105 cfs while the maximum mean daily peaks ranged from 73 to 80 cfs. 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

TABLE 1. MEAN HYDRAULIC CHARACTERISTICS OF THE FOUR NORTH FORK STUDY REACHES AT A LOW AND A HIGH DISCHARGE.

	Hydraulic Characteristics					
Reach	Discharge (cfs)	Top Width (ft)	Cross-Sectional Area (ft^2)	Mean Depth (ft)	Mean Velocity (ft/sec)	Water Surface Slope (percent)
#1	3.5	19.0	7.1	0.36	0.56	2.6
	39.6	21.6	21.2	0.98	1.90	--
#2	4.2	20.9	4.3	0.20	1.08	4.5
	64.7	23.6	20.5	0.89	3.18	--
#3	3.5	19.8	6.5	0.33	0.52	3.0
	74.6	24.6	26.1	1.08	2.89	--
#4	3.2	16.0	6.8	0.43	0.49	0.4
	101.1	28.1	48.1	1.74	2.23	--

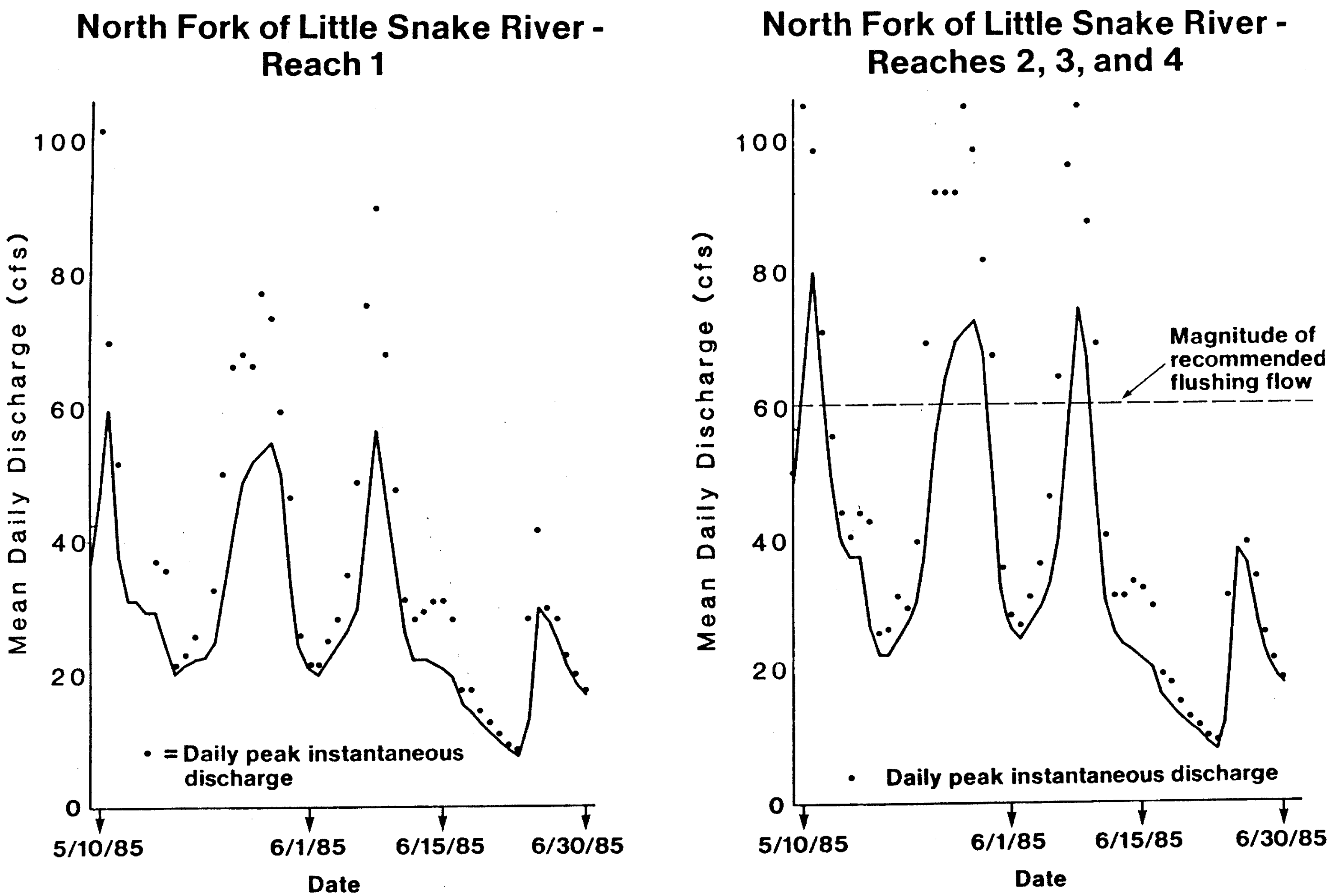

Figure 1. Spring runoff hydrographs for the two North Fork stream gage stations.

(June 6 to 10). A fourth peak occurred in late June during which the maximum flow approached the 60 cfs 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 2. 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 16.1 to 31.2 pounds/feet^2. The high gradient through Reach 2 probably explains the relative lack of deposition in this area. Based upon the October 1984 and the July 1985 data, Reach 2 experienced a net export of 7.3 pounds/feet^2 through the spring runoff period. Reach 1, a moderate gradient section, realized a net gain of 5.7 pounds/feet^2 by early July 1985. As there was additional construction activity in the North Fork drainage during 1984 above Reach 1, a small increase, such as that observed, was not unexpected.

The quantity of deposited material sampled in Reach 3 ranged from 29.5 to 46.9 pounds/feet^2. From October 1984 to early July 1985, no net gain or loss was observed in this moderate gradient reach. The trend of the data, while greater in magnitude, did parallel 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. Measurements indicated 31.6 pounds/feet^2 were present during October 1984. By early May, prior to the first peak in the hydrograph, the amount of deposition had increased to 82.1 pounds/feet^2, indicating considerable pool aggradation had occurred during winter and early spring. The effects of the three major peak runoff events and one minor event observed during

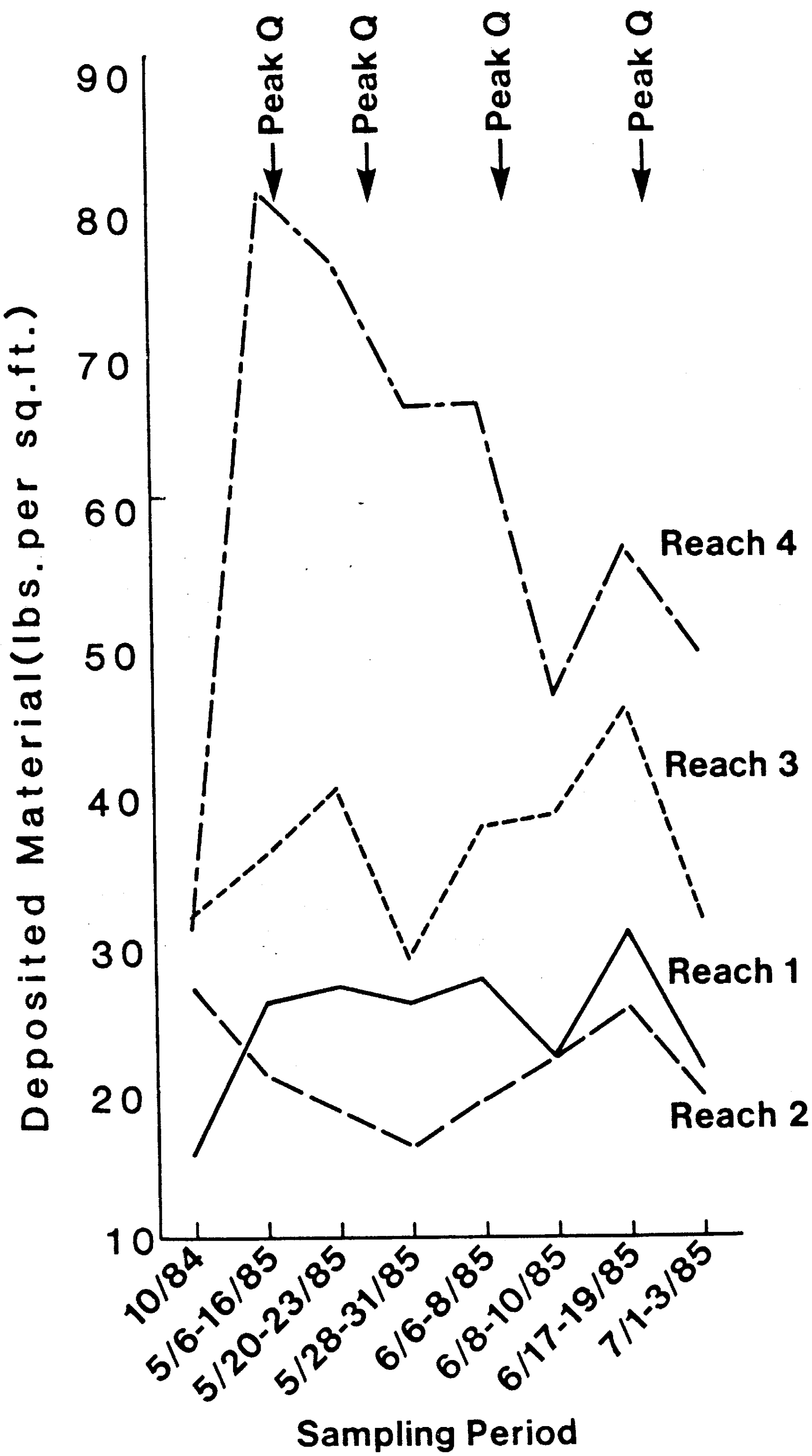

Figure 2. Comparison of deposited material in the four North Fork study reaches in relation to the spring runoff peak discharges.

the spring of 1985 on the quantity of deposited material in Reach 4 are evident from Figure 2. In total, these four flushes reduced the amount of deposition from 82.1 to 50.5 pounds/feet^2. Through the entire sampling period, Reach 4 realized a net import of 18.9 pounds/feet^2.

The relative quality of deposited material in each of the study reaches over time is provided in Figure 3. 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 0.39 to 0.51 inches) and 2 (range 0.39 to 0.55 inches) than in the lower two sections. Data for Reach 3 varied from 0.16 to 0.28 inches while the range for Reach 4 was 0.13 to 0.20 inches. Geometric means for both Reaches 3 and 4 increased in response to the runoff peaks.

Fredle indices for deposited material in all study reaches appear to be quite low 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

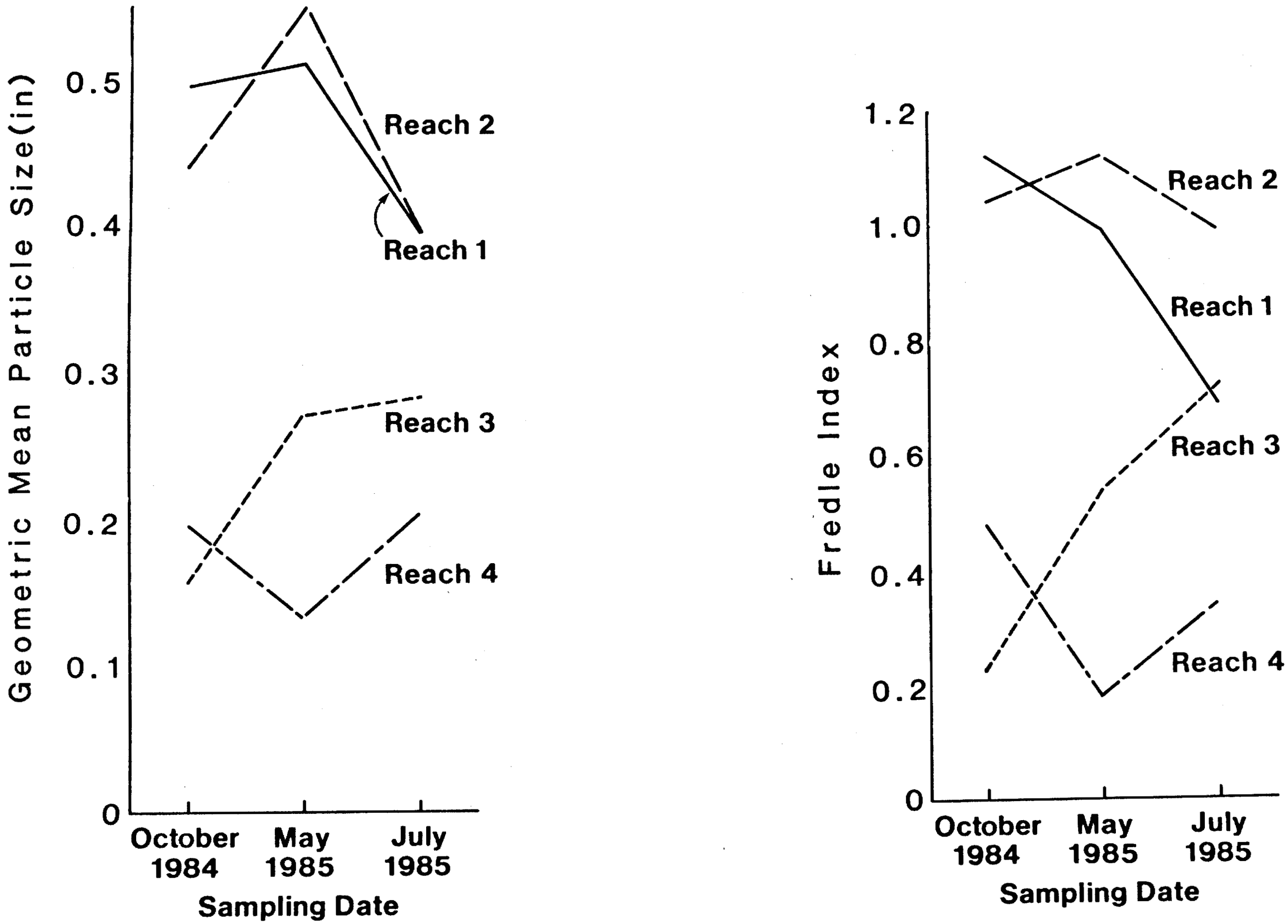

Figure 3. Quality of deposited material in the four North Fork study reaches over time.

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 those study reaches having the largest quantities of deposition.

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