SEDIMENT TRANSPORT RELATIONS AND CHANNEL MAINTENANCE IMPLICATIONS FOR BIG SANDSTONE CREEK

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EXECUTIVE SUMMARY

Study Objectives

The objective of this study has been to investigate sediment transport and storage processes in the Big Sandstone Creek drainage in the vicinity of proposed water diversion structures and relate these findings to the need for channel maintenance flow releases.

Study Approach

In July 1986, three reaches were selected for study in the Big Sandstone Creek drainage. Two reaches were located at proposed diversion points on the North and South Forks, while a third was downstream below the confluence of these tributaries. Multiple transects were established at each reach to investigate bedload and suspended load transport and sediment storage characteristics through the 1987 and 1988 spring runoff seasons. Based upon dimensionless flow duration analysis and the developed sediment transport relations, mean annual sediment budgets were determined for each reach. Also, simulated hydrographs and sediment budgets were developed for the lowermost study reach by applying a development scenario to the measured 1987 and 1988 natural hydrographs.

Study Findings

Under the natural flow regime, sediment storage in the Big Sandstone reaches is quite stable. High, short duration flows import more finer material (less than 2.0 mm) into the reaches than is exported, while lower, more frequent discharges tend to export this excess, thus maintaining a relative balance. Dominant discharges are less than 10 times the average annual flow and are less than bankfull.

Analysis of natural and simulated post-development average annual sediment budgets indicates that channel aggradation and encroachment should not occur in upper Big Sandstone Creek as a result of water development. This conclusion is supported by the findings of Wesche et al (1988), who found that the dimensions of steep, rough mountain stream channels could be maintained despite significant flow depletion in the forest snowpack zone. The key to maintaining such channels does not appear to be the release of relatively large channel maintenance flow regimes, but rather an effective erosion control program during and after construction.

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 being actively debated by water development and resource management agencies is the need for, and the determination of, channel maintenance flow requirements. Such flow releases may 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.

Given the quantities of project water typically requested for channel maintenance purposes, basic questions have been raised regarding the quantitative response of stream channels to flow regulation. Results of a field survey conducted by Wesche et al (1988) suggested that moderate to high gradient mountain stream channels located in the forest snowpack zone of the Central Rocky Mountain region can be maintained with reduced streamflow regimes. The authors hypothesized that in such high elevation, steeper gradient channels, where sediment transport capacity is high, sediment loadings are low, growing seasons are short, and the rate of accretion flows from spring snowmelt runoff is relatively rapid, available stream power is still sufficient to transport the sediment supplied and maintain channel dimensions.

The research presented herein has been conducted as a companion project to that described above by Wesche et al (1988). With funding provided by the Wyoming Water Development Commission and the Wyoming Water Research Center, our objective has been to investigate sediment transport processes in a high mountain stream system where water development is planned and relate these findings to channel maintenance flow needs.

DESCRIPTION OF STUDY AREA

The Big Sandstone Creek drainage was selected for study following discussions with the Wyoming Water Development Commission. Located on the west slope of the Sierra Madre Mountains of south-central Wyoming in the Upper Little Snake River watershed (Figure 1), Big Sandstone Creek has been considered for development under the proposed Fish Creek Collector System. Three stream reaches were selected for study: 1) the North Fork of Big Sandstone Creek near the proposed diversion; 2) the South Fork of Big Sandstone near the proposed diversion; and, 3) Big Sandstone Creek proper immediately below the confluence of the North Fork and the South Fork. The relative locations of the three reaches are shown on Figure 2.

The North Fork study reach is located at an elevation of approximately 8660 feet above mean sea level (msl) in the northwest quarter of Section 12, T14N, R87W. This forested watershed encompasses 2.28 sq. miles and has a mean basin elevation of 9520 feet. Average annual flow was estimated to be 3.6 cubic feet per second (cfs), while the gradient of the reach was 2.8 percent.

The South Fork study reach is located in the southwest quarter of Section 12, T14N, R87W at an elevation of approximately 8650 feet above msl. This watershed encompasses 2.95 sq. miles and has a mean basin elevation of 9540 feet. Average annual flow was estimated to be 3.9 cfs, while the gradient of the reach was approximately 3.4 percent.

The Big Sandstone study reach is located 1200 feet below the confluence of the North and South Forks at an elevation of approximately 8530 feet above msl in the northeast quarter of Section 11, T14N, R87W. At this location, Big Sandstone Creek drains 6.08 sq. miles and has a

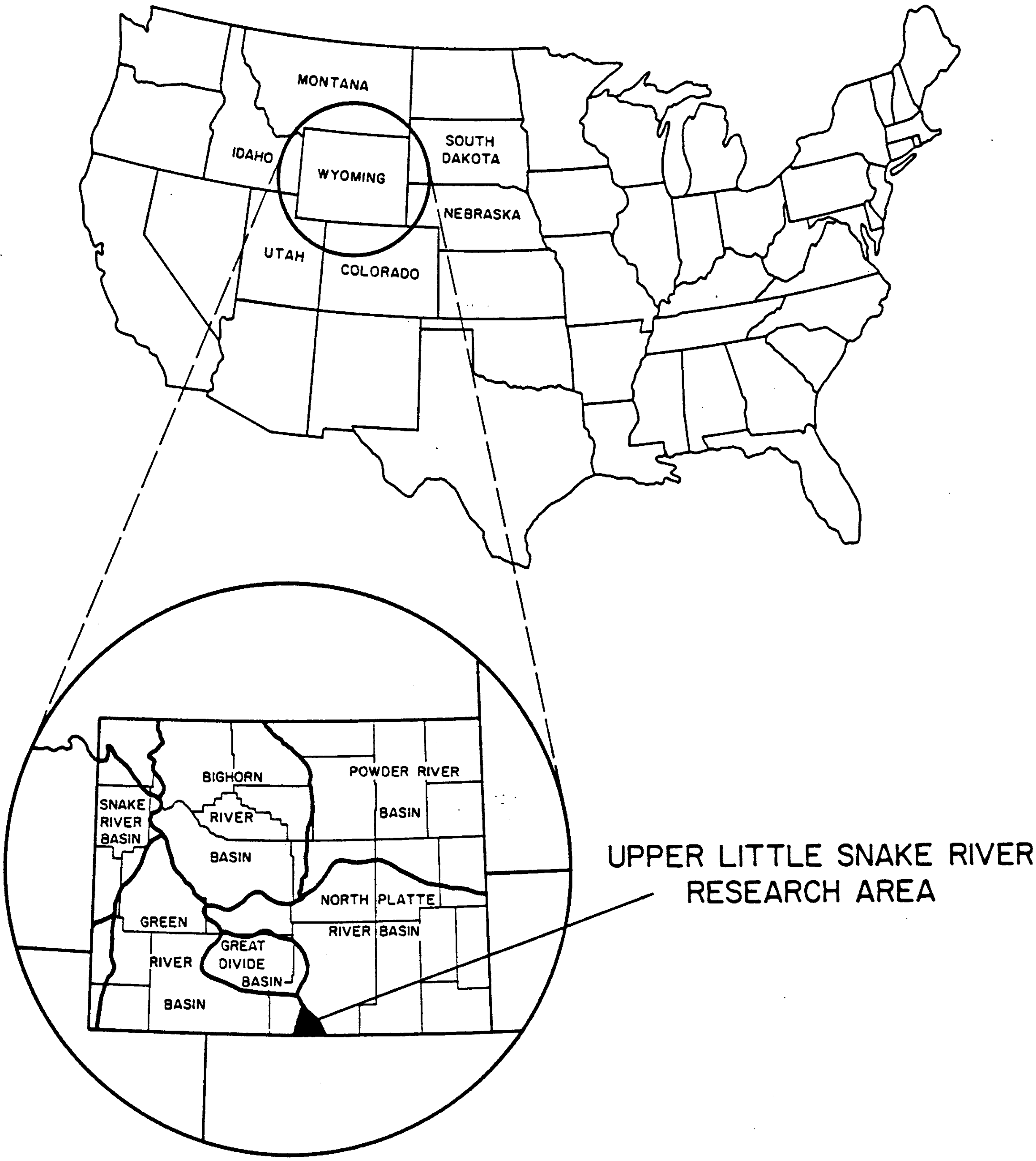

Figure 1. Location of the Wyoming Water Research Center's Upper Little Snake River Research Area.

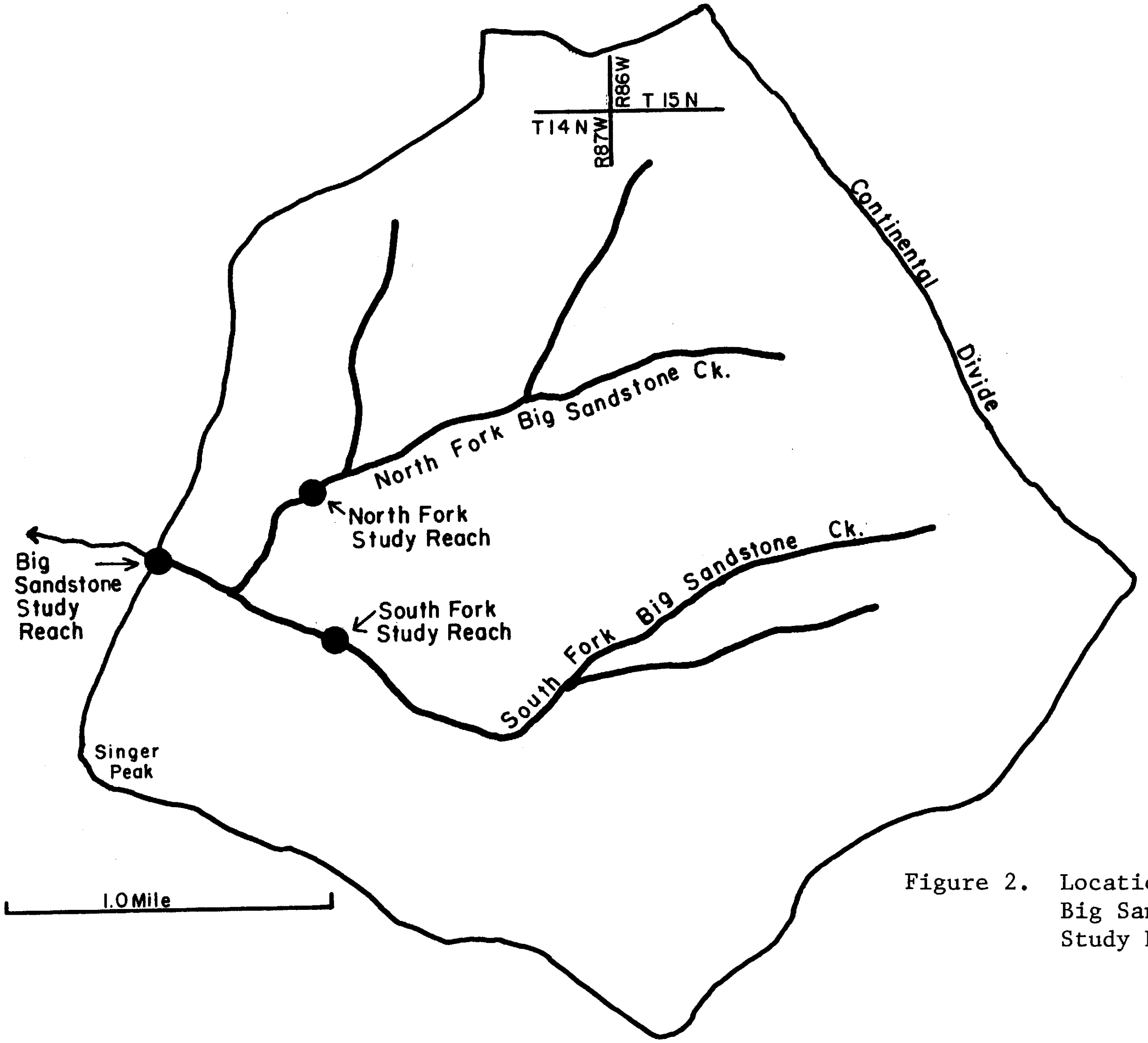

Figure 2. Location of the Three Big Sandstone Creek Study Reaches.

mean basin elevation of 9455 feet. Average annual flow was estimated to be 9.6 cfs, while the gradient of the reach was 1.6 percent.

METHODS

The three Big Sandstone Creek study reaches were selected in early July 1986 based upon 1) their representation of general channel geometry, hydrologic, hydraulic, and sediment characteristics, 2) their location in relation to the proposed diversion system; 3) the presence of a diversity of fish habitat types; and 4) the absence of significant land use effects.

Hydrologic

Two recording streamflow gaging stations were installed during early July, 1986, one at the North Fork study reach and one on the South Fork. Each station consisted of a stilling well constructed from perforated plastic pipe, a Leopold and Stevens Type F water stage recorder, a steel recorder platform and an outside staff gage. A rating curve for each gage station was developed following standard U.S. Geological Survey procedures (Buchanan and Somers, 1969). The gage stations were operated from July to September, 1986; April to September, 1987; and, May through June, 1988. No attempt was made to operate the stations through the winter months due to their remote locations. A staff gage was installed at a rated cross-section in the Big Sandstone reach and daily records were developed by correlation analysis with the recording stations. All streamflow records have been entered onto the Water Resources Data System (WRDS) maintained by the Wyoming Water Research Center at the University of Wyoming.

As no long-term streamgage records are available for Big Sandstone Creek, it was necessary to estimate the average annual discharge at each reach following the procedures of Lowham (1976). Application of the channel geometry method resulted in exceptionally high estimates while the basin characteristics estimates were felt to be too low based upon our limited gage record. As a result, the two estimates for each reach were averaged. As these average values agreed quite closely with the average annual flow values reported by Stone and Webster (1986), they were selected for use in our analysis.

Hydraulic

Four cross-channel transects were established in the North Fork and South Fork study reaches to evaluate hydraulic characteristics over a wide range of streamflow conditions. Five such transects were established at the Big Sandstone reach. Measurements of water depth, mean velocity and bottom velocity were made at approximately 20 locations along each transect at a series of low, moderate and high discharges. These data, in conjunction with measurements of top width (B) and water surface slope (S), were then used to develop power function relationships with stream discharge (QW) for the following hydraulic variables:

D (mean transect depth, in feet)

$\overline{V}$ (mean transect velocity, in ft/sec)

Vb (mean transect bottom velocity, in ft/sec)

B (transect top width, in feet)

To (shear stress, in lbs/ft)

P (unit stream power, in lbs/ft-sec)

B/D (width to depth ratio in ft/ft).

All velocity measurements were made with Marsh-McBirney current meters. Mean velocity measurements were made at 0.6 of depth, while bottom velocities were measured as near to the streambed as was physically possible. Water surface slope was measured with a surveyor's level and rod over each transect for a range of flow conditions.

Sediment

The primary sampling units for sediment transport and storage were the 13 transects described above. Suspended sediment samples were taken with USDH-48 samplers using the Equal Transit Rate (ETR) technique described by Guy and Norman (1970). Bedload transport was measured using a Helley-Smith sampler as described by Emmett (1980), with each transect sample being composed of at least 20 subsamples each of one minute duration. While sediment transport samples were taken at each transect over a range of discharges and locations on the runoff hydrograph during the spring and summer of 1987 and 1988, our sampling emphasis was focused on the uppermost and lowermost transects in each reach to attempt to define sediment import and export from a reach perspective.

The particle size distribution of stored sediment in each reach was sampled four times over the course of the study. Three core samples were taken in the vicinity of each transect at each sampling time using a six inch diameter McNeil sampler following techniques described by Reiser and Wesche (1977). Coring depth was a maximum of six inches, dependent upon the depth of underlying boulders and bedrock. The quantity of stored sediment in each reach was estimated near the beginning and at the end of the study. Depth of deposition was measured at 20 locations along each transect at each sampling time by driving a graduated steel rod into the bed until bedrock or boulder was encountered.

Laboratory analysis of all sediment samples was done at the Watershed Laboratory of the Range Management Department in the University of Wyoming's College of Agriculture. Suspended sediment samples were analyzed by the filtration method (U.S. Geological Survey, 1977), with results reported in mg/l. Suspended load discharge (Qsl) in tons/day was calculated using the equation:

$$Qsl = .0027\ CsQw$$

where

Cs = sediment concentration in mg/l

Qw = water discharge in cfs

and .0027 is a constant.

All bedload samples were oven dried for 24 hours at 140°F, dry sieved, and weighed. Bedload discharge (Qbl) in tons per day was then calculated directly based upon the weight of the sample, the width of the sampler orifice, the top width of the transect at the time of sampling, the number of subsamples taken across the transect, and the total sampling time.

Bed material core samples were also oven dried for at least 24 hours at 140°F, dry sieved and weighed. Particle size distributions were then plotted on log probability paper to determine the d84, d50 and d16 values (those particle diameters for which 84, 50 and 16 percent, respectively, of the sample is finer than by weight) and the gradation coefficient ($G = 1/2\ (\frac{d84}{d50} + \frac{d50}{d16})$), as described by Simons and Senturk (1977).

RESULTS

Hydrology

Streamgage stations at the North Fork and South Fork study reaches were operated during both the 1987 and the 1988 spring snowmelt runoff seasons. As shown on Figure 3 for the North Fork station, runoff occurred earlier during 1987, peaking in mid-May, and was of lesser volume than during 1988. Runoff volumes, means and peak discharges are compared on Table 1 for the May-June period at the three study reaches. Average water yield above the Big Sandstone reach for the two month runoff period was 0.93 acre-ft per acre in 1987 and 1.55 acre-ft per acre in 1988. Base flows at this reach during the study period ranged from 2.3 to 3.0 cfs in late August and early September.

Hydraulic Geometry

Hydraulic geometry relations are empirically derived equations which express the physical characteristics of a river cross-section as a power function of discharge (Qw) through that cross-section. Once developed, these relations can be used to describe not only how a cross-section varies dimensionally with streamflow, but also how different cross-sections compare at the same relative discharge. Typically, hydraulic geometry equations are developed for stream top width, mean water depth and mean water velocity. By incorporating w, the specific weight of water (62.4 lbs/ft^3), and an estimate of the energy slope, S, the force (shear stress) exerted by the discharge on the channel boundary and the stream power available for sediment transport can be determined.

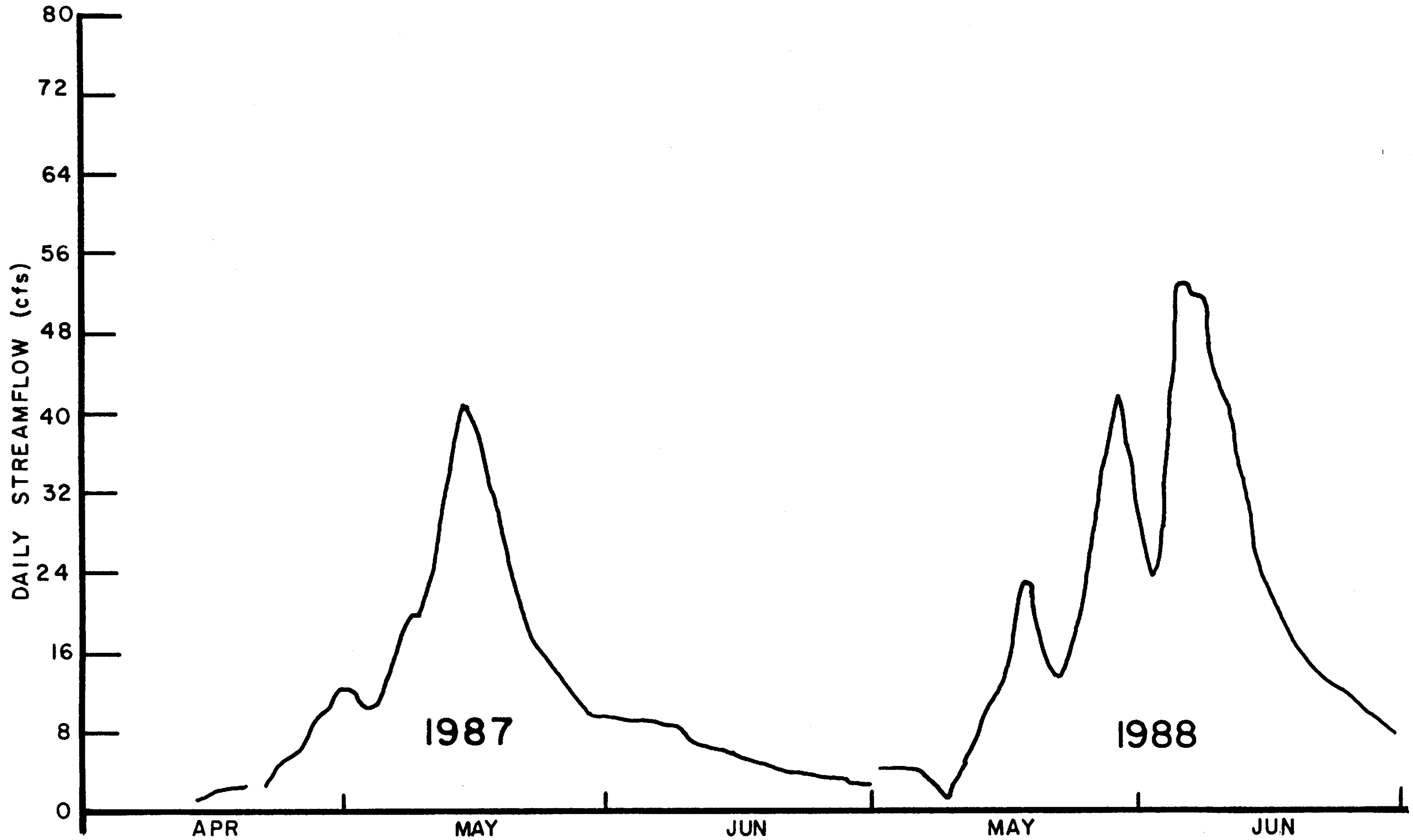

Figure 3. Spring Runoff Hydrographs for the North Fork of Big Sandstone Creek Study Reach During 1987 and 1988.

Table 1. Comparison of Streamflow Characteristics at the Three Big Sandstone Creek Study Reaches During May and June, 1987 and 1988.

	North Fork		South Fork		Big Sandstone	
	1987	1988	1987	1988	1987	1988
Total Runoff[1] Volume (SFD)	799	1211	886	1059	1814	3016
Mean Daily Flow for Period (cfs)	13.1	20.0	14.5	17.4	29.7	49.4
Peak Daily Flow (cfs)	40.7	52.5	41.3	41.9	89.1	131.0
Average Annual[2] Flow (cfs)	3.6		3.9		9.6	

[1]SFD = second foot days

[2]Estimated following Lowham (1976)

Hydraulic geometry relations for the upper and lower transects in the North Fork, South Fork and Big Sandstone Creek study reaches are presented in Tables 2, 3 and 4 respectively. The relationship of the width to depth ratio, a dimensionless parameter describing the shape of the cross-section, to discharge has also been included. As local water surface slope at each of these transects showed little variation with discharge, a constant slope was used for each transect to estimate shear stress and stream power.

Stream power, as defined by Graf (1971), is the supply of energy available for the transport of sediment. For the purposes of this study, we attempted to locate the upper transect of each reach at a cross-section having relatively higher available energy than at the lower cross-section, thereby attempting to gain insight regarding the question of whether the study streams were supply or energy limited. Stream power-discharge relations at each of the study reaches are compared in Figure 4.

Sediment Transport Relations

The equations developed at the upper and lower transects of each study reach describing sediment transport as a power function of discharge are presented in Table 5. Sediment transport has been considered from the aspect of total bedload, sand bedload (that fraction of the total bedload having a particle diameter less than 2.0 mm), and suspended load. All correlation coefficients were statistically significant at the .05 level.

Table 2. Hydraulic Relations for Transects 1 and 4, North Fork of Big Sandstone Creek Study Reach.

Hydraulic Parameter	Units	Equation[1]	Transect
Stream Width (B)	Feet	$B = 11.763\ Qw^{.061}$	1
		$B = 9.617\ Qw^{.004}$	4
Mean Depth (D)	Feet	$D = 0.210\ Qw^{.305}$	1
		$D = 0.177\ Qw^{.454}$	4
Mean Velocity (V)	Feet/sec	$V = 0.402\ Qw^{.638}$	1
		$V = 0.589\ Qw^{.541}$	4
Bottom Velocity (Vb)	Feet/sec	$Vb = 0.341\ Qw^{.493}$	1
		$Vb = 0.634\ Qw^{.261}$	4
Shear Stress (To)	lbs/ft^2	$To = 0.133\ Qw^{.302}$	1
		$To = 0.655\ Qw^{.452}$	4
Stream Power (P)	lbs/ft-sec	$P = 0.052\ Qw^{.948}$	1
		$P = 0.383\ Qw^{.996}$	4
Width to Depth Ratio (B/D)	ft/ft	$B/D = 56.0\ Qw^{-.244}$	1
		$B/D = 54.2\ Qw^{-.450}$	4

[1]Qw= streamflow in cfs

Table 3. Hydraulic Relations for Transects 1 and 4, South Fork of Big Sandstone Creek Study Reach.

Hydraulic Parameter	Units	Equation[1]	Transect
Stream Width (B)	Feet	$B = 14.000Qw^{.000}$	1
		$B = 7.697Qw^{.045}$	4
Mean Depth (D)	Feet	$D = 0.308Qw^{.346}$	1
		$D = 0.262Qw^{.409}$	4
Mean Velocity (V)	Ft/sec	$V = 0.233Qw^{.654}$	1
		$V = 0.498Qw^{.545}$	4
Bottom Velocity (Vb)	Ft/sec	$Vb = 0.180Qw^{.529}$	1
		$Vb = 0.248Qw^{.495}$	4
Shear Stress (To)	lbs/ft^2	$To = 0.114Qw^{.350}$	1
		$To = 0.620Qw^{.409}$	4
Stream Power (P)	lbs/ft-sec	$P = 0.028Qw^{.979}$	1
		$P = 0.311Qw^{.952}$	4
Width to Depth Ratio (B/D)	ft/ft	$B/D = 45.6Qw^{-.349}$	1
		$B/D = 29.4Qw^{-.363}$	4

[1]Qw= streamflow in cfs.

Table 4. Hydraulic Relations for Transects 1 and 5, Big Sandstone Creek Study Reach.

Hydraulic Parameter	Units	Equation[1]	Transect
Stream Width (B)	Feet	$B = 18.503\ Qw^{.001}$	1
		$B = 17.100\ Qw^{.000}$	5
Mean Depth (D)	Feet	$D = 0.172\ Qw^{.507}$	1
		$D = 0.408\ Qw^{.287}$	5
Mean Velocity (V)	Ft/sec	$V = 0.306\ Qw^{.498}$	1
		$V = 0.142\ Qw^{.716}$	5
Bottom Velocity (Vb)	Ft/sec	$Vb = 0.322\ Qw^{.282}$	1
		$Vb = 0.059\ Qw^{.855}$	5
Shear Stress (To)	lbs/ft^2	$To = 0.061\ Qw^{.522}$	1
		$To = 0.204\ Qw^{.286}$	5
Stream Power (P)	lbs/ft-sec	$P = 0.020\ Qw^{.997}$	1
		$P = 0.030\ Qw^{.996}$	5
Width to Depth Ratio (B/D)	ft/ft	$B/D = 108.9\ Qw^{-.510}$	1
		$B/D = 42.7\ Qw^{-.288}$	5

[1]Qw= streamflow in cfs.

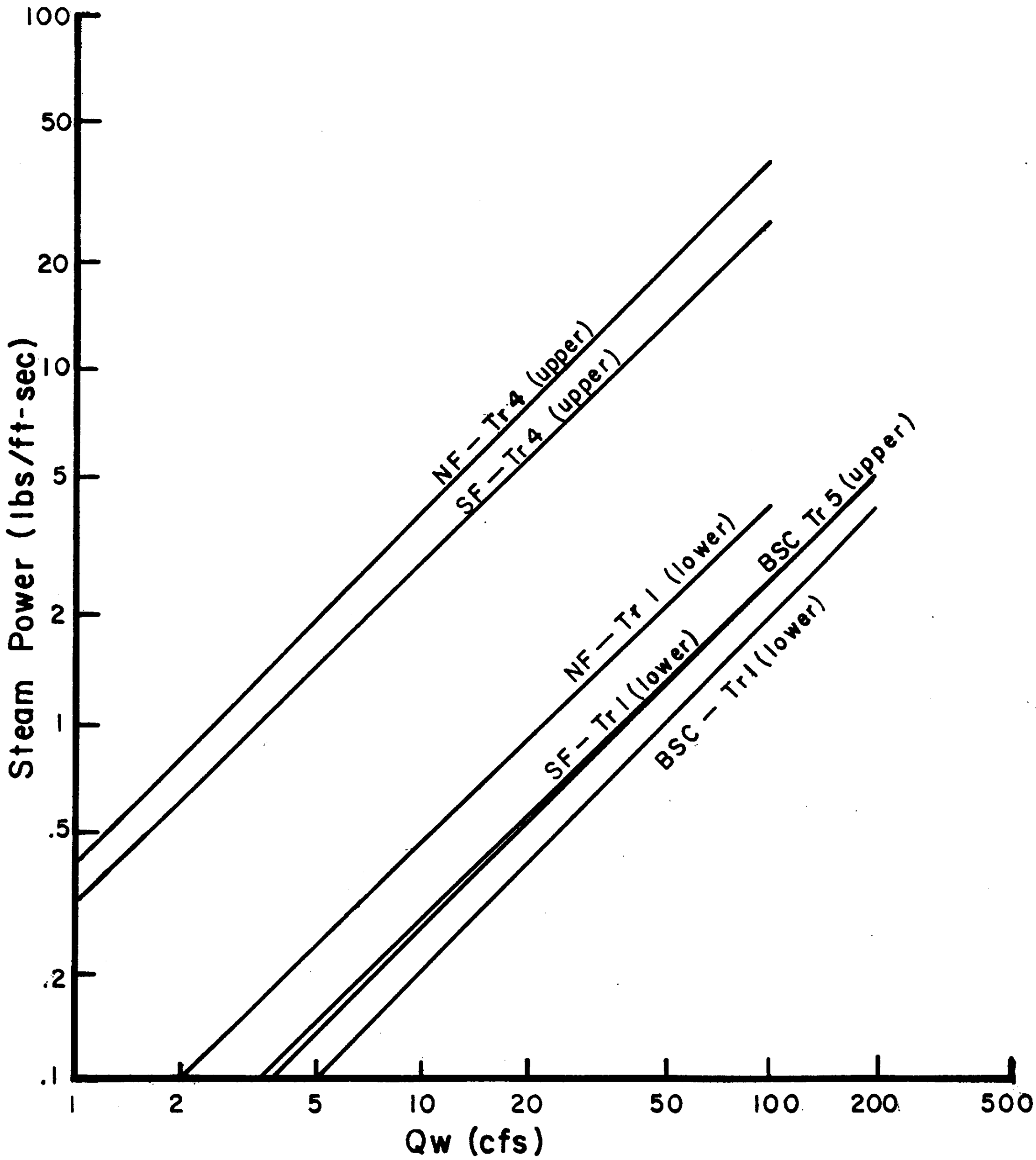

Figure 4. Stream Power-Discharge (Q_w) Relations at the Upper and Lower Transects in the North Fork (NF), South Fork (SF) and Big Sandstone Creek (BSC) Study Reaches.

Table 5. Relations of Bedload (Qbl), Sand Bedload (Qbls) and Suspended Load (Qsl) Transport (tons/day) to Discharge (Qw,cfs) at the North Fork (NF), South Fork (SF) and Big Sandstone Creek (BSC) Study Reaches.

Reach	Transect	Equation	Sample Size	Correlation Coefficient (r)
NF	1	$Qbl = .0007\ Qw^{2.069}$	25	.90
		$Qbls = .0009\ Qw^{1.682}$	25	.86
		$Qsl = .0115\ Qw^{1.168}$	27	.77
NF	4	$Qbl = .00045\ Qw^{2.435}$	22	.87
		$Qbls = .0006\ Qw^{1.921}$	22	.79
		$Qsl = .0017\ Qw^{1.662}$	27	.55
SF	1	$Qbl = .0025\ Qw^{1.173}$	23	.61
		$Qbls = .001\ Qw^{1.175}$	23	.70
		$Qsl = .0122\ Qw^{0.842}$	28	.45
SF	4	$Qbl = .0006\ Qw^{1.052}$	19	.46
		$Qbls = .0002\ Qw^{1.087}$	19	.64
		$Qsl = .0049\ Qw^{1.229}$	24	.59
BSC	1	$Qbl = .0021\ Qw^{1.530}$	26	.90
		$Qbls = .0029\ Qw^{1.330}$	26	.90
		$Qsl = .0031\ Qw^{1.274}$	30	.50
BSC	5	$Qbl = .000014\ Qw^{2.882}$	27	.83
		$Qbls = .00002\ Qw^{2.552}$	27	.83
		$Qsl = .0020\ Qw^{1.421}$	32	.65

As shown on Figure 5, the percent of the total load (bedload plus suspended load) transported as bedload increased with increasing streamflow. The only exception to this trend was at the inflow (Tr4) to the South Fork reach. Here, large immovable bed material hampered sample collection efficiency, as indicated by the relatively low correlation coefficient. The median particle size (d50) being transported as bedload increased with increasing streamflow (Figure 6) while the percentage of sand tended to decrease. The d50 at the upper cross-section in each reach typically exceeded that at the lower transect for the higher flow ranges, with the trend being generally similar to that shown in Figure 4. At Tr.4 in the North Fork reach, the d50 first exceeded 2.00 mm (very fine gravel) at a flow of 9.2 cfs (250 percent of mean daily flow), while at the upper transects in the South Fork and Big Sandstone reaches, gravel transport did not predominate until flow exceeded the mean daily discharge by a factor of at least four. Medium and coarse gravels (8 to 32 mm in diameter) did not significantly enter the bedload until discharge was at least eight times the mean daily flow.

As the focus of this study is channel maintenance, particular attention was given to the transport of the smaller particle sizes. By combining the sand bedload fraction with the suspended load transport, total sediment transport curves were developed for particles less than 2.00 mm, as shown on Figure 7. While these curves vary in magnitude between the reaches, the general trend within each reach is similar. At the higher, less frequent discharges, the upper transects (higher energy) each import more sand to the reaches than is transported past the lower transect. At the lower, more frequent discharges, more sand is exported. While this trend does not necessarily follow that of the

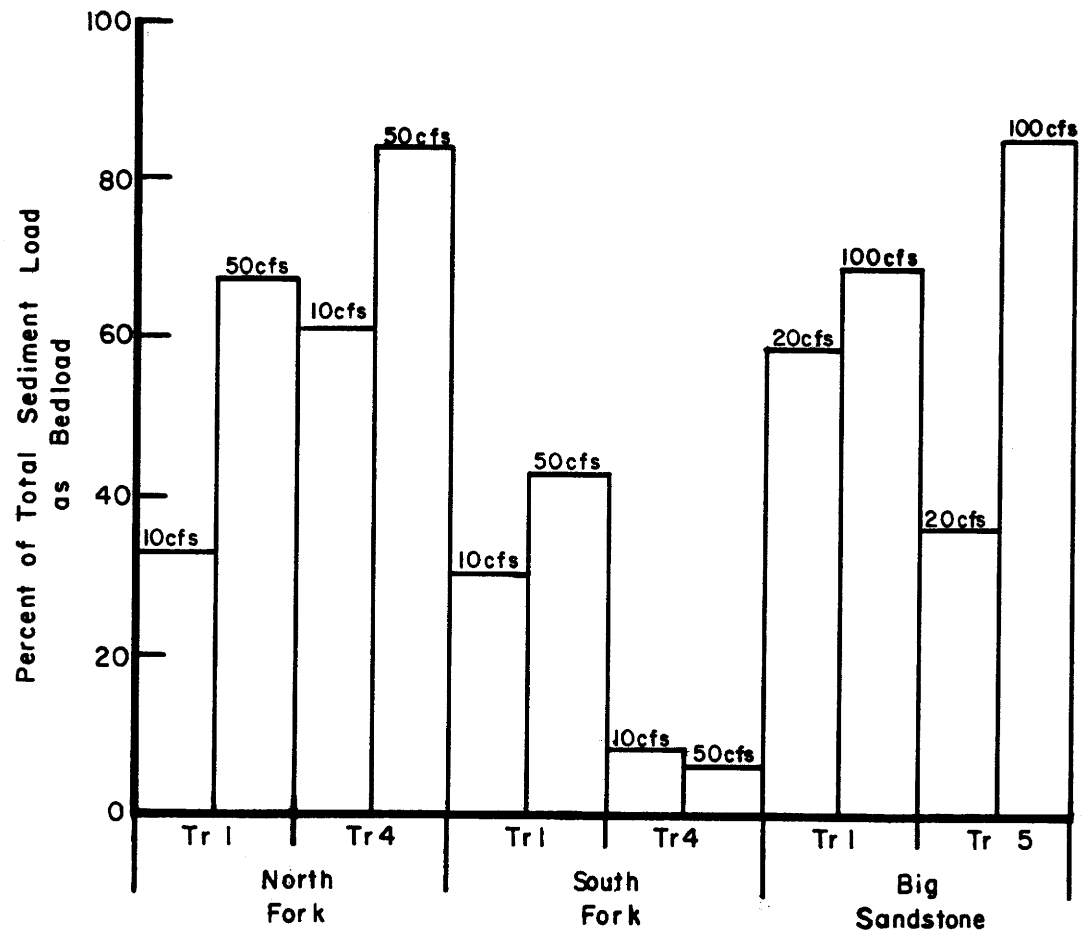

Figure 5. Percent of Total Sediment Load Transported as Bedload at a Moderate and a High Flow for the Three Big Sandstone Creek Study Reaches.

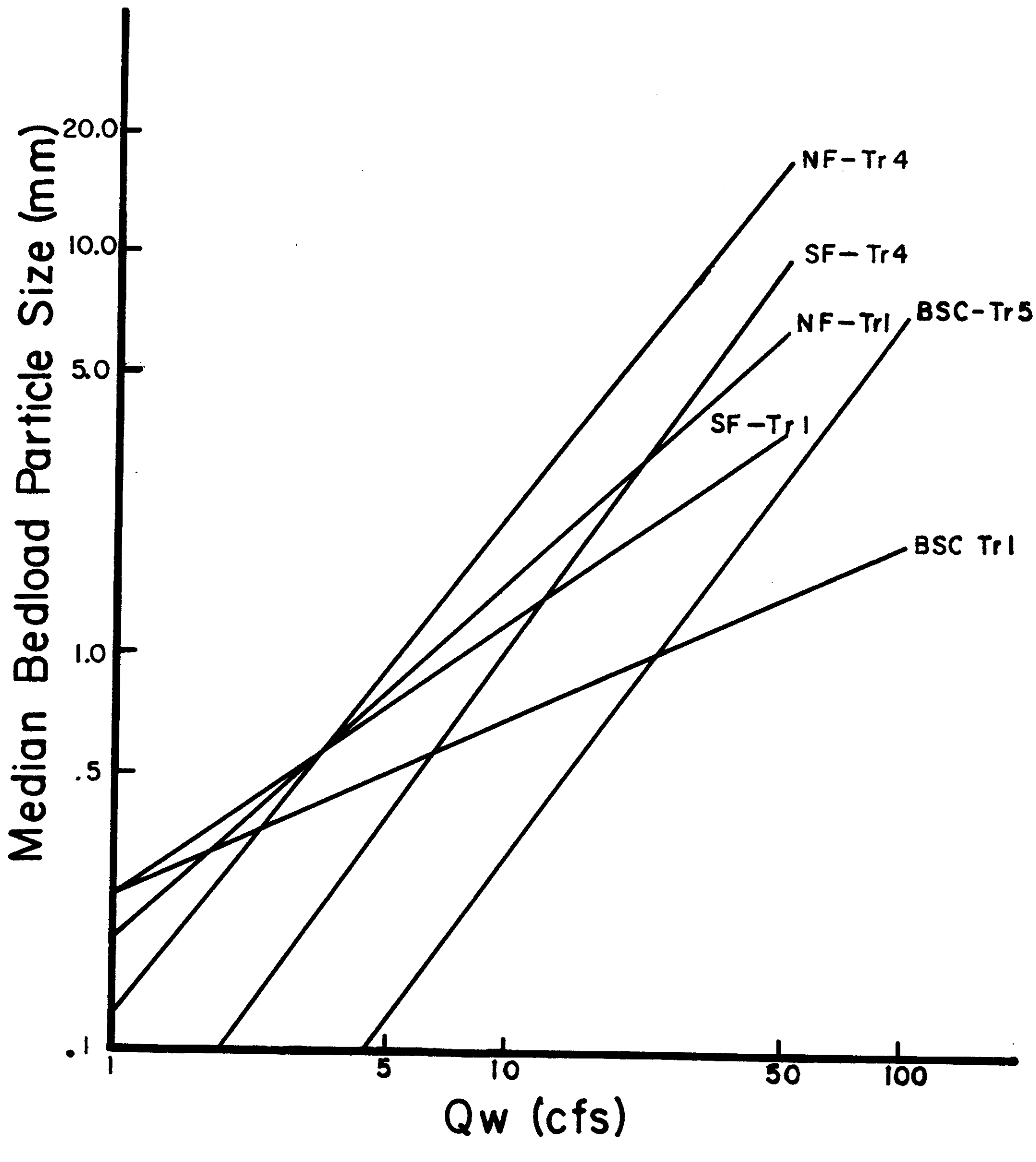

Figure 6. Relations Between Discharge (Q_w) and Median Bedload Particle Size at the North Fork (NF), South Fork (SF) and Big Sandstone Creek (BSC) Study Reaches.

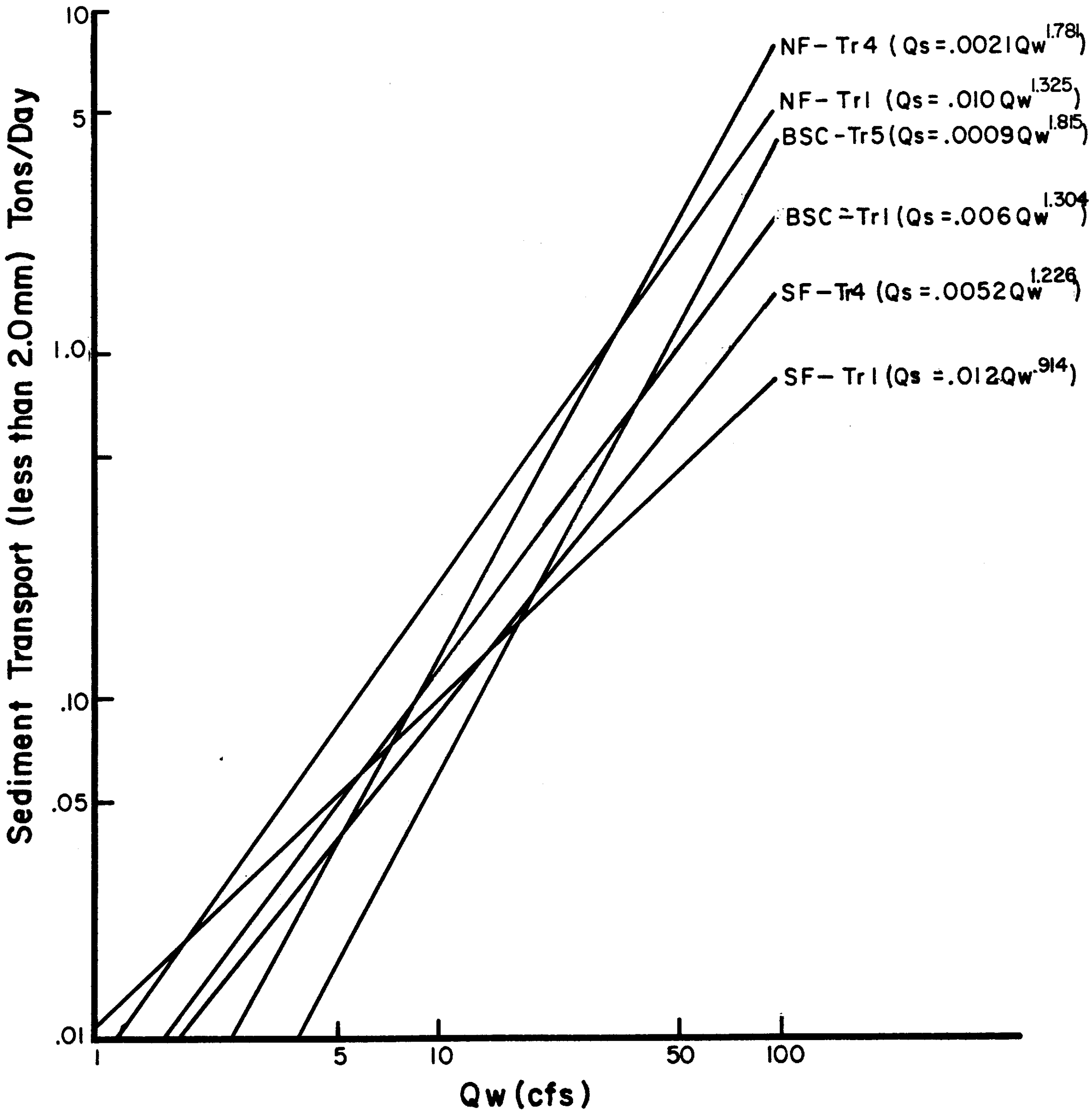

Figure 7. Sediment Transport (less than 2.0 mm) - Discharge (Q_w) Relations at the Upper and Lower Transects in the North Fork (NF), South Fork (SF) and Big Sandstone Creek (BSC) Study Reaches.

hydraulic relations presented in Tables 2, 3 and 4 and in Figure 4, it must be kept in mind that these hydraulic relations are based on mean cross-section values. Mavis and Laushey (1949), as reported in Chang (1988), found the critical bottom velocity for mobilization of 2-mm diameter particles to be approximately 0.8 ft/sec. Applying this minimum criterion to the bottom velocities measured at the Big Sandstone study reaches as shown in Figure 8, it is evident that sand transport could still occur at low discharges over approximately 20 to 35 percent of the cross-section width at the lower transects.

Stored Sediment Characteristics

The particle size distributions of stored sediments in the three reaches were quite stable over the duration of the study (Figures 9, 10 and 11). Median particle sizes ranged from 21 to 39 mm in diameter while the sand fraction (less than 2.0 mm) varied from 7.5 to 16.5 percent. Generally, stored material was slightly coarser at the South Fork reach. Throughout the study, the quality of the stored bed material compared favorably with the particle size distributions used by trout for spawning elsewhere in the Medicine Bow National Forest (Figure 12), as determined by Reiser and Wesche (1977).

The quantity of stored bed material also was relatively stable over the duration of the study. Deposition depths were lowest at the South Fork reach, averaging 0.14 ft in late April, 1987 and 0.15 ft on June 30, 1988. Over this same time period, the mean depth at the North Fork reach decreased from 0.42 to 0.30 ft, while deposition at the Big Sandstone reach increased slightly from 0.36 to 0.38 ft.

The quality and stability of the Big Sandstone bed material reflect the natural condition of the watershed when compared with similar data

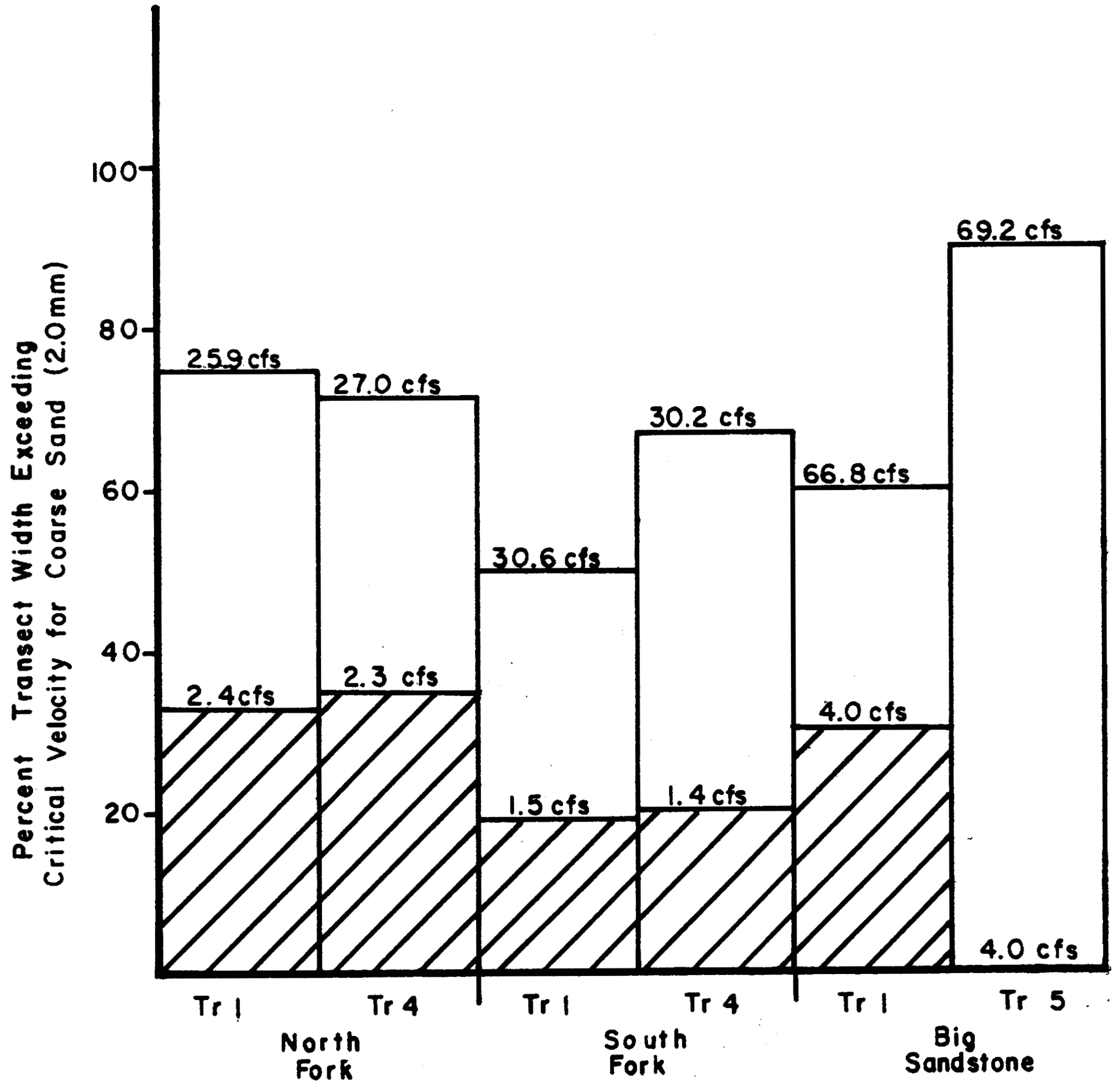

Figure 8. Percent Transect Width Exceeding Critical Velocity for Coarse Sand at High and Low Discharges at the Big Sandstone Creek Study Reaches.

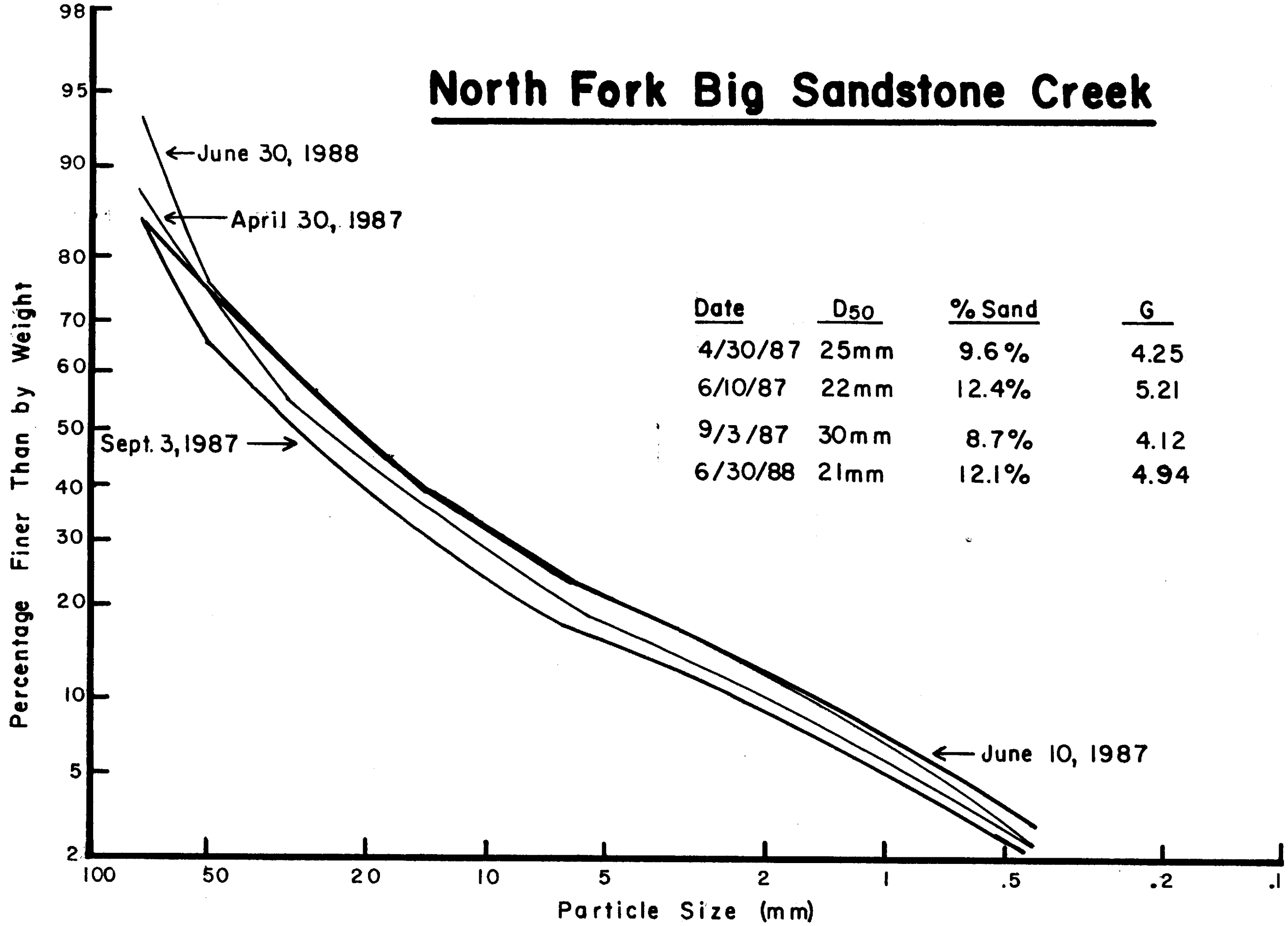

Figure 9. Particle Size Distributions of Stored Bed Material at the North Fork Study Reach.

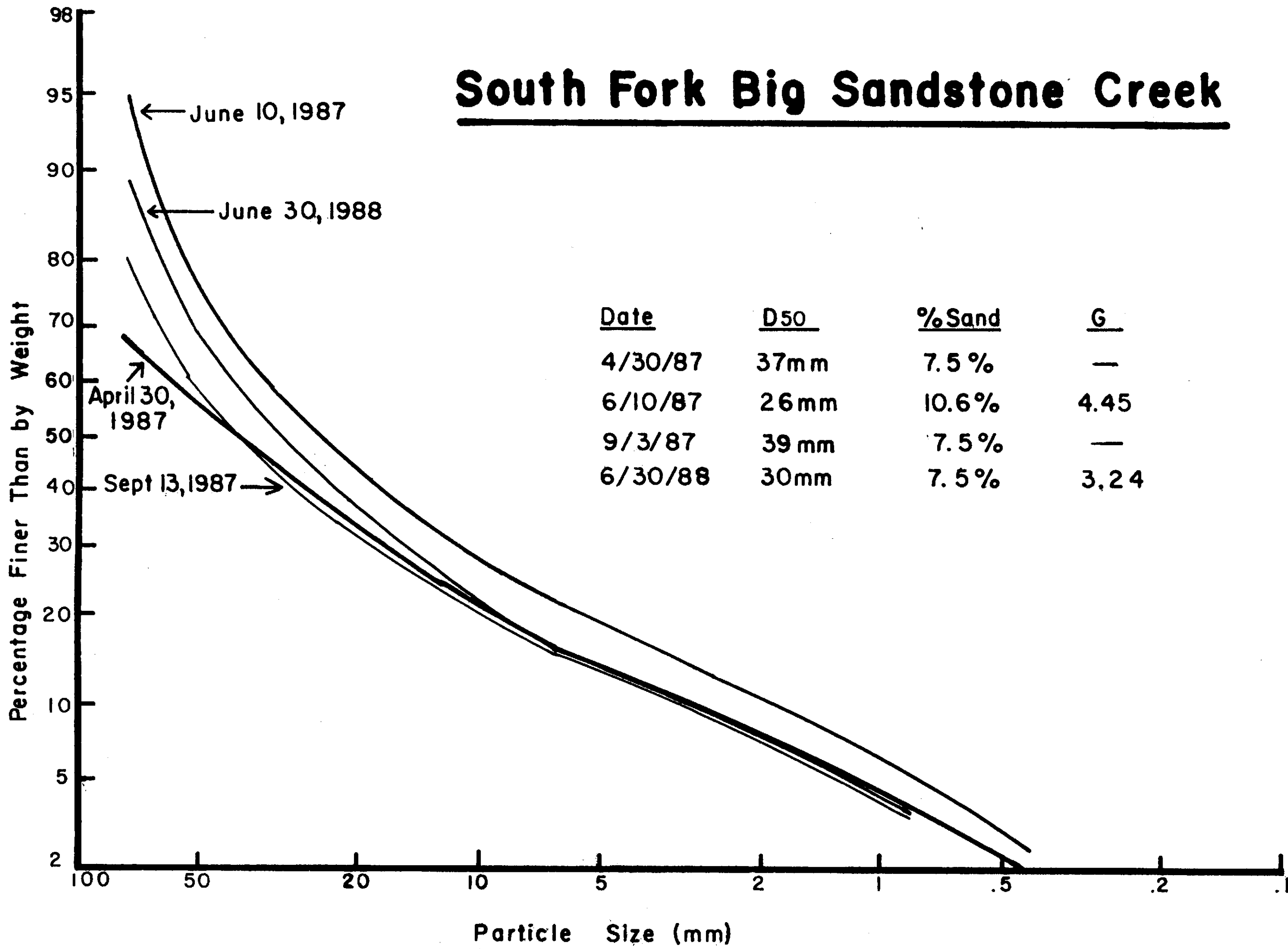

Figure 10. Particle Size Distributions of Stored Bed Material at the South Fork Study Reach.

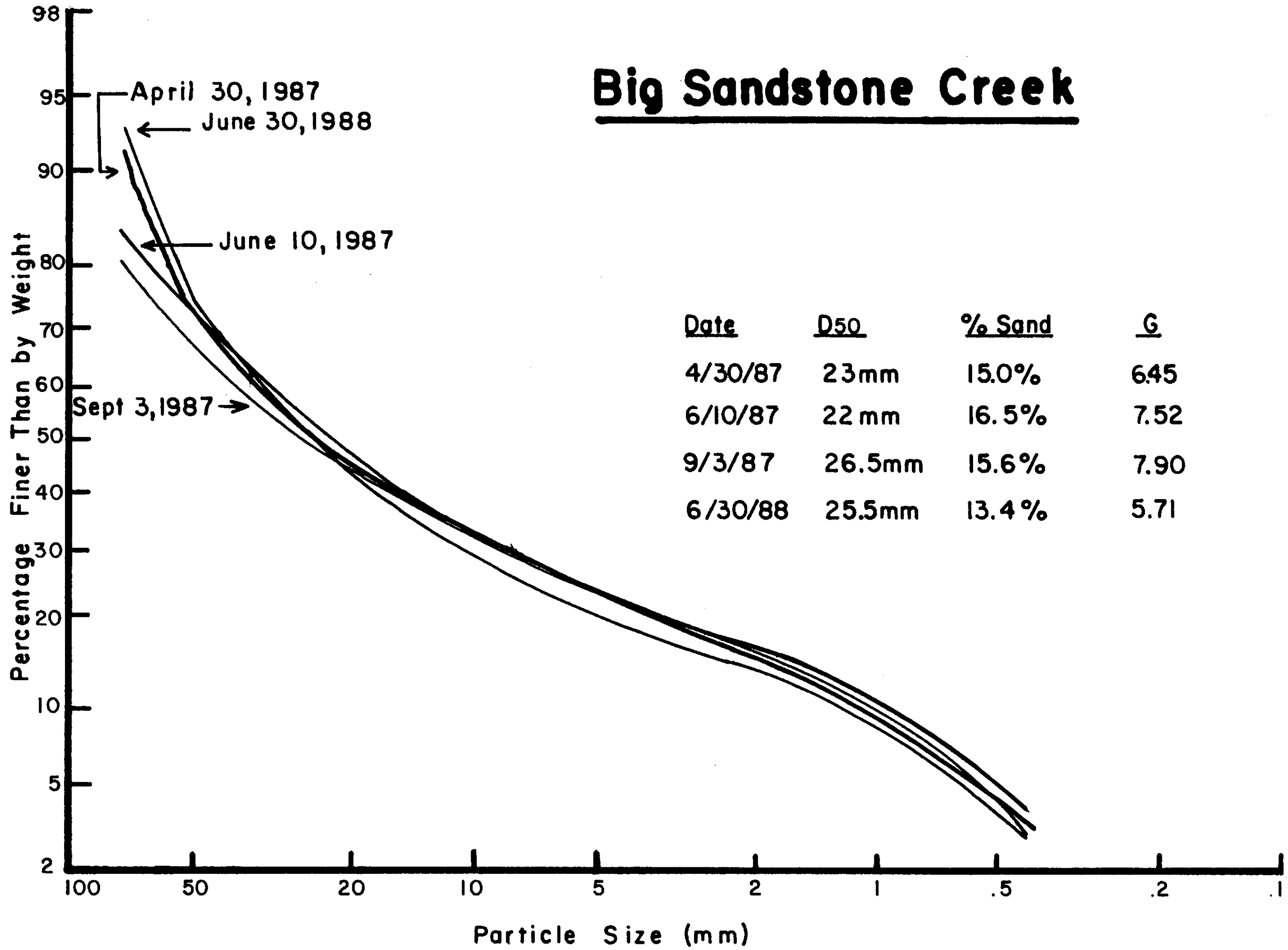

Figure 11. Particle Size Distributions of Stored Bed Material at the Big Sandstone Study Reach.

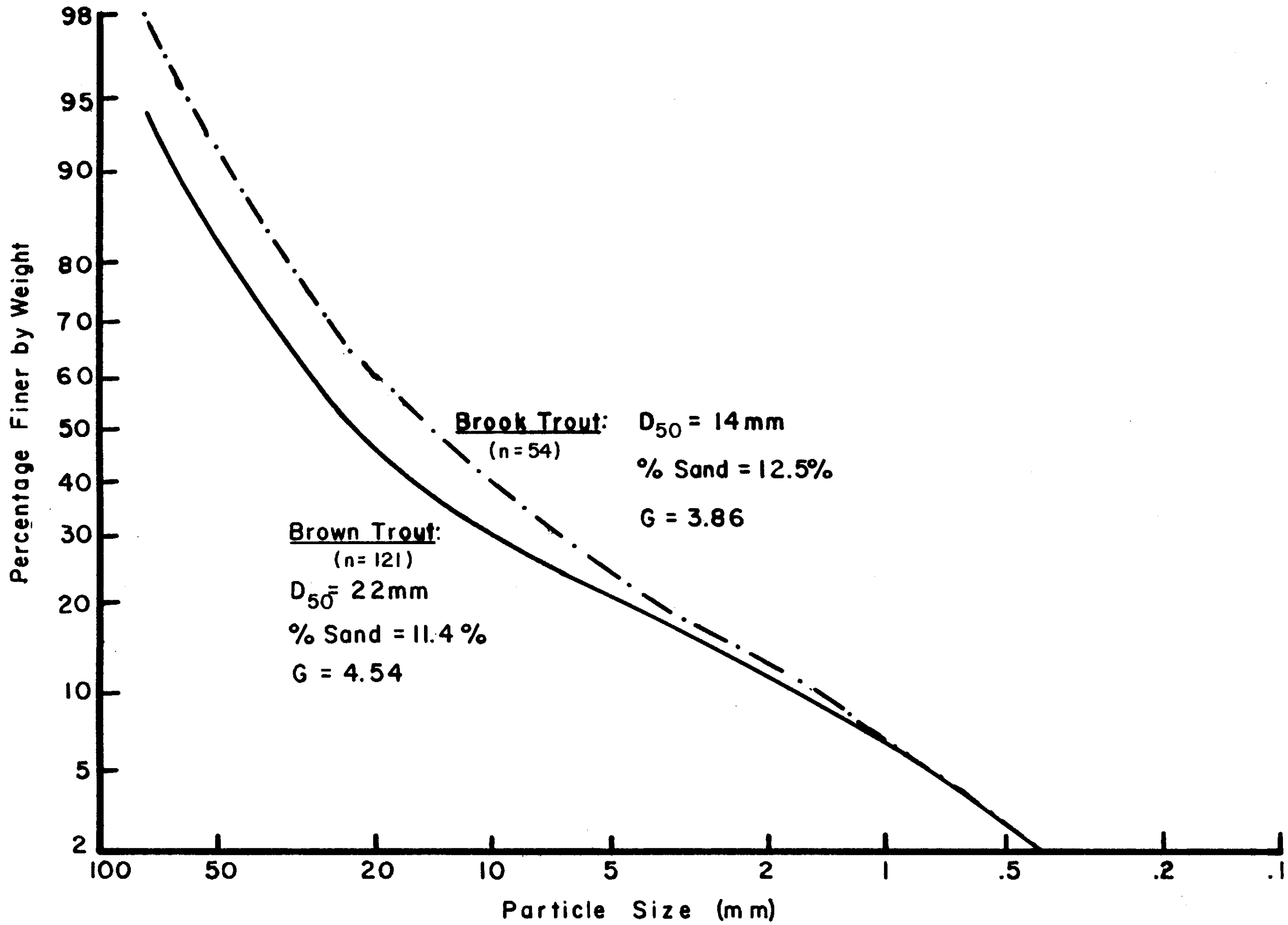

Figure 12. Particle Size Distribution of Bed Material Used by Spawning Trout on the Medicine Bow National Forest.

reported by Wesche et al (1987) for the North Fork of the Little Snake River (NFLS), a nearby stream also located in the upper Little Snake River drainage. At Reach 4 on the NFLS, mean particle size varied from 3 to 11 mm and deposition quantity fluctuated over 250 percent during 1984 to 1987. While the hydraulic characteristics of this reach were similar to the Big Sandstone reaches, poor erosion control practices associated with water development related construction activity had resulted in excessive sediment contributions to the channel.

IMPLICATIONS FOR CHANNEL MAINTENANCE

The processes of sediment transport and storage are fundamental to the concept of channel maintenance. Lane (1955) considered channel equilibrium for alluvial streams as a balance between stream power (a function of streamflow, Qw, and channel slope, S) and the sediment load transported (a function of bedload discharge, Qs, and the size of the bed material, expressed as d50). Applying Lane's relationship, the potential effect of water development can be qualitatively evaluated. If Qw is reduced by diversion, a corresponding reduction in sediment transport should occur, thereby re-establishing a new equilibrium condition, assuming the channel is alluvial (i.e., the river flows through material which it has deposited) and sediment supply is not limiting.

While the Big Sandstone study reaches are not necessarily alluvial channels, Lane's balance can be used to provide insight regarding the question of whether such steep, rough mountain channels are limited by sediment supply or by available energy. The relationships between unit stream power and bedload transport for the three reaches are presented in Figure 13. Given the similarities between the particle size distributions of stored bed material between reaches and transects, Lane's d50 term was not considered. The general trend of these relations indicates that for a given quantity of bedload transport, available energy was less at the lower transect of each reach than at the upper cross-section. This suggests a surplus of available energy at the upper transects and a supply shortage of transportable sized material. The only exception occurred at higher flows (~10 times

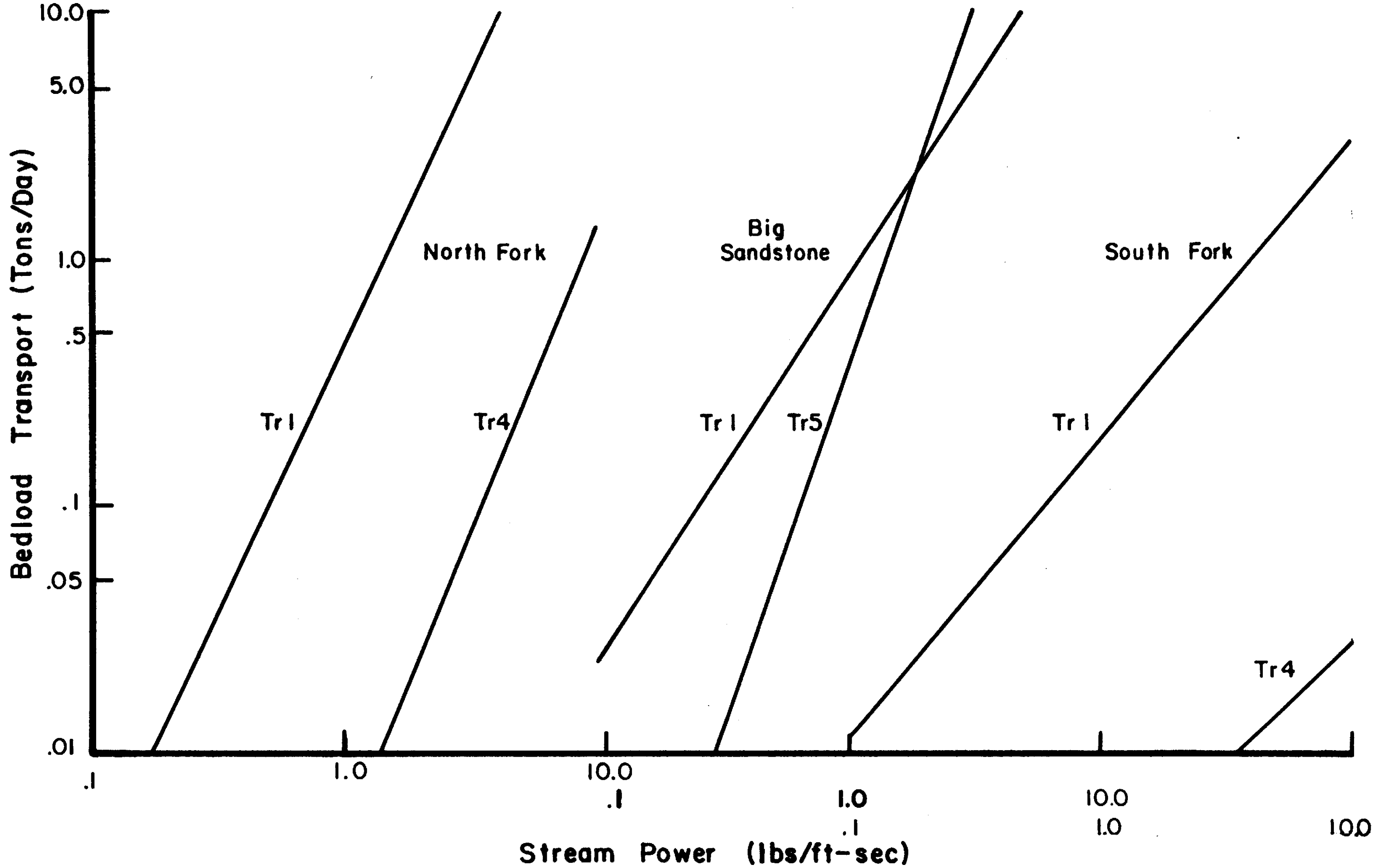

Figure 13. Bedload Transport-Stream Power Relations at the Three Big Sandstone Creek Study Reaches.

average annual discharge) on the Big Sandstone reach, where energy and supply were more in balance.

As mentioned previously, the issue of channel maintenance as well as fish habitat maintenance depends in large measure on the transport and storage of the finer fraction of the sediment load. These smaller particles, for the purposes of this study considered to be less than 2.0 mm diameter, provide the growth medium for invading streamside vegetation and have been shown to influence the survival-to-emergence of embryonic salmonids. To investigate the net import and export of this material through the study reaches under "average" flow conditions, the dimensionless flow duration curve (Figure 14) developed by Stone and Webster (1986) was utilized in conjunction with the sediment transport relations presented in Figure 7. The resultant average annual sediment budgets are presented in Tables 6, 7 and 8, respectively, for the North Fork, South Fork and Big Sandstone study reaches. In all cases, the trends are similar. Higher, short duration flows (approximately 8 times average annual discharge and above) tend to import more material than can be exported out of the reaches, while the lower discharges of greater frequency tend to export more than is being brought in. Over the entire water year, a balance appears to exist which results in stable bed material conditions. In all cases, the dominant discharge (the flow which transports the most material based upon transport rate and availability) was less than 10 times the average annual flow.

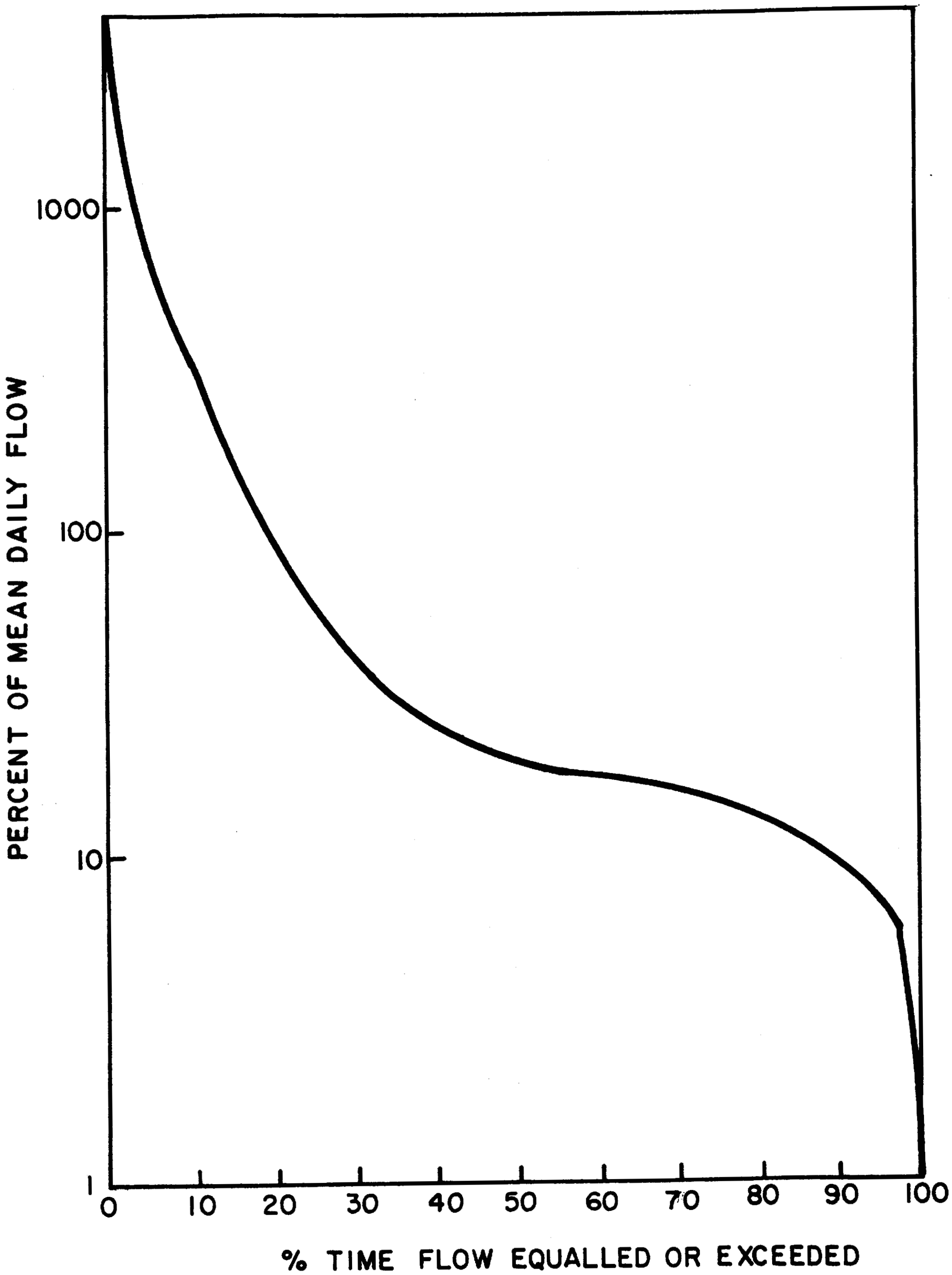

Figure 14. Dimensionless Flow Duration Curve Developed for the Fish Creek Collector System (from, Stone and Webster, 1986).

Table 6. Estimated Annual Sediment Transport (less than 2.0 mm) Through the North Fork of Big Sandstone Creek Study Reach.

Qw (cfs)	No. Days Qw Present	Sediment Transport (tons) Transect 4 (Import)	Transect 1 (Export)
89.30	.0365	0.228	0.140
82.10	.1095	0.590	0.377
75.00	.1825	0.837	0.557
67.80	.3650	1.400	0.975
60.70	1.0950	3.445	2.524
46.10	1.8250	3.512	2.920
35.70	3.6500	4.465	4.161
27.70	10.9500	8.504	8.913
10.40	36.5000	4.919	8.066
3.00	36.5000	0.552	1.584
1.40	36.5000	0.138	0.566
0.89	36.5000	0.062	0.314
0.68	36.5000	0.039	0.219
0.61	36.5000	0.032	0.190
0.50	36.5000	0.022	0.146
0.45	36.5000	0.016	0.120
0.32	36.5000	0.001	0.080
0.21	10.9500	0.001	0.014
0.18	3.6500	-	0.004
0.14	3.2850	-	0.002
0.11	0.3650	-	-
	TOTAL[1]	28.8	31.9

[1]Total in tons/yr.

Table 7. Estimated Annual Sediment Transport (less than 2.0 mm) Through the South Fork of Big Sandstone Creek Study Reach.

		Sediment Transport (tons)	
Qw (cfs)	No. Days Qw Present	Transect 4 (Import)	Transect 1 (Export)
96.70	.0365	.051	.029
89.00	.1095	.139	.080
81.20	.1825	.207	.122
73.50	.3650	.366	.223
65.80	1.0950	.959	.605
49.90	1.8250	1.138	.783
38.70	3.6500	1.668	1.242
30.00	10.9500	3.661	2.952
11.20	36.5000	3.648	4.000
3.30	36.5000	0.810	1.302
1.50	36.5000	0.313	0.641
0.96	36.5000	0.180	0.424
0.74	36.5000	0.131	0.334
0.66	36.5000	0.114	0.301
0.54	36.5000	0.089	0.250
0.47	36.5000	0.075	0.221
0.35	36.5000	0.052	0.169
0.23	10.9500	0.009	0.034
0.20	3.6500	0.003	0.010
0.15	3.2850	0.002	0.007
0.12	0.3650	-	0.001
	TOTAL[1]	13.6	13.7

[1]Total in tons/yr.

Table 8. Estimated Annual Sediment Transport (less than 2.0 mm) Through the Big Sandstone Creek Study Reach.

		Sediment Transport (tons)	
Qw (cfs)	No. Days Qw Present	Transect 5 (Import)	Transect 1 (Export)
238.00	.0365	0.68	0.27
219.00	.1095	1.76	0.72
200.00	.1825	2.48	1.04
180.90	.3650	4.14	1.88
161.90	1.0950	10.14	4.87
122.80	1.8250	10.24	5.66
95.20	3.6500	12.90	8.12
73.80	10.9500	24.37	17.49
27.60	36.5000	13.63	16.18
8.09	36.5000	1.47	3.27
3.71	36.5000	0.36	1.18
2.38	36.5000	0.16	0.66
1.82	36.5000	0.10	0.47
1.63	36.5000	0.08	0.40
1.34	36.5000	0.06	0.31
1.15	36.5000	0.04	0.26
0.85	36.5000	0.02	0.17
0.56	10.9500	-	0.03
0.48	3.6500	-	0.01
0.37	3.2850	-	0.01
0.29	0.3650	-	-
	TOTAL[1]	82.6	63.0

[1]Total in tons/yr.

Only the Big Sandstone reach exhibited a net import of finer material over the average water year based upon the dimensionless flow duration curve approach. The 24 percent difference between import and export can be attributed to flows greater than 8 times the average annual discharge for which available transport energy is not sufficient at the lower cross-section (Figure 13). For a lower than average water year, such as 1987 when the peak daily flow was only 9 times the average annual flow of 9.6 cfs, a balance was maintained, with an estimated 34.0 tons imported and 34.7 tons exported.

To simulate possible conditions at the Big Sandstone reach given water development, the natural hydrographs for spring runoff during 1987 and 1988 were adjusted to reflect the diversion of all water at the North Fork and South Fork reaches except for a combined minimum flow release of 2.5 cfs. The resultant hydrographs and cumulative sediment transport curves are presented in Figures 15 and 16. Given this development scenario, slightly more material is exported from the reach each year than is imported, indicating that aggradation and channel encroachment likely would not occur.

These findings tend to substantiate the results of Wesche et al (1988), who found that the dimensions of steep, rough mountain stream channels could be maintained despite significant flow depletion. The key to maintaining channels such as the North Fork, South Fork and Big Sandstone study reaches does not appear to be the release of relatively large channel maintenance flows below water development structures. Rather, primary consideration should be given to immediate and effective erosion control measures during and after construction. If such

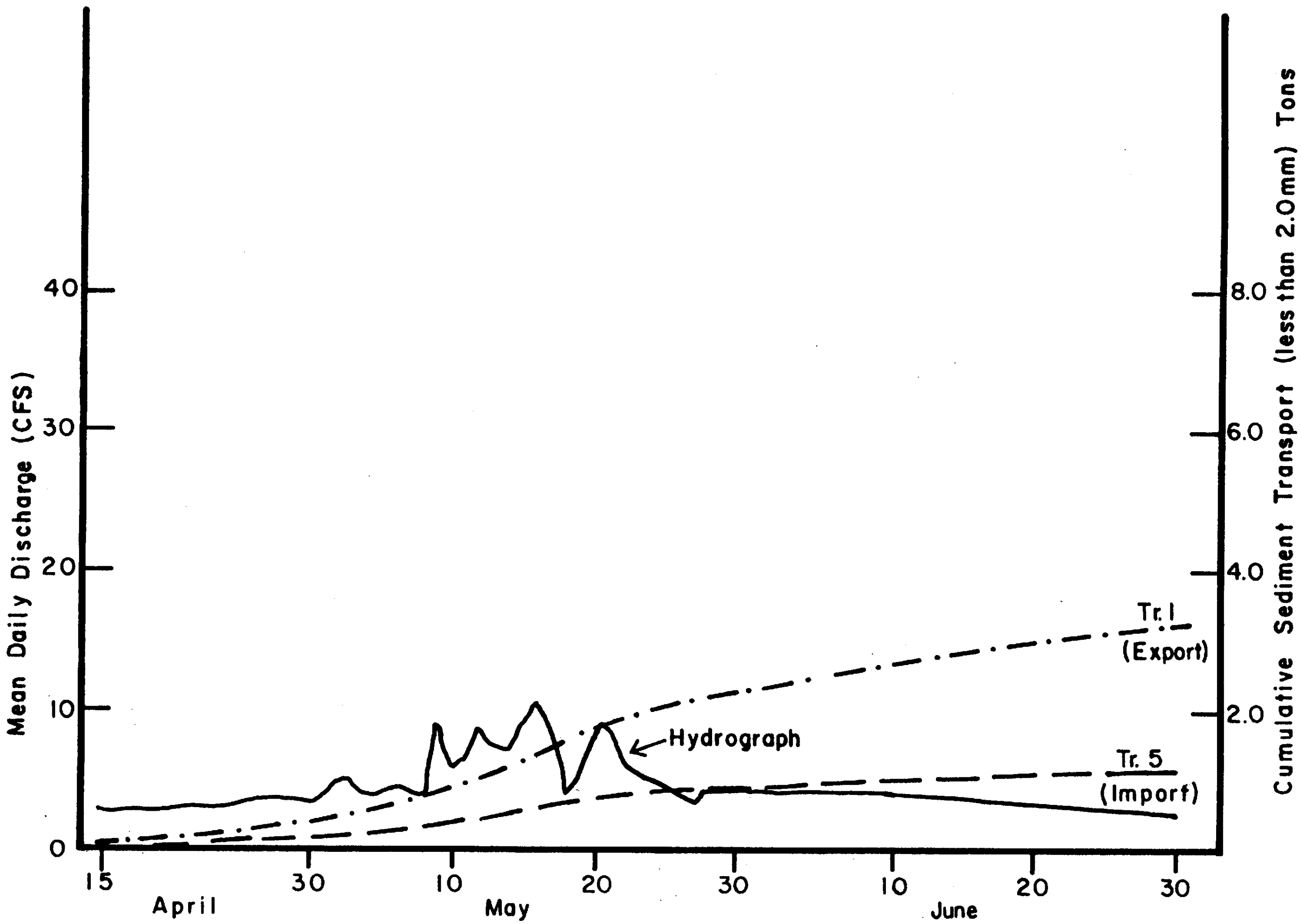

Figure 15. Simulated Hydrograph Assuming Water Development and Cumulative Sediment Transport for the Big Sandstone Study Reach Based Upon the 1987 Spring Runoff Period.

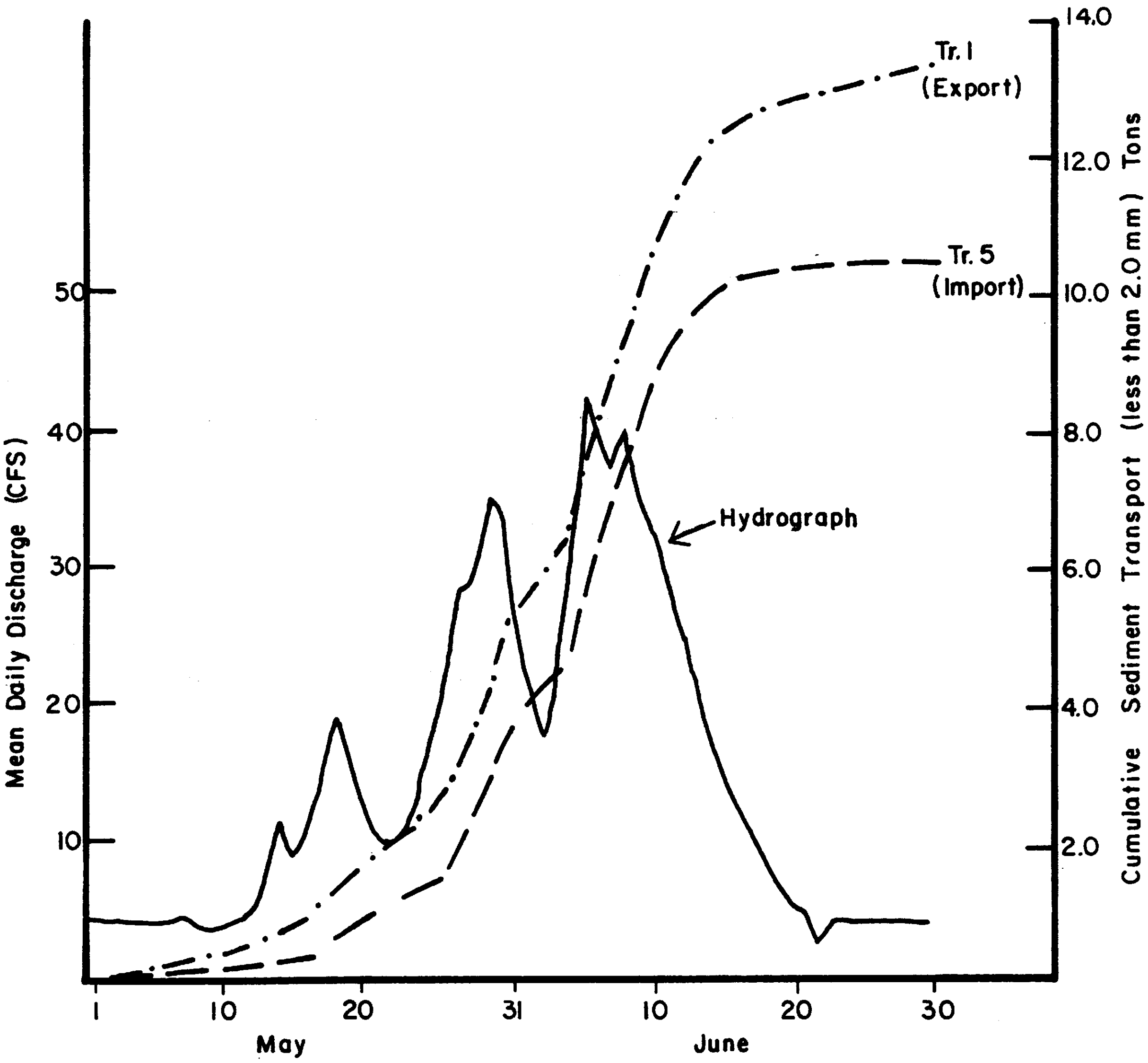

Figure 16. Simulated Hydrograph Assuming Water Development and Cumulative Sediment Transport for the Big Sandstone Study Reach Based Upon the 1988 Spring Runoff Period.

measures are not taken, an alternative could be controlled flushing flow releases to remove the additional sediment supplied.

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