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Sediment Transport Data and Related Information for Selected Coarse-Bed Streams and Rivers in Idaho

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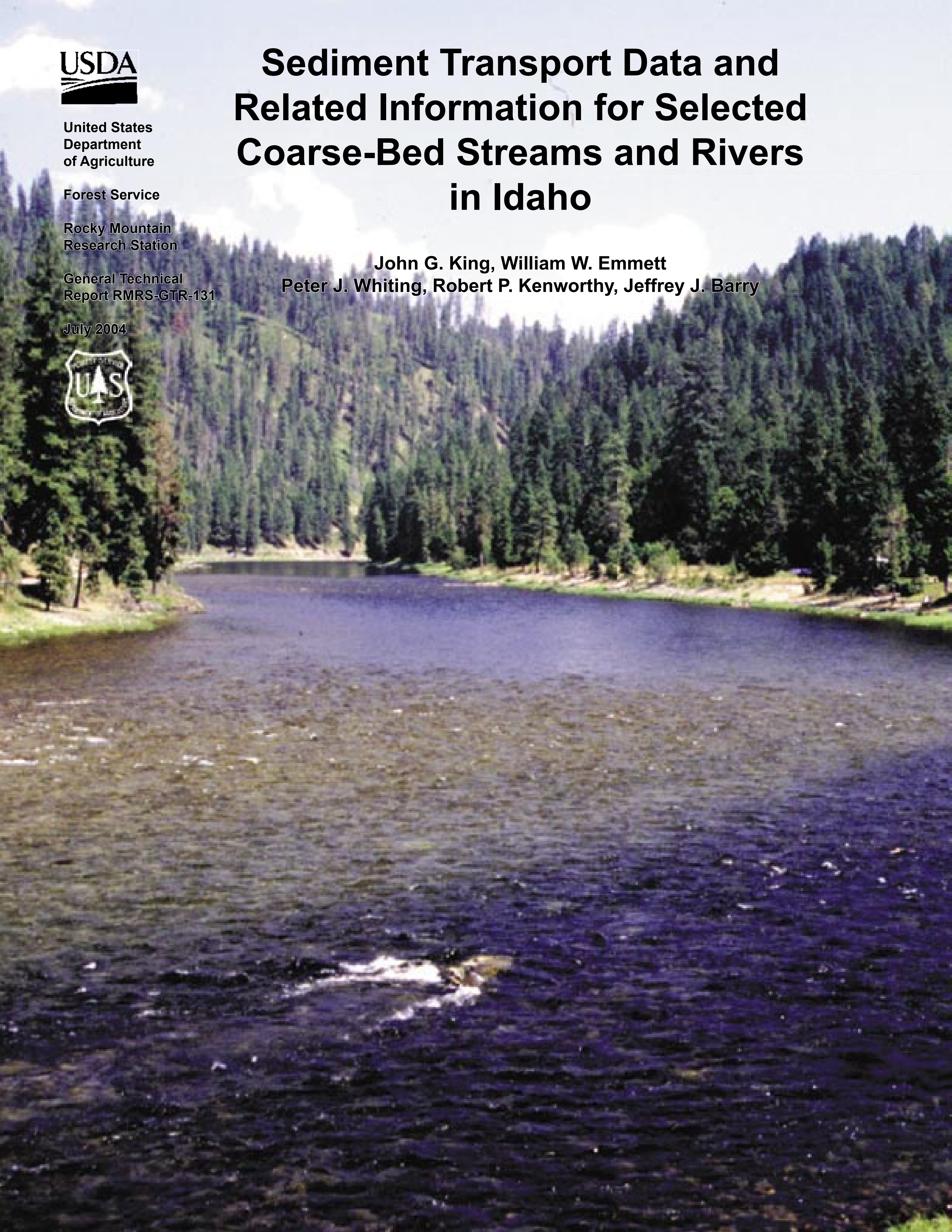

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Abstract

This report and associated web site files provide sediment transport and related data for coarse-bed streams and rivers to potential users. Information on bedload and suspended sediment transport, streamflow, channel geometry, channel bed material, floodplain material, and large particle transport is provided for 33 study reaches in Idaho that represent a wide range of drainage areas, average annual streamflows, channel gradients, and substrate sizes. All the study reaches have a coarser layer of surface bed material overlaying finer subsurface material.

Both bedload and suspended sediment transport increase with discharge and the relationship can be reasonably represented using a log-log model. At most sites, the suspended load makes up the majority of the total sediment load. The size of the largest bedload particle in transport and usually the median size of the bedload increase with discharge. However, the median size of the bedload is much smaller than the channel surface material and sand is the primary or a large component of the bedload material.

A large proportion of the annual sediment production occurs at the higher streamflows during snowmelt. On average, discharges equal to or larger than bankfull occur 3.3 percent of the time and transport 61.5 percent of the annual bedload sediment. Discharges less than the average annual discharge, on average, occur 75.0 percent of the time and transport about 3.8 percent of the annual bedload sediment.

Key words: channel bed material, channel geometry, sediment transport, stream discharge

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Cover photo: Selway River near Lowell, Idaho, looking upstream of the U.S. Geological Survey gaging station.

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Acknowledgments

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Sediment Transport Data and Related Information for Selected Coarse-Bed Streams and Rivers in Idaho

John G. King, William W. Emmett, Peter J. Whiting, Robert P. Kenworthy, Jeffrey J. Barry

Introduction

The United States Forest Service is a participant in the adjudication of water rights within the Snake River Basin of Idaho. Partly for purposes of the adjudication, the Forest Service desired to gain a better understanding of the nature of sediment transport in Idaho gravel-bed streams and rivers. Thus, the agency explored the availability of existing sources of suspended and bedload sediment transport information for streams and rivers within the National Forests of Idaho. In 1994, the agency also initiated a program to measure bedload and suspended sediment transport and collect supporting site information for selected streams and rivers. This program, which involved collection of data during water years 1994 to 2000, included agreements with the United States Geological Survey (USGS), Case Western Reserve University (CWRU), and Utah State University (USU) to collect information for selected sites. This program also involved collaboration with National Forest personnel to provide existing sediment transport and streamflow data and modify existing sediment transport measurement programs for selected sites.

This report and the associated web site files (http://www.fs.fed.us/rm/boise/teams/soils/Bat%20WWW/index.htm) present the sediment transport data and related information collected and summarized as part of this effort. Sediment transport and related data are provided for 33 coarse-bed streams and rivers within Idaho. The related information includes streamflow, channel geometry, and bed material data for all of the sites, and information on floodplain material, painted rock movement, particles in bedload traps, and the largest particles recently moved for selected study sites.

Measuring sediment transport in gravel-bed streams and rivers, especially bedload transport, is difficult (Ryan and Emmett 2002), time consuming, and expensive (Edwards and Glysson 1998). Due to the high spatial and temporal variability associated with sediment transport (Ryan and Emmett 2002; Wohl 2000), a large number of measurements that span a large range of streamflows are often needed to adequately understand and describe the transport processes. Short-term sediment sampling programs often fail to measure transport over a representative range of flows, especially higher flows, in part due to the less frequent occurrence of higher flows. As a result, there are relatively few data sets of sediment transport that span a wide range of streamflow. We were fortunate in that the streamflow associated with sediment transport measurements exceeded bankfull discharge for 29 of the sites and exceeded twice bankfull discharge for nine of the sites. Additionally, very few good sets of sediment transport, especially bedload (Wohl 2000), exist for mountain streams and rivers and a regional set of sediment transport data for an array of streams is rare. These Idaho data sets represent one of the largest and most intensive regional concentrations of sediment transport and related information.

Some of the study sites are long-term monitoring sites on various Idaho National Forests. Streamflow and sediment transport measurements have continued beyond the dates shown in this report and in the web site files. We anticipate updating information for these sites as new data become available and as resources allow for quality assurance and quality control of the data.

Our primary purpose for this report and the associated web site files is to provide sediment transport data and supporting site information to potential users. These data are useful for improving our understanding of the sediment transport processes in gravel-bed mountain streams and rivers, developing and testing sediment transport models, estimating sediment production, and quantifying instream flow requirements for various purposes. We have received many requests for all or portions of these data. Our hope is that making this information available on a web site in an organized fashion will provide for continued use of the data for a variety of purposes.

In this report, we provide a brief overview of the study site characteristics and details of the methods used to measure and/or collect the various types of data. The results section of the report contains some relationships and observations about the nature of streamflow

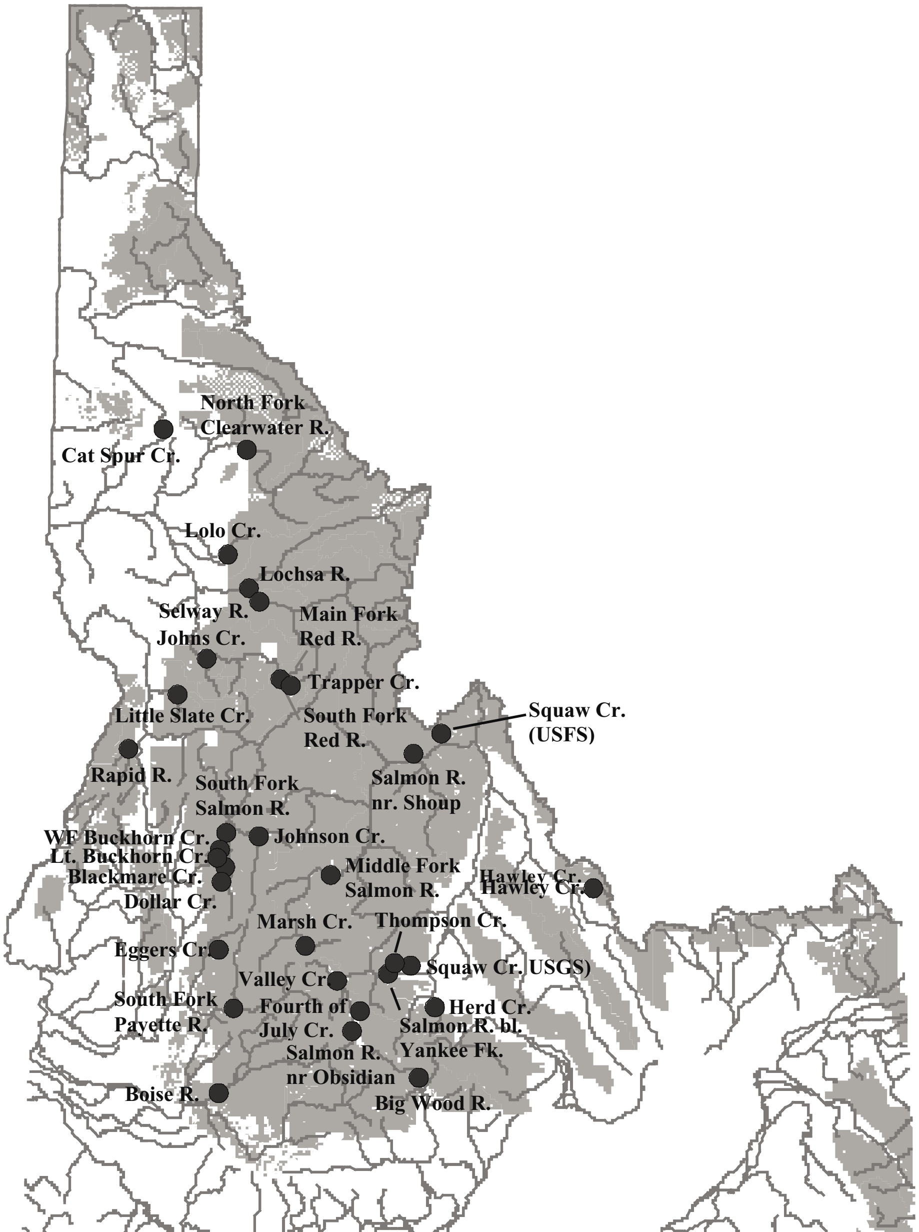

Figure 1. Location of the study streams and rivers.

and sediment transport for these sites. The associated web site is structured by study site. For each study site, we provide data files in a spreadsheet format, with one worksheet for each type of data and a site map of the study reach. The web site also includes a brief narrative report for each study site. This report contains general information about the study site, one or two photographs of the study reach, and sections on channel profile and cross-section, channel geometry, channel bed material, and sediment transport.

Study Sites

The study sites include 33 stream and river reaches in Idaho (figure 1). All of the study sites, except Cat Spur Creek, are within the Snake River Basin. Cat Spur Creek, in the Panhandle National Forest of northern Idaho, is part of the Spokane River Basin. The headwaters of Cat Spur Creek abut the topographic divide that defines the Snake River Basin. All but one of the study watersheds

Table 1. Summary of selected characteristics of the study sites.

Site[a]	Drainage[b] area mi²	Predominant[c] geology	Gage elevation ft	Average reach gradient	Surface[d] D_{50} mm
Big Wood River	137	mixed volcanics	6,240	0.0091	119
Blackmare Creek	17.8	igneous intrusions	4,180	0.0299	95
Boise River	832	igneous intrusions	3,256	0.0038	76
Dollar Creek	16.5	igneous intrusions	4,900	0.0146	74
Johnson Creek	216	igneous intrusions	4,656	0.0040	190
Little Buckhorn Creek	5.99	igneous intrusions	4,150	0.0509	28
Lochsa River	1,180	igneous intrusions, metamorphic	1,453	0.0023	126
Middle Fork Salmon River	1,040	igneous intrusions, mixed volcanics	4,350	0.0041	146
North Fork Clearwater River	1,290	igneous intrusions, metamorphic	1,660	0.0005	95
Salmon River nr Obsidian	93.9	igneous intrusions, sedimentary, glacial deposits	6,950	0.0066	61
Salmon River nr Shoup	6,240	sedimentary, mixed volcanics	3,154	0.0019	96
Salmon River bl Yankee Fork	811	igneous intrusions, mixed volcanics, glacial deposits	5,900	0.0034	104
Selway River	1,910	igneous intrusions, metamorphic	1,540	0.0021	173
South Fork Payette River	449	igneous intrusions	3,790	0.0040	110
South Fork Salmon River	329	igneous intrusions	3,750	0.0025	38
Squaw Creek (USGS)	71.6	sedimentary, mixed volcanics	5,710	0.0100	43
Thompson Creek	21.8	mixed volcanics, sedimentary	5,700	0.0153	66
Valley Creek	149	igneous intrusions, glacial deposits	6,222	0.0040	40
West Fork Buckhorn Creek	22.6	igneous intrusions	4,140	0.0320	180
Cat Spur Creek	10.8	metamorphic	2,930	0.0105	27
Eggers Creek	0.497	igneous intrusions	4,750	0.0718	23
Hawley Creek	42.2	sedimentary	6,630	0.0233	40
Johns Creek	113	igneous intrusions, metamorphic	2,410	0.0207	207
Little Slate Creek	62.6	igneous intrusions, metamorphic	3,500	0.0268	102
Lolo Creek	41.0	igneous intrusions	3,040	0.0097	68
Main Fork Red River	49.7	metamorphic	4,350	0.0059	50
Rapid River	108	sedimentary	2,200	0.0108	63
South Fork Red River	38.2	metamorphic	4,350	0.0146	106
Squaw Creek (USFS)	14.3	metamorphic	3,940	0.0240	27
Trapper Creek	8.00	metamorphic	4,880	0.0414	85
Fourth of July Creek	17.1	igneous intrusions, sedimentary, mixed volcanics	7,300	0.0202	51
Herd Creek	110	mixed volcanics	5,900	0.0077	67
Marsh Creek	79.7	igneous intrusions	6,540	0.0060	56

[a] In the site names, nr stands for near and bl stands for below.
[b] Drainage areas for USGS gaged sites are from either Hortness and Berenbrock (2001) or O'Dell and others (2002). Drainage areas from other sites are from Forest Service records or were measured from topographic maps. All drainage areas are expressed to three significant figures.
[c] Geology information extracted from Bond and Wood (1978).
[d] The median diameter of the surface bed material from measurements within the reach. Due to multiple measurements over time at some sites, other data may apply and are presented in subsequent tables in this report.

are within the Northern Rocky Mountain Physiographic province (Fenneman 1931). The exception is Rapid River, which is in the Columbia Intermontane Province.

The study sites span a wide range of site characteristics (table 1). All of the streams have coarse-bed composed primarily of gravel and cobbles. The median diameter of the surface bed material ranges from about 23 to 207 mm. Although several of the study reaches have small areas of exposed bedrock, all the sites have sufficient alluvial material to be considered self-forming channels. The drainage area ranges from 0.5 to 6,240 mi², the average reach gradient ranges from 0.0005 to 0.0718, and the stream gage elevation ranges from 1,453 to 7,300 feet above sea level.

There is a variety of rock types represented in the study watersheds (table 1). One of the most notable geologic features is the Idaho batholith, a large igneous intrusion in central Idaho that extends about 250 miles in a north-south direction and 90 miles in an east-west direction (Bennett 1974). Twenty-one of the study watersheds have a large portion of their area on the batholith. Many of these areas are characterized by rock that weathers deeply to produce coarse sandy soils with high erosion rates if disturbed. Other lithologies at the study sites include metamorphic formations usually associated with the border of the batholith, mixed extrusive volcanics in watersheds in the upper portion of the Salmon River basin, and sedimentary rocks associated with the Seven Devils formations, the upper portion of the Salmon River basin, and in the vicinity of the Lemhi River basin. General information on predominant geology for each watershed was extracted from the "Geologic Map of Idaho" (Bond and Wood 1978). Some of the study watersheds contain a number of types of lithology and readers are referred to the map for more specific information.

Higher mountains throughout central Idaho and the Seven Devils mountain range were glaciated during the Pleistocene by alpine glaciers (USDA Forest Service Draft Upper Columbia River Basin EIS 1997; Ross and Savage 1967). Many of the high elevation study reaches in the upper Salmon River basin—Herd Creek, Marsh Creek, Valley Creek, Fourth of July Creek, Salmon River near Obsidian, ID, and the Big Wood River—flow through valley deposits associated with glaciation (Bond and Wood 1978).

Frontal systems moving eastward from the Pacific Ocean are the source of most precipitation for these study sites. As these systems are lifted over the Idaho mountains, they cool and release their moisture. Thus, it is common to see increasing precipitation with increasing elevation throughout the state. Average annual precipitation in these basins ranges from about 10 inches to over 70 inches (University of Idaho 1995). In most areas, winters are wet and summers are relatively dry. At higher elevations, snow accumulates from fall through spring and the accumulated spring snowpack may account for over half the annual precipitation. Rainstorm activity in the summer months is generally in the form of thunderstorms associated with unstable air masses. Summer rainfall is generally of short duration and may be of high intensity.

Methods and Data Display

This section describes the methods used in collection of sediment transport and related data for the study sites. It also provides examples of how the data are displayed in the narrative reports for each study site available on the web. One consistent set of methods does not necessarily apply to all of the study sites or to all of the data for a given study site. This is due to reliance on previously collected information by different agencies for a variety of purposes and differences in the purposes for the collection of additional data between study sites. We describe the methods and indicate, either in this report or in the web site data files, to which study reaches they apply. Users of the data are encouraged to contact the appropriate agency or agency representatives (see acknowledgments) that collected the different data sets if additional information on methods and accuracy is desired.

Stream Reach Surveys

Standard surveying equipment and techniques were used to measure the water surface elevations and bed elevations in the center of the channel at about one-channel width intervals within the study reach. The length of the study reaches was about 20 channel widths, except for some of the larger rivers where the length was about 10 channel widths. Floodplains were identified and the elevations associated with streamflow just overtopping the floodplain were surveyed. This elevation, extrapolated to the stream gage location, represents the stage of bankfull discharge. Elevations were also surveyed at frequent intervals across at least one representative channel cross-section, perpendicular to the streamflow. All the elevations were surveyed with respect to a fixed datum elevation, often one of the reference datums associated with the gaging station. Longitudinal profiles and planimetric maps of the reaches were prepared for most sites. Both hand-drawn plots and computer-generated plots of the data were made, depending on the individual site. At sites where computer data files were prepared, the data and plots of the longitudinal profiles are included in the web site files. The longitudinal profile displays the water surface, channel bottom and floodplain elevations, and locations of the surveyed cross-sections and the gaging station (figure 2). In this example, cross-section 1 (XS1) is at the cableway where discharge and sediment transport measurement were typically made. The gaging station is several feet upstream of the cableway.

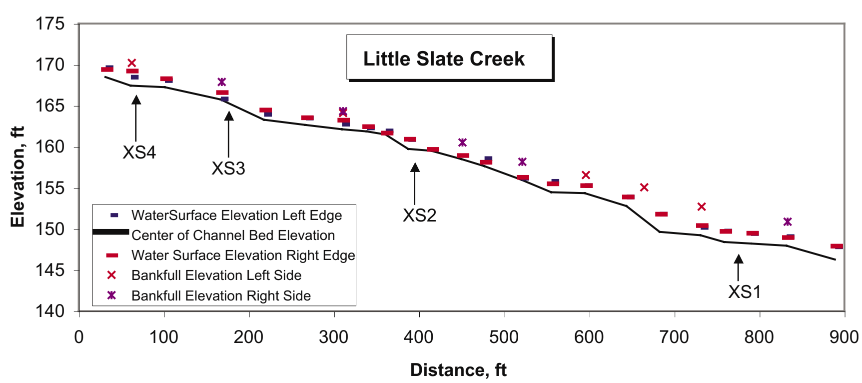

Figure 2. Example of a longitudinal profile of the study reach for Little Slate Creek.

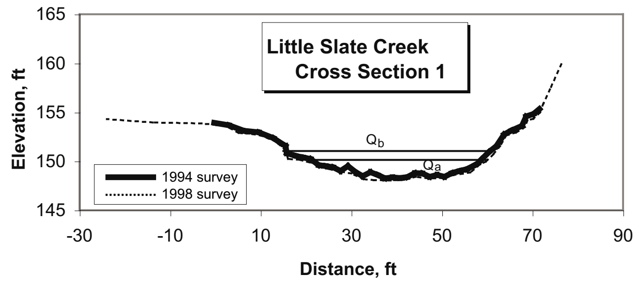

Figure 3. Example of a cross-section in the Little Slate Creek study reach.

The distance and elevation data for all the surveyed cross-sections in a given study reach are provided in the web site data files. In the narrative for each site, we display one cross-section graph (figure 3), which is usually the cross-section associated with sediment transport measurements. In 1998, many of the previously surveyed cross-sections at selected study sites were resurveyed to extend survey information laterally on each side of the channel. We include data collected from both surveys in the web-page data files. Typically, we also display the approximate elevations of the average annual discharge (Q_a) and bankfull discharge (Q_b) to give perspective to the cross-section.

Gradient was usually calculated as an average over the entire study reach. If a large shift occurred within the reach, gradient was calculated for that portion that typically included the gage location and sediment measurement location. The gradients associated with channel bed elevations, floodplain elevations, and water surface elevations were all used in determining the average gradient for the study reach.

"At-a-Station" Channel Geometry

Instantaneous discharge measurements made by the agencies operating the gaging stations were used to develop a relationship between stage and discharge. Information available from the field notes taken during instantaneous discharge measurements typically includes discharge, width, and depth and velocity at intervals across the channel. We used this information to develop power relationships between discharge and width, discharge and average depth, and discharge and average velocity (figure 4). Average depth was determined as cross-section area divided by width. Average velocity was determined as discharge divided by cross-section area. In developing these power relationships, we generally only used data collected during the water years of sediment transport measurements and within the range of discharges associated with the sediment transport measurements. However, additional data not meeting these criteria are often provided in the web site files. To the extent possible, only data collected at or

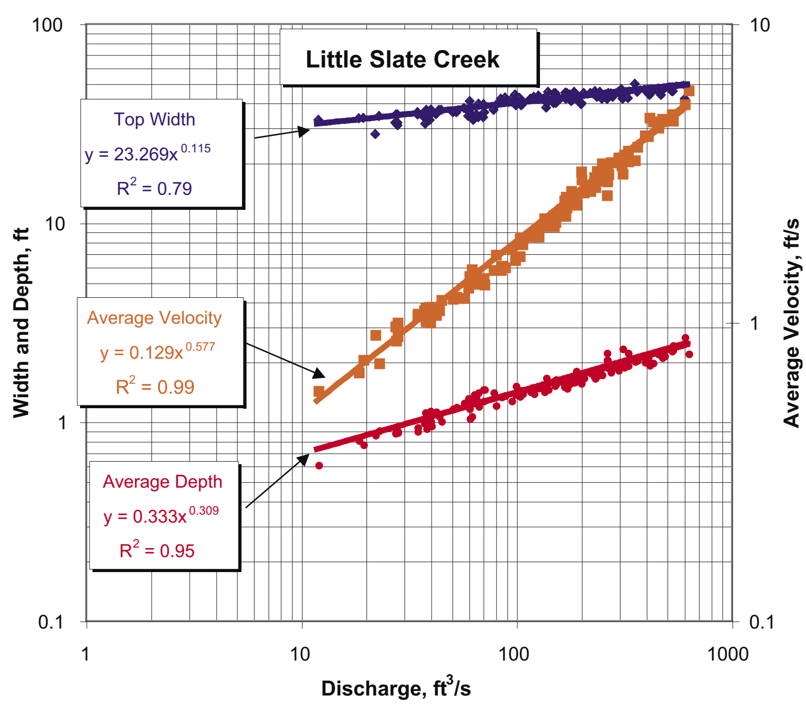

Figure 4. Example of channel geometry relationships for the Little Slate Creek study site.

very near the cross-section(s) where sediment transport measurements were made were used in developing these relationships. Also, geometry data associated with noted "ice" influences were not used. Measurements of channel geometry are useful for estimating the shear stress and stream power associated with individual sediment transport measurements.

The power relationships were used to estimate width, average depth, and average velocity at bankfull discharge or for the 1.5 year return interval discharge. We then developed regional power relationships relating estimates of average velocity, width, and average depth to both drainage area and bankfull discharge.

Channel Bed Material

Three different methods were used to characterize the particle size distribution of the bed material in the study reaches (table 2). These include: Method (1) pebble counts of the surface material often at a single cross-section that is either representative of the reach or is the location of sediment transport measurements; Method (2) pebble counts of the surface material and core samples of the subsurface material at several locations within the reach; or Method (3) pebble counts of the surface material and core samples of both the surface and subsurface material at several locations within the reach. At many of the study sites, more than one method was used to characterize the bed material. For example, at many sites during the first field season Method 1 was used to characterize surface material at or near the sediment transport cross-section. In the following field season, Method 2 was used to characterize both surface and subsurface substrate within the entire study reach.

For all three methods, the particle size distributions of the bed surface grains were measured using a pebble count procedure (Wolman 1954). The intermediate axis (b-axis) of surface particles was measured at fixed intervals along transects perpendicular to the streamflow. The sampling interval along a transect was several grain diameters (of the larger grains) apart to discourage serial correlation (Church and others 1987) and to

Table 2. Channel material collection method and date of sampling for the study sites.

	Bed material			
Study site	**Method 1**	**Method 2**	**Method 3**	**Floodplain**
Big Wood River			7/13/2000	
Blackmare Creek	7/27/1994		9/15/2000	
Boise River	9/9/1994	10/19/1995		10/30/1997
Dollar Creek	7/25/1994		7/21/2000	
Johnson Creek	10/11/1994			
Little Buckhorn Creek	7/29/1994		9/16/2000	
Lochsa River	9/12/1994	9/27/1995		11/7/1997
Middle Fork Salmon River			7/27/2000	
North Fork Clearwater River	9/13/1994	9/28/1995		11/5/1997
Salmon River nr Obsidian			7/10/2000	
Salmon River nr Shoup			8/12/2000	
Salmon River bl Yankee Fork			7/14/2000	
Selway River	9/11/1994	9/27/1995		11/8/1997
South Fork Payette River	8/19/1994	10/23/1995		10/31/1997
South Fork Salmon River	10/10/1994, 4/6/1999, 9/13/1999			11/1/1997
Squaw Creek (USGS)	6/29/1994		7/12/2000	
Thompson Creek	6/27/1994		7/11/2000	
Valley Creek[a]	6/22/1994 , 8/17/1994	11/15/1995		8/8/1998
West Fork Buckhorn Creek	7/28/1994			
Cat Spur Creek	10/7/1994			
Eggers Creek[b]	1975,77-84,10/23/1994			
Hawley Creek	7/7/1994			
Johns Creek	9/13/1995	9/26/1995		
Little Slate Creek 1	10/19/1994	10/4/1995		11/3/1997
Lolo Creek	10/9/1994, 7/21/1995	8/24/1995		11/6/1997
Main Fork Red River	7/11/1994	8/23/1995		11/4/1997
Rapid River	7/17/1994	10/3/1995		11/2/1997
South Fork Red River	7/12/1994	8/23/1995		11/4/1997
Squaw Creek (USFS)	7/5/1994			
Trapper Creek	7/22/1994	8/22/1995		
Fourth of July Creek	6/17/1994			
Herd Creek	7/1/1994			
Marsh Creek	6/13/1994			

[a] Valley Creek pebble counts were made at three cross-sections on the 8/17/1994 sampling date.
[b] Eggers Creek pebble counts in 1975 and 1977-1984 were made at five cross-sections.

avoid consecutive hits on all but an unusually large particle. Typically, particles smaller than 2 mm in diameter were not measured, but coded as "<2 mm" (Harrelson and others 1994). Hits on bedrock, vegetation, and woody debris were so noted. At a sampling cross-section, typically at least 100 particles were measured (Wolman 1954; Harrelson and others 1994). In narrow streams, sampling 100 particles often required sampling at additional transects. These transects were spaced at about 1 m intervals from the original transect. Once sampling began along a transect, the entire transect was sampled. At some sites, pebble counts of the surface grains were done on more than one sampling date.

In 1995 and 2000, Forest Service personnel walked many of the study stream reaches and took notes and made sketches concerning the sizes and distribution of the surface material and the location of pools. Major differences in the general size characteristics of the substrate over an appreciable area of the reaches were observed in Valley Creek, South Fork Salmon River, Main Fork Red River, Thompson Creek and Rapid River. For these sites, channel units of two different substrate classes were mapped and two locations were sampled (Methods 2 or 3) within each mapped channel unit. Three locations were sampled at the remainder of the study sites. Sampling locations were chosen at approximately equally spaced distances within a mapped substrate unit throughout the length of the study reach. The length of reach represented by pools was omitted because of difficulty in sampling in pools. At each sampling location along the reach, the location of the core sample was either ¼, ½, or ¾ of the distance across the channel for mapping units in reaches with three sampling areas or 1/3 or 2/3 across the channel for mapping units in reaches with two sampling areas. On the larger rivers, if depth of water prohibited sampling, the field crew was given some latitude to move upstream and/or downstream, within the same substrate mapping unit, to an area where sampling was feasible. If this option did not allow for sampling, the crew moved shoreward to the first location where sampling was possible.

The particle size distributions of the subsurface bed material were measured at many of the sites. Surface material was removed to a depth of approximately one diameter of the larger particles adjacent to the sampling site (Church and others 1987). A 33 gallon drum (cut in half) was placed on the sample site and worked into the substrate to reduce the loss of fines by streamflow. Subsurface material was removed to at least two diameters in depth or until sufficient material was removed such that the largest particle in the sample represented less than 5 percent of the total sample. Samples were wet-sieved in the field (Platts and others 1983) into the following size classes: >64 mm, 32-64 mm, and 16-32 mm and <16 mm. The b-axis of all particles greater than 64 mm was measured individually. The volume of each of the other three size classes was determined by measuring water displacement in a bucket. Sample particles of typical mineralogy on the streambed were saved for later particle density determination. Particle density was determined in the laboratory by weighing the particle(s) and then determining the volume, using a water displacement technique. In order to determine the weight associated with the three larger size classes, both particle density information and a correction for water retention in the sample was used (Shirazi and Seim 1979 in Platts and others 1983). Material less than 16 mm diameter was bagged for later sieve analysis. In the laboratory, a mechanical shaker and sieves were used to separate material into the following size classes: 8-16 mm, 4-8 mm, 2-4 mm, 1-2 mm, 0.5-1 mm, 0.25-0.5 mm, and <0.25 mm.

Core sampling was done in 1995 to characterize the subsurface material while pebble counts were used to characterize the surface material. For the core sampling done in 2000, the surface material was retained and particle size distributions were determined for both surface and subsurface material using methods described in the previous paragraph. In 2000, pebble counts were also done at transects across the channel at the core locations.

Samples of floodplain material were collected at 12 study sites in 1997 and 1998. At one to four floodplain locations, identified in the 1994 field surveys, small pits were excavated to at least 30 cm to expose a vertical wall of the floodplain sediment. Samples were collected of all visually apparent strata with different textural composition. Typically, one to three strata were identified and sampled. Samples were dried in the laboratory and the particle size distribution of each sample was determined using a mechanical shaker and the following sieve sizes: 256 mm, 128 mm, 64 mm, 32 mm, 16 mm, 8 mm, 4 mm, 2 mm, 1 mm, 0.5 mm, 0.25 mm, 0.125 mm, and 0.0625 mm.

The web site files include the locations, sampling dates, and particle size distributions for all of the individual pebble counts and core samples along with the sampling dates and particle size distributions for the individual floodplain strata at each study site. The narrative report for each site includes the graphical display of these data (figure 5).

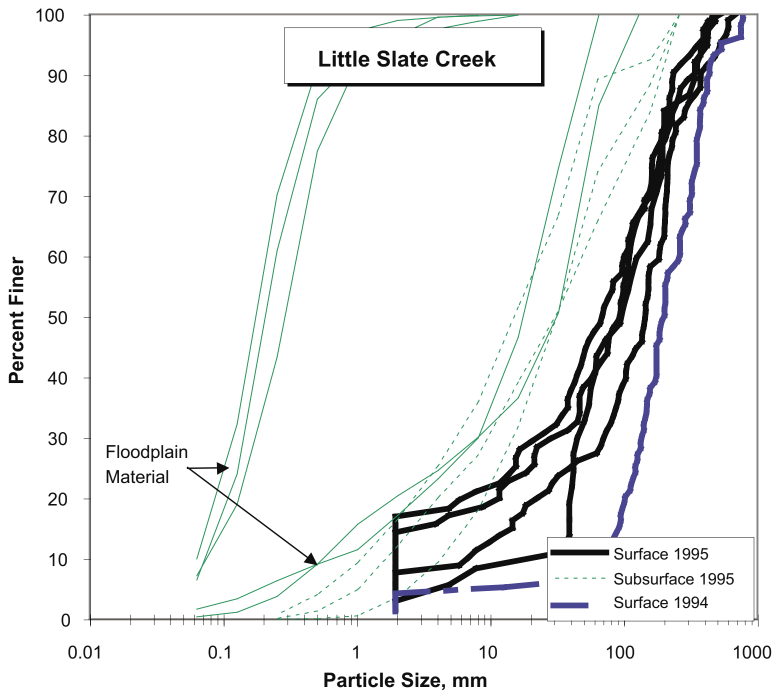

Figure 5. Particle size distributions of surface and subsurface bed material and floodplain material in the Little Slate Creek study reach.

Streamflow Records

Most of the study sites are associated with a currently operational or discontinued gaging station operated by either the U.S. Geological Survey or the U.S. Forest Service (table 3). In most instances, the gage is located within the study reach. The exceptions are Thompson Creek, the Salmon River near Shoup, ID, and the Middle Fork Salmon River. The brief narrative reports on the web site describe the location of these study sites with respect to the gage location. Three study sites were not associated with a USGS or USFS gaging station: Marsh Creek, Fourth of July Creek, and Herd Creek. At these sites, temporary gaging stations using pressure transducer technology were installed and operated by Case Western Reserve University (CWRU) personnel in water years 1994 and 1995. The CWRU gages and many of the USFS gages operated seasonally, typically from near the initiation of spring snowmelt to freeze up in the fall.

Streamflow records are often used to estimate total water yields and integrated with sediment transport relationships to estimate sediment yields. Estimates of long-term average water and sediment yields are dependent upon completeness of the existing streamflow record and the representativeness of the period of record. The representativeness of the existing record is a potential concern at study sites where a relatively short-term flow record may not represent the distribution of flows associated with climatic variation over the long term. Thus, for study sites with seasonally operated gages and/or with relatively few years of record (17 sites), missing daily mean flows were estimated and streamflow records were extended to estimate distributions of streamflow over the long term. The streamflow extension procedure relates daily mean flows at short-term gages with a nearby continuously operated USGS "base station" having a longer discharge record. Often there was more than one long-term station that could serve as the base station. In choosing a base station, consideration was given to similarity of basin size, proximity, and mean elevation in the expectation that hydrological responses would be similar. Emphasis was also given to the goodness-of-fit between the two stations. A relationship was developed using pairs of daily mean flows from the concurrent period, the period during which data were available from both stations. This relationship was used to estimate missing values and extend the records using base-station daily mean flows. The technique (Moog and others 1999) is derived from a method outlined by Hirsch (1982), Maintenance Of Variance Extension (MOVE.1). Although each daily mean discharge at the short-term station is estimated as a function of the corresponding base-station discharge, the focus is not to match each daily mean discharge, but to accurately reproduce the distribution of discharges over the period of extended record. Extended discharge data were then used to estimate long-term average annual discharge for the study sites. Extended discharge data was also used in conjunction with sediment-discharge relationships to estimate the long-term average annual distribution of sediment production with streamflow and time at some sites. These sites include those where the base-station analysis period of record extended up to water year 1999 (table 3). For sites not extended up to water year 1999, we relied on average annual discharge estimates previously reported by Whiting (1998).

Records of daily mean discharge for sites gaged by the USGS are available from annual USGS publications of water-resources data *Water Resources Data - Idaho*, from commercial production and sales of CD-ROMs (updated annually), and from electronic listings on the World Wide Web (http://nwis.waterdata.usgs.gov/id/nwis/discharge). Therefore, these records are not included in our web site files. However, records of daily mean discharge for sites gaged by the USFS or Case Western Reserve University (table 3) for the period of record are included in the web site files. For the five study sites where the base-station analysis period of record extended up to water year 1999, the extended daily mean discharge records are also provided. We again emphasize that the extension procedure estimates a distribution of mean daily discharges. Thus, estimates should not be viewed as the best prediction of streamflow for any particular day.

A flow frequency analysis was performed on the annual maximum series to estimate the return interval of bankfull discharge and to estimate the discharge associated with the 1.5 year return interval event. The flow frequencies were estimated using the Log Pearson Type III analysis (U.S. Interagency Advisory Committee on Water Data 1982). For several sites with short term records, the two-station comparison procedure was used

Table 3. A summary of stream discharge record information for the study sites.

Site	USGS station number	Agency	Gage period of record[a] (complete WY)	Total years of discharge record[b]	Base station for record extension[c]	Base station analysis period of record
Big Wood River	13135500	USGS	1949-71	23	not extended	
Blackmare Creek	13310565	USGS	1990-94	5 (23)	13310700	1967-82, 86, 90-95
Boise River	13185000	USGS	1912-P	90	not extended	
Dollar Creek	13310520	USGS	1990-94	5 (23)	13310700	1967-82, 86, 90-95
Johnson Creek	13313000	USGS	1928-P	74	not extended	
Little Buckhorn Creek	13310660	USGS	1990-94	5 (23)	13310700	1967-82, 86, 90-95
Lochsa River	13337000	USGS	1911-12, 30-P	73	not extended	
Middle Fork Salmon River	13309220	USGS	1973-81, 00-P	10	not extended	
North Fork Clearwater River	13340600	USGS	1968-P	34	not extended	
Salmon River nr Obsidian	13292500	USGS	1942-52	11	not extended	
Salmon River nr Shoup	13307000	USGS	1944-81	38	not extended	
Salmon River bl Yankee Fork	13296500	USGS	1922-91	70	not extended	
Selway River	13336500	USGS	1930-P	71	not extended	
South Fork Payette River	13235000	USGS	1942-P	60	not extended	
South Fork Salmon River	13310700	USGS	1967-82, 86, 90-02	29	not extended	
Squaw Creek (USGS)	13297355	USGS	1971-P	31	not extended	
Thompson Creek	13297330	USGS	1973-P	25	not extended	
Valley Creek	13295000	USGS	1912-13, 22-71, 93-P	61	not extended	
West Fork Buckhorn Creek	13310670	USGS	1990-94	5 (23)	13310700	1967-82, 86, 90-95
Cat Spur Creek		USFS	1987-97	11 (32)	12414900	1966-97
Eggers Creek		USFS	1965-96	32	not extended	
Hawley Creek[a]		USFS	1989-95	6 (23)	13297355	1973-95
Johns Creek		USFS	1986-97	12 (31)	13338500	1965-95
Little Slate Creek[a]		USFS	1986-99	14 (46)	13316500	1952-54, 57-99
Lolo Creek[a]		USFS	1986-99	14 (35)	13338500	1965-99
Main Fork Red River[a]		USFS	1986-99	14 (35)	13338500	1965-99
Rapid River		USFS	1986-99	14 (87)	13317000	1911-17, 20-99
South Fork Red River[a]		USFS	1986-99	14 (35)	13338500	1965-99
Squaw Creek (USFS)[a]		USFS	1990, 1992-95	5 (23)	13297355	1973-95
Trapper Creek[a]		USFS	1986-97	12 (33)	13338500	1965-97
Fourth of July Creek[a]		CWRU	1994-95	2 (55)	13295000	1921-72, 92-95
Herd Creek[a]		CWRU	1994-95	2 (55)	13295000	1921-72, 92-95
Marsh Creek[a]		CWRU	1994-95	2(55)	13295000	1921-72, 92-95

[a] Gage operated seasonally, usually started before spring runoff and stopped in the fall before freeze-up.
[b] Numbers in parenthesis represent the actual plus extended period of record.
[c] 13310700 South Fork Salmon River near Krassel Ranger Station; 13338500 South Fork Clearwater River at Stites, ID; 13316500 Little Salmon River at Riggins, ID; 13317000 Salmon River at Whitebird, ID; 12414900 St. Maries River near Santa, ID; 13295000 Valley Creek at Stanley, ID; 13297355 Squaw Creek near Clayton, ID.

to adjust frequency estimates. The generalized skew coefficients for Idaho and the standard errors of the generalized skew coefficients used in this analysis are from Kjelstrom and Moffatt (1981). For some sites we relied on earlier reported estimates of the return period of bankfull discharge (Whiting 1998).

For most USFS gaged study sites, we participated with personnel from the various National Forests in review of historical field measurements of discharge and stage-discharge relationships. Stage-discharge relationships were occasionally adjusted to ensure accurate estimates of daily mean discharges and peak flows. There was no additional review or modification of daily mean discharge records from USGS and CWRU gage sites, from a USFS research watershed, Eggers Creek, or from a USFS gage site, Cat Spur Creek.

Bedload Transport

Bedload transport rates were measured with the pressure-difference Helley-Smith bedload sampler (Helley and Smith 1971) at all of the study sites. The standard nozzle has a 3-in (76.2 mm) square entrance and was used in most instances. At a few sites, the 6-in (152 mm) square entrance model was used during higher flows. The catch bag on the samplers had a 0.25 mm mesh. A sediment-trapping efficiency of 100 percent was assumed for all particle sizes. Emmett (1980) suggests that the Helley-Smith sampler not be used for particles smaller than 0.25 mm and for sediment of particle sizes that are also transported in suspension. However, since we want to display and make all of the data available, we define bedload sediment as all of the material collected in the sampler, even though smaller particles may be transported in suspension. Users of this data may wish to redefine bedload sediment to meet their specific needs.

The sampling procedures employed in the collection of bedload data were based upon the Single Equal Width Increment method (Edwards and Glysson 1988; Williams and others 1988). Multiple samples at equal width intervals across the channel were collected and composited. Following recommendations of Emmett (1980), bedload sampling after 1993 typically was done using two traverses of the stream at about 20 verticals. The material collected on each traverse was considered as one sample. There were, however, some exceptions to this guideline, and the number of verticals, sample time per vertical, and stream width for each sample are detailed in the data files. In several instances the entire stream width was not sampled. Portions of the unsampled width were usually associated with shallow stream margins, often during overbank flow. In these instances, the portion of the width that was not sampled was not included in calculating bedload transport and the "comment" column in the bedload data table reflects a width adjustment.

Bedload transport measurements at many of the sites were confined to the period of the snowmelt hydrograph in the spring and early summer. Agencies responsible for the measurements included the U.S. Geological Survey, U.S. Forest Service, Case Western Reserve University, and Utah State University (table 4). Due to logistics specific to a site, sampling was not always done at the same cross-section in the study reach. For example, during high streamflow sampling may be done from a cableway and during lower flows sampling may be done by wading the stream directly below the cableway or at some other wadeable cross-section, usually reasonably close to the cableway. Occasionally, a considerable distance separated measurement locations. The locations of each of the sediment transport measurement cross-sections are provided in the web site data files.

Bedload samples were dried and standard procedures were used for particle size analysis. Typically full phi-interval sieves (64 mm, 32 mm, 16 mm, 8 mm, 4 mm, 2 mm, 1 mm, 0.5 mm, 0.25 mm) were used for samples collected in water year 1994 and later, although Case Western Reserve University personnel used 0.5 phi-interval sieves.

All bedload transport data were reviewed for accuracy. For most sites this consisted of a review of field and laboratory procedures, field and laboratory notes, and subsequent calculations. For most sites, the discharge associated with a bedload sample was based on the stage(s) during sampling and the current stage-discharge rating. Any shifts in the rating were also taken into account. Exceptions to the level of data review and exceptions to the procedure for determining the associated discharge are noted in the web site bedload files.

The following information is included for each bedload sample: sample date, stream discharge, total bedload transport rate, percent of the total bedload rate by size fraction, length of the b-axis of the largest particle in the sample, median diameter of the sample, total weight of the sample, sample location, sample type, number of verticals, time per vertical, stream width, and any comments.

Suspended Sediment Transport

Suspended sediment samples were collected using either a wading version (USDH-48 or USDH-81) or a suspension version (USDH-59, USD-49, USD-74,

Table 4. A summary of sediment transport sampling for the study sites.

Site	Agency[a] measuring sediment transport	Water years of sediment transport collection	Number of bedload samples	Number of suspended sediment samples	Range of discharge for bedload sampling[b]	
					ft³/sec	Q/Q_b or $Q/Q_{1.5}$
Big Wood River	USU	1999-2000	100	26	213-1,090	**0.28-1.41**
Blackmare Creek	USFS	1990-94	88	83	12.0-166	0.07-0.99
Boise River	USGS	1994-97	82	40	1,190-10,400	0.20-1.76
Dollar Creek	USFS	1990-94	85	76	14.0-239	0.06-1.05
Johnson Creek	USGS	1994-95, 97	70	35	224-2,870	0.16-2.05
Little Buckhorn Creek	USFS	1990-94	78	73	2.40-26.0	No Qb est
Lochsa River	USGS	1994-97	72	36	3,910-26,800	0.25-1.70
Middle Fork Salmon River	USU	1997	64	31	2,950-15,300	**0.39-2.03**
North Fork Clearwater River	USGS	1994-97	72	36	3,560-34,400	0.22-2.15
Salmon River nr Obsidian	USU	1999	51	23	264-739	**0.59-1.64**
Salmon River nr Shoup	USU	1997	61	21	3,830-19,100	**0.33-1.66**
Salmon River bl Yankee Fork	USGS	1999-2000	60	30	1,360-5,070	**0.33-1.22**
Selway River	USGS	1994-97	72	36	4,760-37,700	0.21-1.64
South Fork Payette River	USGS	1994-97	72	37	721-6,390	0.24-2.10
South Fork Salmon River	USGS	1985-86, 94-97	130	92	137-5,260	0.05-2.10
Squaw Creek (USGS)	CWRU	1994-95	92	32	4.93-267	0.03-1.48
Thompson Creek	CWRU	1994-95	84	24	8.15-124	0.09-1.42
Valley Creek	USGS/CWRU	1994–97	116	71	139-1,420	0.16-1.67
WF Buckhorn Creek	USFS	1990-94	85	68	12.0-242	0.06-1.20
Cat Spur Creek	USFS	1988-93, 95	35	32	6.70-67.0	0.08-0.80
Eggers Creek	USFS	1975-76, 78-84	137	130	0.426-8.75	0.25-5.18
Hawley Creek	USFS	1990-95	85	82	9.83-94.6	0.21-2.02
Johns Creek	USFS	1994-95	115		21.1-1,210	0.01-0.70
Little Slate Creek	USFS	1986-99	157	80	18.7-647	0.04-1.50
Lolo Creek	USFS	1982-83, 86, 88-90, 92-95, 97	112	136	26.8-809	0.06-1.95
Main Fork Red River	USFS	1986-99	200	136	9.88-646	0.03-1.96
Rapid River	USFS	1986-99	191	85	32.3-1,300	0.05-2.08
South Fork Red River	USFS	1986-99	204	136	5.93-458	0.02-1.79
Squaw Creek (USFS)	USFS	1991, 93-96	42	90	0.76-53.6	0.03-2.44
Trapper Creek	USFS	1987-97	166	143	1.69-135	0.02-1.49
Fourth of July Creek	CWRU	1994-95	78	25	5.46-137	0.04-1.00
Herd Creek	CWRU	1994-95	72	23	10.2-287	0.05-1.49
Marsh Creek	CWRU	1994-95	98	27	30.0-796	0.04-1.08

[a] USGS (United States Geological Survey); USFS (United States Forest Service); CWRU (Case Western Reserve University, Department of Geological Sciences); USU (Utah State University).
[b] The range of discharge expressed as a ratio of bankfull discharge (Q/Qb) or as a ratio of the 1.5 return interval discharge (bold), for sites with no field identification of bankfull stage.

or USD-77) of a depth integrating sampler. For suspended load, sampling from about 10 cross-channel locations is adequate to obtain a mean rate of transport through the cross-section. The vertical transit rate of lowering and raising the suspended-sediment sampler was everywhere an Equal Transit Rate to maintain the equal-discharge weighting (Edwards and Glysson 1988). Suspended-sediment samples were analyzed using standard laboratory procedures. Suspended sediment concentration is expressed in milligrams per liter. The percent of suspended sediment in the sand size class (>0.063 mm) was determined by weight for many of the samples.

All suspended sediment transport data were reviewed for accuracy. For most sites this consisted of a review of field and laboratory procedures, field and laboratory notes, and subsequent calculations. The discharge associated with a suspended sediment sample was based on the stage(s) during sampling and the current stage-discharge rating. Shifts in the rating were also taken into account. Exceptions to the level of data review and exceptions to the procedure for determining the associated discharge are noted in the web site suspended sediment files.

The suspended sediment sampling information provided includes sample date, stream discharge, suspended sediment concentration, suspended sediment transport rate, percent sand or larger in the sample, sample location, sample type, number of verticals, and any comments.

Sediment Transport-Discharge Relationships

Relationships (sediment ratings) were developed between sediment transport and water discharge pairs of data. Scatterplots of logarithms of these data tend to plot as linear patterns with approximately constant variance across the range of discharge. Therefore, relationships were developed using least squares regression analysis on log transformed data using the following model,

$$\log \hat{G} = \hat{\alpha}_0 + \hat{\alpha}_1 \log Q \qquad \text{(equation 1)}$$

where log $\hat{G}$ is the predicted logarithm of sediment transport, log Q is the logarithm of the corresponding water discharge, and $\hat{\alpha}_0$ and $\hat{\alpha}_1$ are regression estimates of unknown parameters computed from the collected data. The log-log model was the only model used to develop sediment ratings for these data sets. However, other models may also perform well for some of the individual data sets.

Sediment ratings (equation 1) were developed for total bedload, bedload by selected size classes, and suspended sediment. At a few sites, the collecting agency reported a bedload transport rate of zero on selected sampling dates. Since the log of zero is undefined, these data were not used in developing the sediment ratings. However, all of the bedload data (total and by size fraction) and suspended data are provided in the web site files.

The back transformation of the log-log relationships expresses the sediment transport rate (either bedload or suspended load), G, as a power function of water discharge, Q. If $\hat{\beta}_0 = anti\log(\hat{\alpha}_0)$ and $\hat{\beta}_1 = \hat{\alpha}_1$, back-transformation gives the power function:

$$\hat{G}_{biased} = \hat{\beta}_0 Q^{\hat{\beta}_1} \qquad \text{(equation 2)}$$

where $\hat{G}_{biased}$ denotes a biased estimate of the mean transport rate due to back-transformation. Several techniques are available to correct for this back-transformation bias (Cohn and Gilroy 1992). We used the "smearing" method described by Duan (1983). If the n regression residuals in log space are denoted by r_i, and b is the base of logarithms used (usually base 10 or base e), the smearing correction factor (or bias correction factor), BCF, for the logarithmic transformation is given by:

$$BCF = \frac{1}{n}\sum_{i=1}^{n} b^{r_i}. \qquad \text{(equation 3)}$$

Multiplying the right side of equation 2 by equation 3 approximately removes the bias so that a bias corrected estimate of the sediment transport rate, $\hat{G}$, can be written:

$$\hat{G} = BCF\,\hat{\beta}_0 Q^{\hat{\beta}_1}. \qquad \text{(equation 4)}$$

In the web site narrative report for each study site, we present and briefly discuss three graphs of relationships between sediment transport and discharge. The first graph displays the total bedload and suspended load transport rate versus stream discharge (figure 6) and provides the model for equation 2, the coefficient of determination (r^2), and the bias correction factor (BCF).

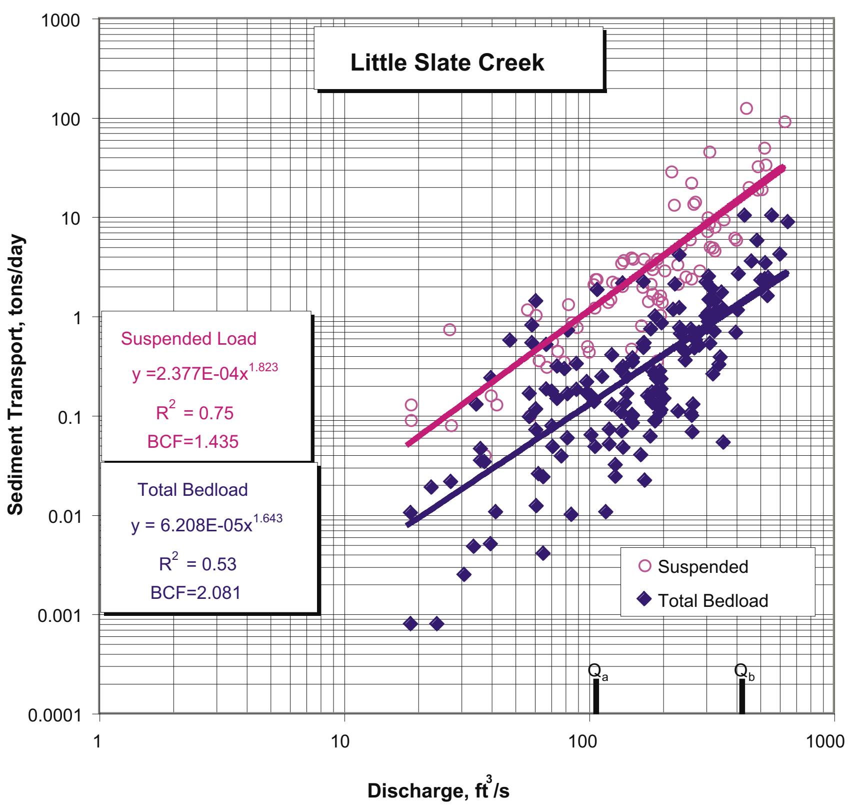

Figure 6. Suspended and bedload sediment transport versus stream discharge for the Little Slate Creek study site.

We also provide the value of the average annual discharge (Q_a) and either the bankfull discharge (Q_b) or the 1.5 year return interval discharge ($Q_{1.5}$) to visually give perspective to the range of discharges associated with the sediment transport measurements.

The second graph displays the bedload transport rate versus discharge and model information for selected bedload size classes (figure 7). To reduce the number of size classes for clearer display, we typically display data for grouped size classes of <0.5 mm, 0.5-2 mm, 2-8 mm, 8-32 mm, and greater than 32 mm. However, the web site files provide data for individual size classes. In this example, bedload transport data collected prior to 1994 used different size classes and are not displayed. However, pre-1994 size class transport data are provided in the web site file. These graphs provide information on the range of discharges during which the different size classes are represented in the sample and the relative magnitudes of transport rates for the different size classes of particles.

The third graph displays the median diameter of the bedload samples and the diameter (b-axis) of the largest particle in the sample versus stream discharge (figure 8). Power curve trend lines and their respective coefficients of determination (r^2) are displayed and discussed for each site. Typically, the largest particle in each bedload sample is only available for samples collected in 1995 and later. The display of median diameter may also be limited to the later years of sampling (1994 and later in this example) depending on the sieve sizes used in the particle size analysis. Also displayed are the average annual discharge (Q_a), either the bankfull discharge (Q_b) or the 1.5 year return interval discharge ($Q_{1.5}$), and the median diameter (D_{50}) of the surface pebble counts and subsurface core samples collected in the study reach. When available, we also plot any additional data related to transport of large particles from painted rock studies, bedload trap studies, or site observations.

Other Sediment Transport Related Information

The movement of painted rocks, the observations of large particles recently moved, and the capture of large particles in bedload traps provide information on the sizes of material the stream is capable of moving at certain discharges. These techniques were used at selected sites to examine the movement of bed surface particles, usually for particles too large to fit into the bedload sampler. In general these techniques provide some indication of the size bed material that moves during the higher flows at the respective sites.

Painted rocks. Painted rocks, as the name implies, are painted and/or otherwise identified (Leopold and others1966; Leopold and Emmett 1981; Emmett and others 1996). The movement of painted rocks was measured during 1995 spring snowmelt discharges at

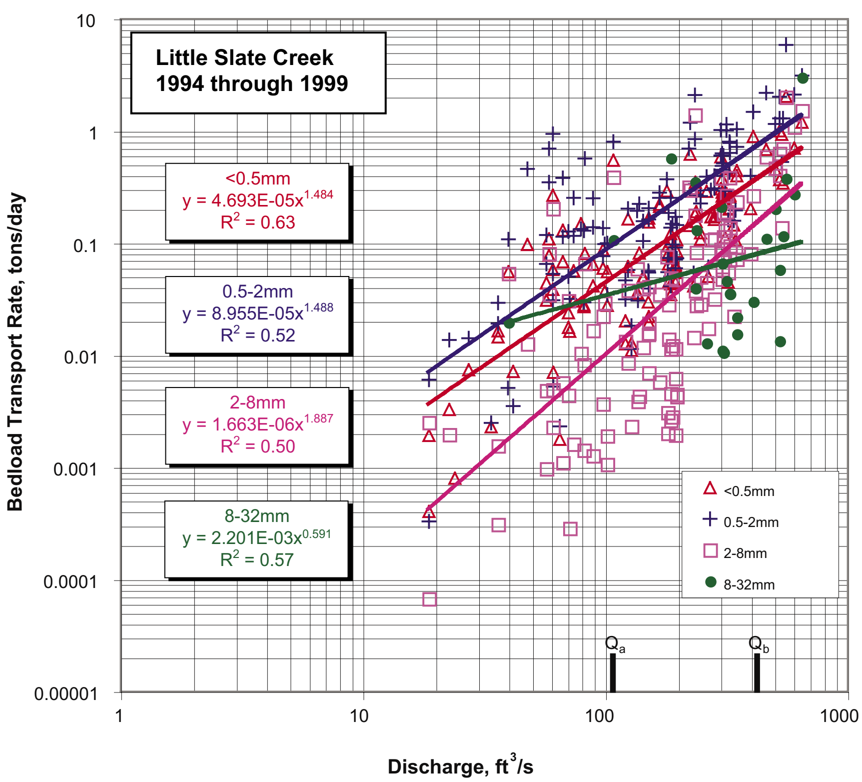

Figure 7. Bedload sediment transport by size class versus stream discharge for the Little Slate Creek study site.

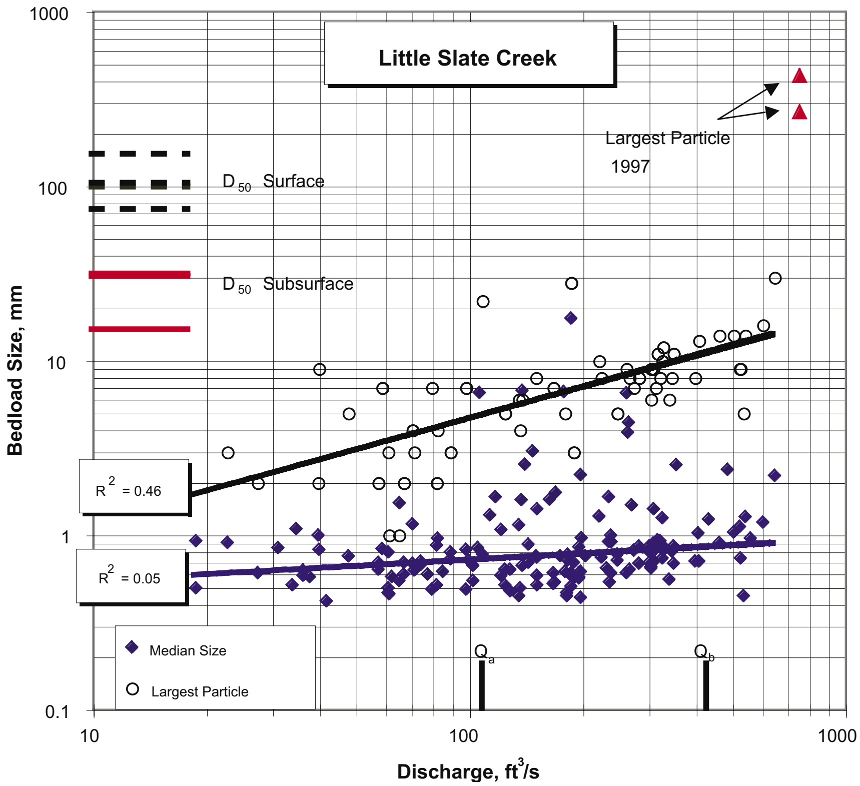

Figure 8. Median diameter of the bedload sample and largest particle in sample versus stream discharge for the Little Slate Creek study site.

the following sites: Rapid River, Valley Creek, Main Fork Red River, South Fork Red River, South Fork Salmon River, Johnson Creek, Herd Creek, Fourth of July Creek, Squaw Creek (USGS), and Thompson Creek.

Prior to the 1995 high snowmelt flows, painted rocks were placed on the channel bed and their subsequent movements were monitored. Twenty painted rocks were placed at approximately equal increments of distance across each of two transects. Transects were located in straight riffle or glide reaches. Stakes or rebar were used to mark the end of transects. At a subset of these study sites, the painted rocks were usually of two particle size classes to represent about the D_{50} and D_{84} of the surface size distribution as determined in 1994. At another subset of sites, particles spanned the range of sizes from about D_{25} to D_{90}. Rocks were placed in a stable configuration in pockets of the bed with their shortest dimension (c-axis) pointing upward. For each rock, the location of placement and length of the b-axis were measured and recorded. At some sites, rocks were monitored for displacement during the snowmelt flows. The painted rocks were retrieved during lower flows following the snowmelt runoff period. Downstream and lateral displacement were measured for those rocks that could be located. Recovery rates varied from 20 to 100 percent. Data tables and graphs in the web site files provide information on the size, location, and movement of each painted rock (figure 9).

The web site report for each site includes a graph that displays the largest particle in the bedload sample and the median size of bedload sample versus discharge, similar to the example provided in figure 8. For painted rock study sites, the largest painted rock moved and the associated instantaneous peak discharge during the sampling time interval are also displayed. It should be noted that the largest painted rock might have been moved by discharges less than the instantaneous peak discharge in the sampling time interval. However, the discharge at the time of movement(s) is not known.

Coarsest particles observed to have recently moved. At some sites, measurements were made of the size (b-axis) of the coarsest particle(s) that appeared to have been recently moved during the preceding spring snowmelt high flows. Particles were interpreted to have been moved recently if they were loose, perched precariously atop other grains, found atop vegetation, or lacked staining or other coatings found on other grains. The web site report for each site includes a graph that displays the largest particle in the bedload sample and the median size of bedload sample versus discharge, similar to the example provided in figure 8. For selected study sites, the largest rock observed to have moved and the associated instantaneous peak discharge during the previous spring

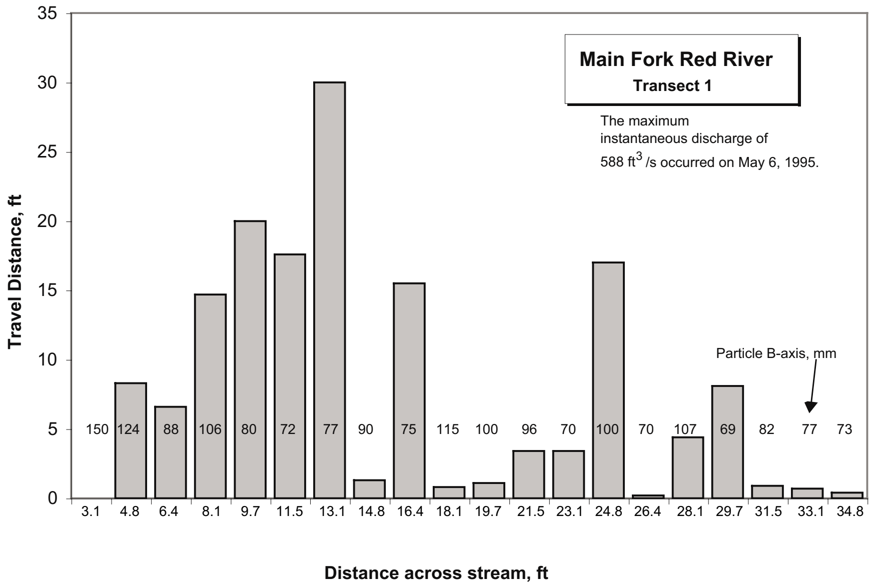

Figure 9. Travel distance of painted rocks along transect 1 of the Main Fork Red River study reach during spring snowmelt flows in 1995.

snowmelt period are also displayed. It should be noted that the largest rock might have been moved by discharges less than the instantaneous peak discharge. However, the discharge at the time of movement(s) is not known.

Bedload traps. At two sites, the Main Fork Red River and South Fork Red River, bedload traps were placed on the streambed during the spring snowmelt of 1997. These traps consisted of 1 inch wire mesh baskets anchored to the streambed. The upstream opening of the baskets was 1.5 feet wide by 0.5 feet high. Three baskets were placed along a transect roughly ¼, ½, and ¾ the distance across the channel. The baskets remained in place for several days at a time. On several occasions the traps were removed and the b-axis of all the collected particles was measured. The web site reports include a graph that displays the largest particle in the bedload sample and the median size of bedload sample versus discharge, similar to the example provided in figure 8. For the Main Fork and South Fork Red River study sites, the largest particle captured in a trap and the associated instantaneous peak discharge during the sampling time interval are also displayed. It should be noted that the largest particle might have been moved by discharges less than the instantaneous peak discharge in the sampling time interval. However, the discharge at the time of movement is not known.

Results

Stream Discharge

These snowmelt-dominated streams and rivers typically reach peak flows in April, May, or June in association with spring snowmelt runoff (figure 10). Even those watersheds with relatively low gage elevations (Selway River, Lochsa River, North Fork Clearwater River, and Rapid River) have most of their drainage area at higher elevations and snowmelt is the dominant annual hydrologic event. High flows occasionally occur in fall and winter in association with cyclonic storms or rain-on-snow events. Rain-on-snow events are more common at lower elevations. Generally, streamflows drop rapidly over the summer following the disappearance of the snowpack, but on occasion increase for short periods in response to rain events. Low flows are reached in September or October and flows typically remain relatively low during winter months.

Average annual discharge (Q_a) for the study sites ranges from 0.604 to 3,730 ft^3/s (table 5). This large range of Q_a is influenced by large differences between sites in both the size of the drainage area and the average annual precipitation. Expressing Q_a as an equivalent depth of water over the contributing watershed removes some of the effects of drainage area. However, there is still a wide range due to large differences in annual precipitation with equivalent depths of Q_a ranging from 3.7 to 36.3 inches. Average annual discharge ranges from $0.11Q_b$ to $0.40Q_b$ for the 27 sites where bankfull discharge (Q_b) was determined, and averages $0.21Q_b$. The two basins with the largest Q_a/Q_b ratios, Hawley Creek and Eggers Creek, are both spring-fed streams. These results are consistent with earlier analyses by Whiting and others (1999) for 21 of these sites plus two additional sites. They also report that the mean annual discharge to bankfull discharge ratio averages 0.21. In Emmett's (1975) analyses of streamflow data for five streams in

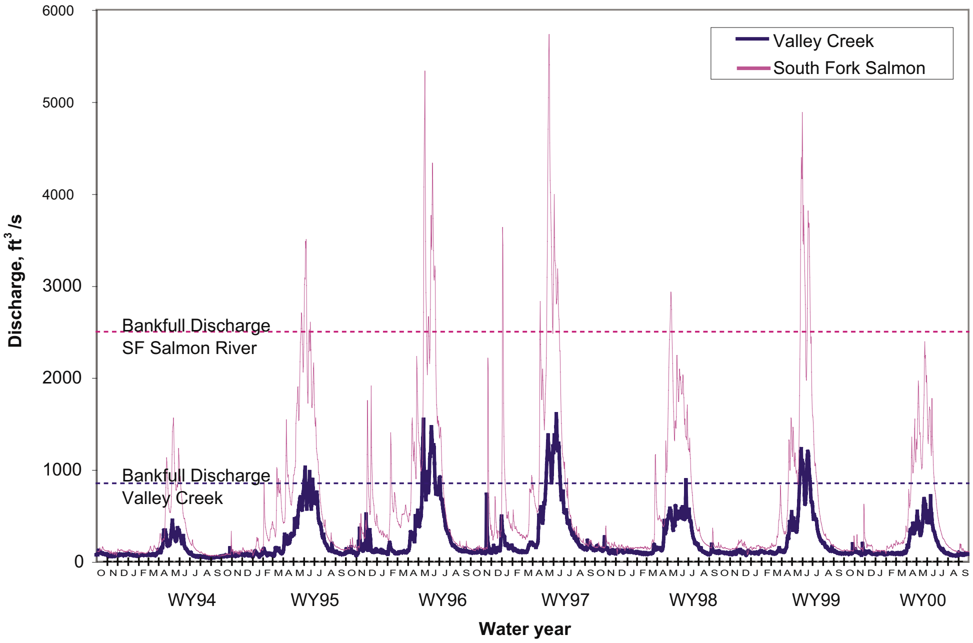

Figure 10. Example hydrographs for two mid-size study watersheds, Valley Creek and the South Fork Salmon River.

Table 5. A summary of stream discharge information for the study sites.

Site	Range daily mean discharge ft³/sec	Average annual discharge[a] ft³/sec	Average annual discharge area-inches	1.5 year return interval discharge ft³/sec	Bankfull discharge[b] ft³/sec	Return period bankfull[c] discharge yrs	Q_a/Q_b
Big Wood River	18-1,510	167	16.5	765	nm		
Blackmare Creek	4.88-430	**39.2**	29.9		167	1.1	0.23
Boise River	123-15,400	1,200	19.6	5,330	5,900	1.7	0.20
Dollar Creek	4.0-391	**34.9**	28.7		227	1.1	0.15
Johnson Creek	28.0-5,440	344	21.6	2410	1,400	0.9	0.25
Little Buckhorn Creek	1.0-46.1	**6.64**	15.1		n		
Lochsa River	110-31,900	2,840	32.7	15,900	15,750	1.5	0.18
Middle Fork Salmon River	240-20,700	1,395	18.4	7,660	nm		
North Fork Clearwater River	253-34,200	3,460	36.3	15,800	16,000	1.5	0.22
Salmon River nr Obsidian	2-663	81.1	11.7	442	nm		
Salmon River nr Shoup	720-25,400	3,040	6.6	11,300	nm		
Salmon River bl Yankee Fork	160-10,300	983	16.5	4,170	nm		
Selway River	150-45,300	3,730	26.5	21,700	23,000	1.7	0.16
South Fork Payette River	130-8,900	862	26.1	3,490	3,050	1.2	0.28
South Fork Salmon River	58.0-6,200	540	22.3	2,730	2,500	1.3	0.22
Squaw Creek (USGS)	3.80-640	34.3	6.51	175	181	1.6	0.18
Thompson Creek	0.861-357	16.6	10.3	77	87.6	1.6	0.19
Valley Creek	34.0-1,900	205	18.3	818	850	1.6	0.24
West Fork Buckhorn Creek	1.78-341	**36.4**	21.9		202	1.2	0.18
Cat Spur Creek	1.07	**14.0**			83.3	1.4	0.17
Eggers Creek	0.179-9.26	0.604	16.5	2.50	1.69	1.2	0.36
Hawley Creek	10.6-68.2	**18.9**	6.1		46.9	2.1	0.40
Johns Creek	15.5-2,919	**158**	19.0		1,730	3.4	0.09
Little Slate Creek	12.5-974	109	23.7	466	430	1.4	0.25
Lolo Creek	6.77-904	93.1	30.8		415	1.2	0.22
Main Fork Red River		73.0		407	330	1.1	0.22
Rapid River	19.1-2,130	162	20.4	687	626	1.4	0.26
South Fork Red River	4.51-972	48.5	17.2	258	256	1.5	0.19
Squaw Creek (USFS)	0.666	**3.89**	3.7		22.0	4.2	0.18
Trapper Creek	1.05-171	**12.7**	21.6		90.4	1.9	0.14
Fourth of July Creek	1.9-181	**15.0**	11.9		137	1.5	0.11
Herd Creek	5.67-505	**46.4**	5.73		193	1.4	0.24
Marsh Creek	25.3-3207	**133**	22.7		734	1.6	0.18

[a] Bolded estimates of average annual discharge from Whiting (1998) and based on extended discharge records.
[b] nm = the stage and discharge of bankfull discharge was not measured. n = no floodplains were present.
[c] Bolded estimates of the return period for bankfull discharge from Whiting (1998).

the upper Salmon River basin, he reports an average Q_a/Q_b ratio of 0.25 and a range of 0.20 to 0.27.

The bankfull discharge for most of these sites is a relatively frequent event. The average return period for bankfull discharge is 1.6 years (range 0.9 to 4.2 years). The average return period of bankfull discharge for long-term USGS gaged sites and USFS gaged sites with flood frequency analysis done on data up to 2001 is 1.4 years (range 0.9-1.7 years). Thus, the 1.5 year event is a reasonable approximation of bankfull discharge for these snow-dominated systems. This is in agreement with Emmett's (1975) determination of about a 1.5 year recurrence interval for bankfull discharge for watersheds in the upper Salmon River basin and with Ryan and Emmett's (2002) conclusion that 1.5 year recurrence discharge approximates the bankfull discharge for Little Granite Creek, a 21.1 mi^2 watershed in the headwaters of the Snake River Basin in Wyoming.

Since a significant snowpack can develop in all of these study watersheds, a large proportion of the annual runoff occurs during a relatively short period of time during the spring and early summer months. For example, flows equaled or exceeded 1, 5, and 10 percent of the time account for, on average, 7.8, 27.2, and 43.0 percent of the annual streamflow (table 6, figure 11). Discharges equal to or larger than the bankfull discharge, Q_b, on average occur 3.3 percent of the time (12.1 days/year) and account for 19.7 percent of the annual streamflow. Discharges less than the average annual discharge, Q_a, on average occur 75.0 percent of the time (273.9 days per year) and account for 31.6 percent of the annual streamflow. The remaining 48.7 percent of the annual streamflow is associated with discharges between Q_a and Q_b that occur 21.7 percent of the time (79.3 days per year).

Bankfull discharge increases with increasing drainage area. This relationship is displayed in figure 12A for the 27 study sites where floodplains were identified and the bankfull discharges were estimated. There is considerable variation around the power curve fit of the data (Equation A) and some of this variation is due to the wide range in precipitation regimes and resulting runoff across the large area that encompasses the study sites. The data points presented in figure 12A are coded by categories of average annual runoff (QA), expressed as a depth of water. The study sites with greater than 30 inches of average annual runoff all plot above the power curve (solid line) and those sites with less than 10 inches of runoff all plot substantially below the power curve. Including average annual runoff in the prediction equation (equation B) significantly improves that coefficient of determination (r^2). Figure 12B displays the actual (field determined) versus predicted values of bankfull discharge using both drainage area and average annual runoff (equation B).

Table 6. Flow duration information for selected study sites.

Study site	0.50	1	5	10	25	50	75	Q_a %Time[a]	Q_a %Q[b]	Q_b or $Q_{1.5}$[c] %Time[a]	Q_b or $Q_{1.5}$[c] %Q[b]
	Percent of time equaled or exceeded — %Q[b]										
Big Wood River	4.0	7.5	27.2	43.8	69.7	84.2	93.3	24.3	69.0	**3.3**	**19.9**
Boise River	3.6	6.5	24.7	40.7	68.3	84.7	93.7	27.1	70.6	2.0	11.9
Johnson Creek	5.4	9.6	33.8	53.4	78.2	89.1	95.5	21.3	75.0	7.0	42.8
Lochsa River	4.2	7.5	27.0	44.0	72.3	88.8	96.0	27.0	74.3	1.8	12.1
Middle Fork Salmon River	5.5	9.1	28.9	45.5	68.4	82.9	92.7	21.5	65.2	**2.0**	**15.0**
North Fork Clearwater River	3.7	6.6	23.3	38.1	65.5	84.9	94.3	30.0	71.1	2.0	11.4
Salmon River nr Obsidian	3.7	7.5	27.9	45. 1	72.5	86.2	95.0	22.7	70.5	**2.4**	**15.6**
Salmon River nr Shoup	3.3	5.9	21.4	34.8	55.9	74.0	88.4	22.7	53.8	**3.0**	**14.6**
Salmon River bl Yankee Fork	3.8	6.9	24.6	39.6	63.7	79.8	91.2	23.8	62.5	**3.2**	**17.7**
Selway River	4.2	7.7	27.9	45.5	73.7	89.1	96.0	26.0	74.7	1.3	9.5
South Fork Payette River	3.6	6.5	23.5	38.9	64.3	81.3	92.0	26.3	65.6	5.1	23.9
South Fork Salmon River	4.5	8.1	28.9	46.2	72.1	86.8	94.7	24.6	71.7	4.0	24.6
Squaw Creek (USGS)	6.0	10.8	35.4	52.3	73.9	86.7	94.7	21.5	70.9	3.8	29.5
Thompson Creek	6.9	12.0	35.9	52.8	76.0	88.5	95.5	22.1	73.4	3.5	28.6
Valley Creek	3.3	6.1	23.3	38.7	64.5	80.7	91.6	25.2	64.7	2.9	14.9
Eggers Creek	4.9	8.6	26.3	38.4	57.0	75.4	89.4	21.9	54.0	6.1	29.6
Little Slate Creek	2.9	5.3	20.6	34.9	62.1	81.9	92.6	29.9	67.6	2.5	11.5
Lolo Creek	3.6	6.5	24.4	40.0	67.9	87.1	95.3	30.3	73.8	2.9	16.0
Main Fork Red River	4.8	8.5	28.9	45.0	71.0	87.4	95.1	27.0	73.1	3.8	23.9
South Fork Red River	5.7	9.86	31.1	47.1	71.7	87.5	95.0	25.8	72.5	2.8	20.8
Rapid River	4.0	7.3	25.8	40.8	63.3	79.3	90.9	23.2	62.0	3.5	20.0
Average	4.4	7.8	27.2	43.0	68.2	84.1	93.5	25.0	68.4	3.3	19.7

[a] Percent of time equaled or exceeded.
[b] Percent of streamflow volume.
[c] Bolded values are for the 1.5 year recurrence discharge, used as an estimate for bankfull discharge.

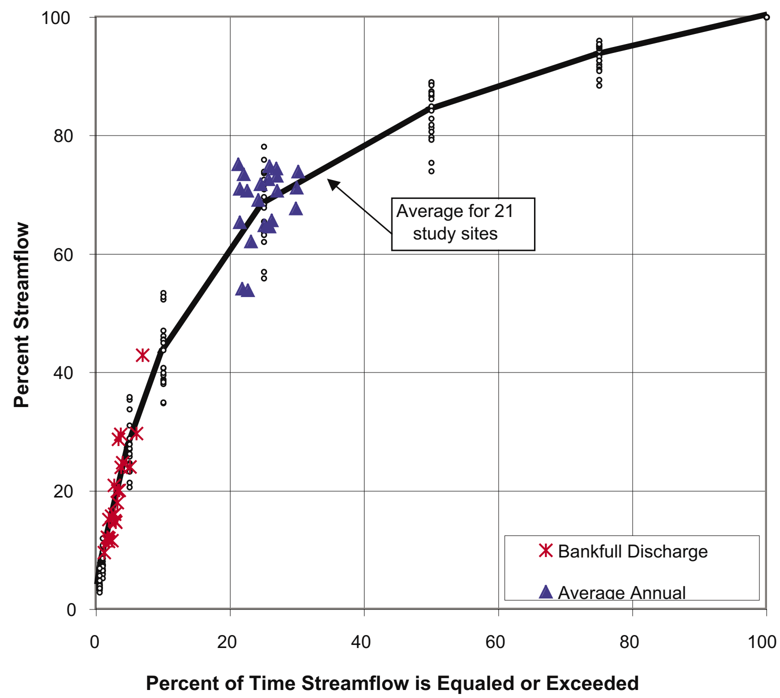

Figure 11. Percent streamflow versus percent of the time streamflow is equaled or exceeded. (Open circles represent the various exceedance flows presented in table 6.)

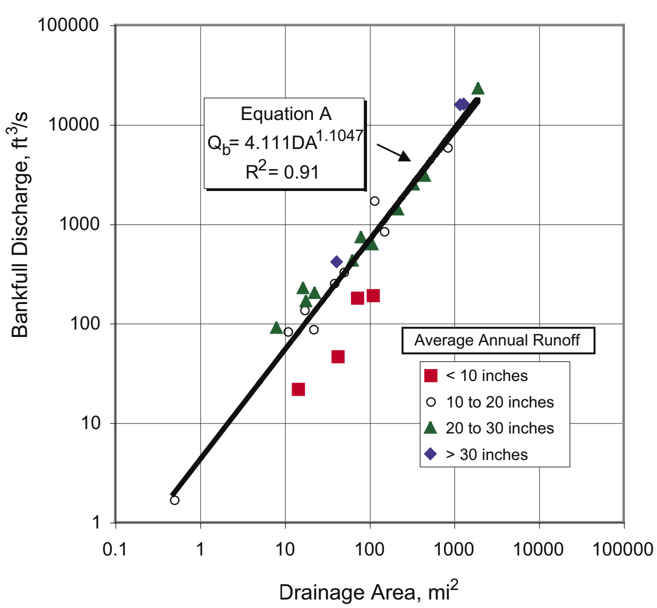

Figure 12A. Bankfull discharge versus drainage area.

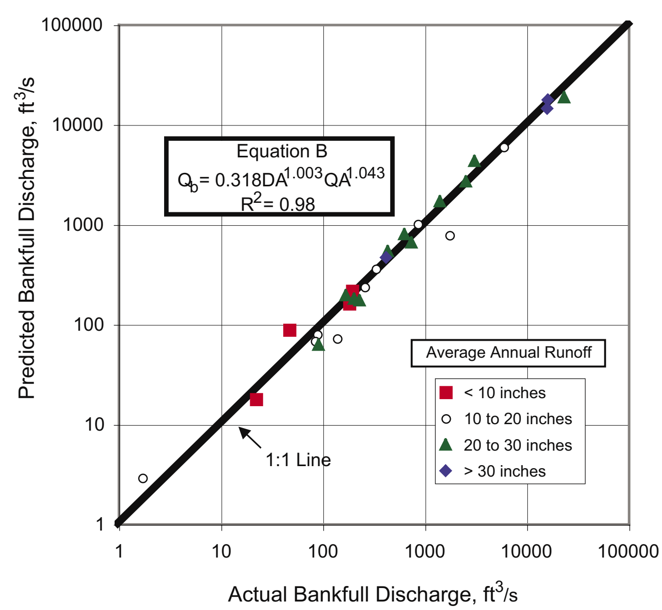

Figure 12B. Actual (field determined) versus predicted bankfull discharge.

Channel Geometry

The "At-a-Station" channel geometry relationships for each study site were used to estimate the width, average depth, and average velocity at bankfull discharge for the sites where bankfull was identified in the field. As shown in the following power curve relationships incorporating data from the individual study sites, width (W), average depth (D), average velocity (V), and gradient (G) at bankfull discharge are strongly related to both bankfull discharge (Q_b) and drainage area (DA). The bankfull discharge is the better predictor for the variables of width, average depth, and average velocity, probably since it incorporates differences in precipitation inputs not reflected in drainage area (figure 13).

$W = 3.934*DA^{0.582}$ $r^2 = 0.92$	$W = 2.005*Q_b^{0.515}$ $r^2 = 0.97$
$D = 0.504*DA^{0.353}$ $r^2 = 0.75$	$D = 0.300*Q_b^{0.330}$ $r^2 = 0.89$
$V = 2.135*DA^{0.169}$ $r^2 = 0.62$	$V = 1.704*Q_b^{0.155}$ $r^2 = 0.70$
$G = 8.738*DA^{-0.526}$ $r^2 = 0.75$	$G = 13.589*Q_b^{-0.438}$ $r^2 = 0.70$

Channel Bed Material

The channel beds at the study sites are typically armored, having a coarser layer of surface material overlaying finer subsurface material. The D_{50} of the surface material ranged between sites from 23 mm to 207 mm and the D_{90} ranged from 74 mm to 1,008 mm (table 7). The D_{50} of the subsurface material ranged from 15 mm to 43 mm and the D_{90} of the subsurface material ranged from 81 mm to 305 mm. The data presented in table 7 reflect combined samples for different methods of data collection that involved sampling throughout the reach (Methods 2 and 3). At all sites, the D_{50} and D_{90} of the surface material was larger than the subsurface material, indicating the presence of a coarser surface (armor) layer. The ratio of the D_{50} for the surface and subsurface material gives an indication of the degree of armoring. Based on comparison of surface pebble count and subsurface core information, this ratio ranges from 1.9 to 7.2 and averages 4.0. Armoring has been linked to sediment supply being less than the ability of the stream to transport that load (Dietrich and others 1989).

Sediment Transport–Discharge Relationships

At all of the study sites, both bedload and suspended sediment transport increases with stream discharge. The relationships between sediment transport and discharge using the log-log model (equation 1) resulted in statistically significant (alpha = 0.01) models for all sites for both total bedload and suspended sediment transport. The coefficients of determination, r^2, ranged from 0.27 to 0.89 for bedload sediment and 0.35 to 0.95 for suspended sediment. Expressed as power relationships

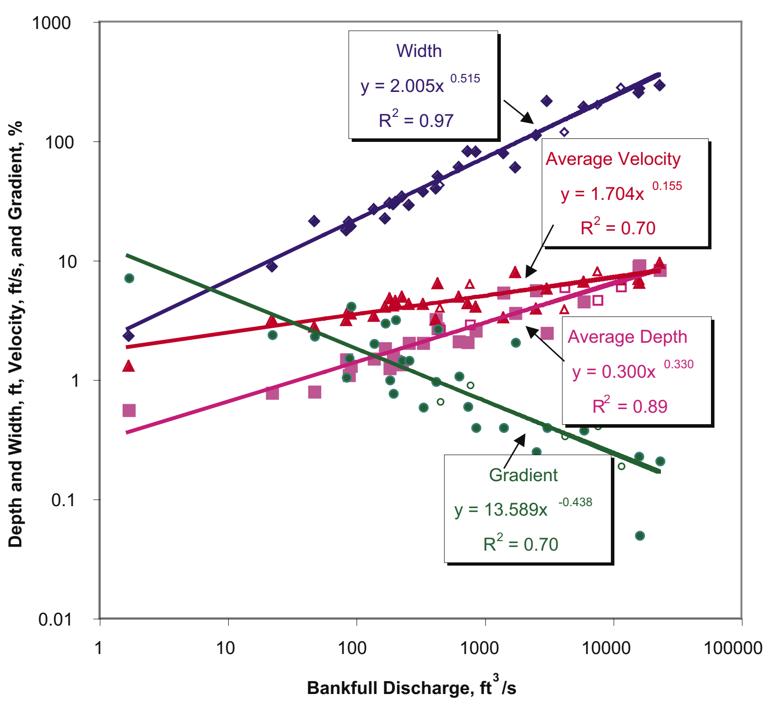

Figure 13. Bankfull width, average depth, and average velocity as a function of bankfull discharge. (Open symbols are width, average depth and average velocity at the 1.5 year return interval discharge, used as an approximation of bankfull discharge, for sites without estimates of bankfull discharge. Data represented by the open symbols were not used in developing the power relationships.)

Table 7. Surface and subsurface bed material information for the study sites.

Site	Surface D_{50} mm[a]	Subsurface D_{50} mm	Ratio:surface to Subsurface D_{50} mm[b]	Surface D_{90} mm[a]	Subsurface D_{90} mm	Sample year
Big Wood River	119/**155**	25	4.8/**6.2**	353/**210**	152	00
Blackmare Creek	95/104/**149**	-/21	-/5.0/**7.1**	252/315/**210**	-/128	94/00
Boise River	71/76	-/23	-/3.3	160/174	-/121	94/95
Dollar Creek	77/87/**100**	-/-/22	-/4.1/**4.5**	174/224/**164**	-/-/94	94/00
Johnson Creek	190			430		94
Little Buckhorn Creek	28/81/**119**	-/15	-/5.4/**7.9**	450/285/**191**	-/108	94/00
Lochsa River	148/126	-/26	-/4.8	320/339	-/177	94/95
Middle Fork Salmon River	146/**128**	36	3.7/**2.9**	370/**221**	174	00
North Fork Clearwater River	60/95	-/23	-/4.1	334/282	-/135	94/95
Salmon River nr Obsidian	61/**64**	26	**2.3**/**2.5**	148/**127**	97	00
Salmon River nr Shoup	96/**150**	28	3.4/**5.4**	203/**207**	164	00
Salmon River bl Yankee Fork	104/**138**	25	4.2/**5.5**	396/**182**	133	00
Selway River	200/173	-/24	-/7.2	315/310	-/131	94/95
South Fork Payette River	55/110	-/20	-/5.8	175/258	-/102	94/95
South Fork Salmon River	38/2/2			113/87/168		94/A99/S99[d]
Squaw Creek (USGS)	43/46/**83**	-/-/29	-/1.6/**2.9**	82/116/**151**	-/-/124	94/00
Thompson Creek	66/59/**135**	-/-/43	-/1.4/**3.1**	130/140/**228**	-/-/164	94/00
Valley Creek	48/70/40	-/-/21	-/-/1.9	107/230/132	-/-/81	94/94/95
West Fork Buckhorn Creek	180			750		94
Cat Spur Creek	27			80		94
Eggers Creek[c]	23/4			164/8		75,77-84,94
Hawley Creek	40			140		94
Johns Creek	180/207	-/35	-/5.9	400/1,008	-/305	94/95
Little Slate Creek	207/102	-/24	-/4.2	450/355	-/169	94/95
Lolo Creek	90/84/68	-/-/20	-/-/3.4	150/127/172	-/-/93	94/95/95
Main Fork Red River	68/50	-/18	-/2.8	110/160	-/86	94/95
Rapid River	94/63	-/16	-/3.9	181/220	-/113	94/95
South Fork Red River	86/106	-/25	-/4.2	165/258	-/145	94/95
Squaw Creek (USFS)	27			74		94
Trapper Creek	67/85	-/17	-/5.0	136/300	-/89	94/95
Fourth of July Creek	51			137		94
Herd Creek	67			122		94
Marsh Creek	56			162		94

[a] Bolded values represent information from surface core samples; unbolded values represent information from pebble counts. In 2000 both pebble counts and surface core information are available.
[b] Bolded values are ratios of surface and subsurface core information; unbolded values are ratios of surface pebble counts and subsurface core information.
[c] Eggers Creek pebble counts in 1994 are influenced by annual flushing of a sediment retention pond.
[d] Sampling occurred twice in 1999; once in April (A99) and again in September (S99).

(equation 2), the exponents range from 1.489 to 5.749 (average 2.711) for total bedload transport and 1.362 to 3.997 (average 2.289) for suspended sediment transport (table 8). Using the average exponent values, doubling stream discharge results in a more than sixfold increase in bedload transport and almost a fivefold increase in suspended sediment transport. These ranges of exponent values are much larger than the range reported by Leopold (1994), who suggests that most sediment transport data sets have exponents between 2.0 and 3.0. We found a high correlation between the exponents for bedload and suspended load ($r = 0.76$), indicating sites with high bedload exponents will generally also have high suspended exponents.

The bias correction factor ranges from 1.203 to 3.460 for the bedload relationships and 1.081 to 3.200 for the suspended sediment relationships. Thus, for most sites, correcting for bias is important for accurate estimation of sediment transport rates and sediment yields.

At most sites, the suspended sediment transport is larger than the bedload transport over the entire range of discharges when sediment transport was measured. At bankfull discharge, suspended sediment transport makes up the majority of the total sediment load for all but five study sites (table 8). We define the total sediment load as the suspended load plus bedload. In general, as watershed size increases, suspended sediment accounts for an increasing percentage of the total sediment in transport. For the four largest basins, Salmon River near Shoup, Selway River, Lochsa River, and the North Fork Clearwater River, bedload accounts for less than 4 percent of the total load at bankfull discharge. Bedload accounts for 62 percent of the total load at bankfull discharge for the smallest basin, Eggers Creek.

Table 8. Bedload and suspended sediment transport model information.

Site	Bedload sediment					Suspended sediment			
	Exponent	r^2	BCF[a]	Rate at Q_b tons/day	% of total at Q_b	Exponent	r^2	BCF[a]	Rate at Q_b tons/day
Big Wood River	3.540	0.87	1.300	33.3	13.7	2.982	0.82	1.102	209
Blackmare Creek	1.986	0.61	1.607	3.70	35.8	1.367	0.49	1.534	6.63
Boise River	2.552	0.85	1.203	339	11.3	3.337	0.93	1.257	2,668
Dollar Creek	2.304	0.72	1.509	9.48	38.9	1.378	0.62	1.413	14.9
Johnson Creek	2.819	0.87	1.326	2.53	6.3	1.767	0.81	1.187	37.7
Little Buckhorn Creek	2.271	0.50	1.844			1.362	0.41	1.962	
Lochsa River	3.891	0.78	1.428	84.2	2.7	3.696	0.85	1.373	3,062
Middle Fork Salmon River	5.749	0.82	1.886	93.6	10.8	3.997	0.89	1.143	771
North Fork Clearwater River	3.862	0.88	1.272	98.7	2.6	3.707	0.92	1.241	3,679
Salmon River nr Obsidian	3.388	0.61	1.246	14.0	16.1	1.803	0.35	1.218	72.9
Salmon River nr Shoup	3.884	0.71	1.350	206	2.8	3.088	0.46	1.59	7,064
Salmon River bl Yankee Fork	3.851	0.72	1.549	56.9	8.2	3.315	0.84	1.25	637
Selway River	4.426	0.84	1.291	246	3.9	3.598	0.76	1.883	5,998
South Fork Payette River	2.020	0.70	1.353	186	15.1	3.174	0.90	1.238	1,044
South Fork Salmon River	3.007	0.74	2.088	166	42.0	2.066	0.91	1.174	229
Squaw Creek (USGS)	2.516	0.79	1.846	12.1	28.9	2.198	0.95	1.103	29.7
Thompson Creek	3.275	0.89	1.522	7.30	28.7	2.478	0.83	1.081	18.2
Valley Creek	2.808	0.59	1.823	75.5	68.0	1.875	0.75	1.32	35.5
West Fork Buckhorn Creek	1.871	0.43	2.083	7.50	23.1	1.618	0.40	3.2	24.9
Cat Spur Creek	2.726	0.63	2.203	3.70	50.3	1.790	0.72	1.229	3.66
Eggers Creek	1.645	0.67	1.341	0.101	62.0	1.912	0.79	1.236	0.062
Hawley Creek	1.589	0.27	1.767	1.41	24.2	1.998	0.76	1.17	4.41
Johns Creek	2.142	0.55	4.507	3.59					
Little Slate Creek	1.643	0.53	2.081	2.74	11.3	1.823	0.75	1.435	21.6
Lolo Creek	1.489	0.37	2.086	4.16	20.2	1.436	0.72	1.538	16.5
Main Fork Red River	2.164	0.70	2.122	17.0	44.2	1.790	0.82	1.363	21.5
Rapid River	2.233	0.59	2.594	15.1	16.9	2.533	0.89	1.34	74.5
South Fork Red River	1.683	0.47	3.460	9.28	35.7	1.613	0.63	1.73	16.7
Squaw Creek (USFS)	2.300	0.49	1.898	0.748	46.8	1.658	0.70	1.521	0.852
Trapper Creek	1.704	0.57	2.548	6.64	53.7	1.492	0.66	1.954	5.73
Fourth of July Creek	2.733	0.78	2.347	13.8	36.2	2.305	0.90	1.277	24.3
Herd Creek	2.458	0.83	1.596	26.1	23.6	2.397	0.95	1.149	84.4
Marsh Creek	2.931	0.74	1.721	79.9	82.0	1.700	0.83	1.176	17.5

[a] BCF = bias correction factor (Duan 1983).

The value of the exponent in the sediment transport power equations exerts much control over the range of flows most responsible for sediment transport. As the exponent increases, a larger proportion of the sediment load is associated with higher discharges that occur a smaller portion of the time. Table 9 provides bedload sediment transport duration information for 21 of the study sites and figure 14 displays this information graphically. These sites represent long-term USGS gaged sites and USFS gaged sites with extended streamflow records through water year 1999. In figure 14, the bedload sediment duration curves for each site are coded by a category for a range of exponent values to illustrate the influence of the value of the exponent. The site with the largest exponent for bedload transport, Middle Fork of the Salmon River, transports 93.7 percent of the bedload at high flows that occur less than 1 percent of the time. On the other extreme, Lolo Creek, with the smallest bedload exponent, only transports about 11.4 percent of the bedload at high flows that occur less than 1 percent of the time.

While differences in the exponent indicate large variation between sites, on average, discharges equal to or larger than bankfull discharge, which occur 3.3 percent of the time (range 1.3-7.0 percent), account for about 19.7 percent of the total streamflow (range 9.5-42.8 percent) and transport 61.5 percent (range 21.1-96.8 percent) of the bedload sediment. Discharges between average annual discharge and bankfull discharge occur 21.7 percent of the time (range 14.3-28.0 percent), account for 48.8 percent of the total streamflow (range 24.4-65.2 percent), and transport 34.7 percent of the bedload (range 10.4-64.5 percent). Discharges less than average annual discharge occur 75.0 percent of the time (range 69.7-78.7 percent) and account for about 31.6 percent of the total streamflow (range 25.0-46.2 percent) but only transport about 3.8 percent of the bedload sediment (range ~0.0 to 21.6 percent). Given that the power relationships (equation 2) predict some amount of bedload transport even for small discharges, our findings should be considered in general agreement

Table 9. Bedload transport duration information for selected study sites.

Study Site	Percent of time equaled or exceeded[a] 0.50	1	5	10	25	50	75	Q_a %Time	Q_a %Bed[a]	Q_b or $Q_{1.5}$ %Time[b]	Q_b or $Q_{1.5}$ %Bed[b]
	% bedload										
Big Wood River	27.0	42.3	82.8	94.9	99.8	100	100	24.3	99.8	**3.3**	**73.0**
Boise River	14.9	24.3	62.4	81.9	97.5	99.5	99.8	27.1	98.0	2.0	38.1
Johnson Creek	25.3	38.2	79.1	94.2	99.8	100	100	21.3	99.6	7.0	87.5
Lochsa River	35.0	48.6	85.0	95.5	99.9	100	100	27.0	99.9	1.8	61.8
Middle Fork Salmon River	89.1	93.7	99.2	99.9	100	100	100	21.5	100.0	**2.0**	**96.8**
North Fork Clearwater River	37.8	50.7	83.5	93.7	99.6	100	100	30.0	99.8	2.0	64.8
Salmon River nr Obsidian	18.1	31.8	77.6	92.8	99.8	100	100	22.7	99.8	**2.4**	**57.4**
Salmon River nr Shoup	35.1	48.9	85.5	96.0	99.5	99.8	99.9	22.7	99.4	**3.0**	**74.8**
Salmon River bl Yankee Fork	34.9	50.1	86.7	96.3	99.8	100	100	23.8	99.8	**3.2**	**77.8**
Selway River	40.2	55.0	89.4	97.6	100	100	100	26.0	100.0	1.3	60.8
South Fork Payette River	11.4	19.0	51.2	72.0	91.8	97.0	98.9	26.3	92.4	5.1	51.9
South Fork Salmon River	25.6	38.2	78.3	92.9	99.5	99.9	100	24.6	99.5	4.0	72.6
Squaw Creek (USGS)	26.9	41.8	83.5	94.7	99.3	99.8	99.9	21.5	99.1	3.8	77.1
Thompson Creek	50.2	66.5	93.6	98.4	99.9	100	100	22.1	99.9	3.5	89.5
Valley Creek	16.3	26.5	65.8	85.1	98.1	99.4	99.8	25.2	98.1	2.9	49.8
Eggers Creek	13.7	22.4	52.5	66.3	80.2	89.9	96.1	21.9	78.4	6.1	56.7
Little Slate Creek	5.9	10.4	35.2	54.2	81.6	93.4	97.7	29.9	85.6	2.5	21.1
Lolo Creek	6.5	11.4	37.5	56.4	83.0	95.2	98.5	30.3	87.5	2.9	25.8
Main Fork Red River	17.9	27.7	65.3	82.3	96.3	99.3	99.8	27.0	96.9	3.8	57.3
Rapid River	16.6	26.3	64.6	82.4	94.9	97.8	99.2	23.2	94.4	3.5	54.9
South Fork Red River	15.0	23.3	56.5	74.1	91.6	97.5	99.2	25.8	92.0	2.8	42.3
Average	26.8	38.0	72.2	85.8	95.8	98.5	99.5	25.0	96.2	3.3	61.5

[a] Values equal to or greater than 99.95 are entered as 100.0.
[b] Bolded values are for the 1.5 year recurrence discharge, used as an estimate for bankfull discharge.

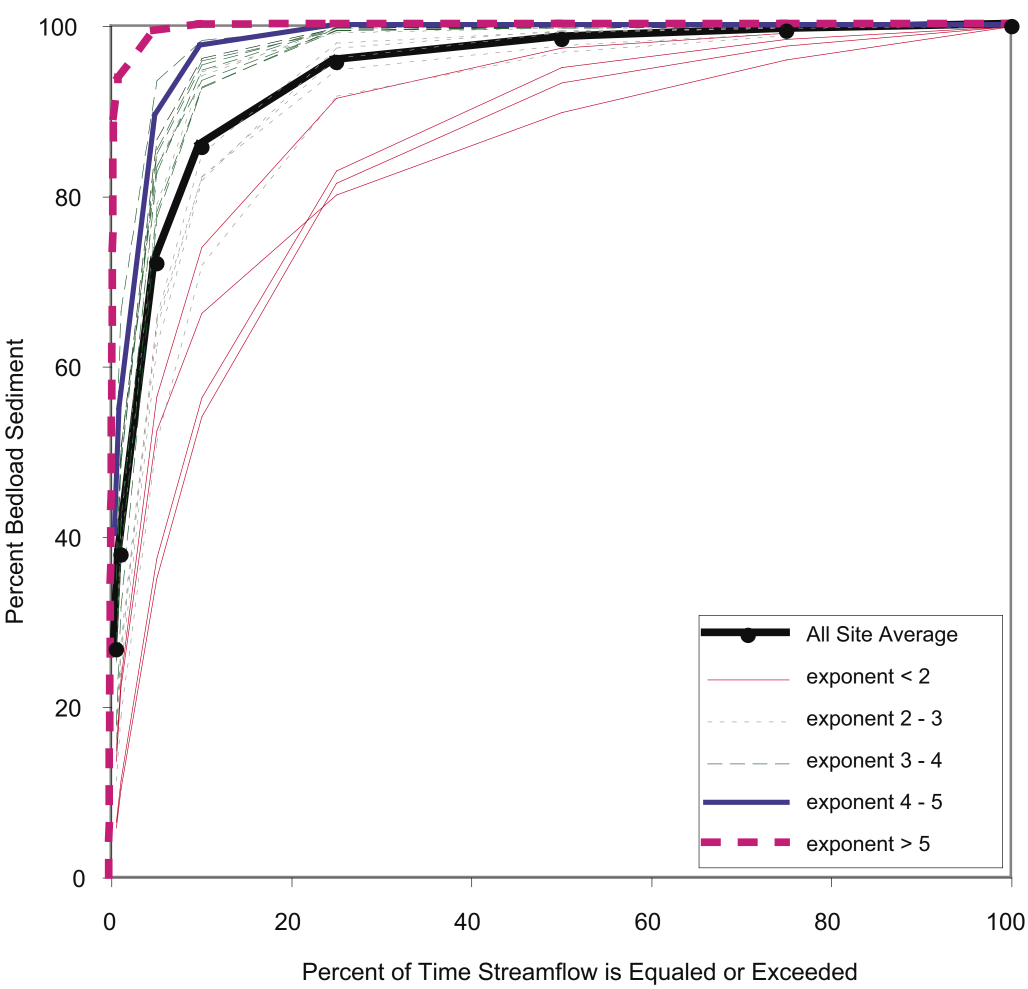

Figure 14. Bedload sediment duration curves for selected study sites.

with Leopold's (1994) observation that in many streams bedload transport begins at discharges greater than the average annual discharge.

The size of bedload material being transported also increases with discharge. The largest particle in the bedload sample increased with increasing discharge at all 24 of the study sites where such information is available (see figure 8 example). A power curve fit of the largest particle size-discharge pairs of data resulted in significant positive relationships ($r^2 = 0.37$-0.75) for all but one site, Lolo Creek ($r^2 = 0.05$) (table 10). The size of the largest particle in the bedload samples ranged from 22 mm to 83 mm for sites where the 76.2 mm square orifice Helley-Smith sampler was used and up to 128 mm and 141 mm at the two sites where the 152.4 mm square orifice sampler was occasionally used at higher discharges. The size of the sampler orifice may have limited measurement of large particles in transport at many of the sites. Additionally, the short sampling times at any given location along the sampling transect and the episodic nature of bedload transport reduce the likelihood of capturing large particles that may be occasionally in transport. Thus, the largest particle in the bedload sample may be much smaller than the largest particle being transported across the sampling transect during any measurement. The bedload sediment size class data for most sites also indicate that the larger size classes generally appear in the bedload samples associated with the higher discharges.

The results of the painted rock and bedload trap studies and the observations of the size of recently moved particles at selected sites all support a hypothesis of transport of coarse material making up much of the channel bed during high but relatively frequently occurring discharges. At the 10 sites where movement of painted rocks was monitored during the snowmelt runoff in 1995, instantaneous peak discharges ranged from 1.26 to 2.12 Q_b. At nine of the 10 sites the largest transported particle was the size of the D_{83} to D_{95} of the bed surface material and for one site it was the size of the D_{71} of the bed surface material. The largest particle observed to have recently moved during the 1997 snowmelt runoff ranged from the D_{85} up to the D_{100} of the bed surface material. At these 11 sites, instantaneous peak discharges ranged from 1.75 to $2.46Q_b$. At the two Red River study sites, the largest particles captured in the bedload traps represent the D_{44} and D_{54} of the surface bed material. Discharges during the 1997 spring snowmelt evaluation period at the Red River study sites were $1.2Q_b$ and $1.6Q_b$, respectively. These observations and measurements of transport of coarse material, coupled with conservative estimates of the largest material in transport in the bedload samples, suggest that at most sites coarse material, often about the median size of the bed material, is in transport at discharges near or slightly above bankfull discharge. This is in general agreement with the findings of others. Andrews (1984) found that in 24 coarse-bed Colorado streams the median diameter particle of the bed surface was entrained by discharges equal to or less than bankfull discharge. Particles as large as the D_{90} were entrained by bankfull discharge. Ryan and Troendle (1996) report that transport of the full range of particle sizes on the bed (up to the limits of the sampler) begins between 0.7 and 1.0 of bankfull discharge for a coarse-bed stream in Colorado.

At most sites, the median diameter of the bedload sample increases with discharge, but the relationship is much weaker than that between the largest particle and discharge (table 10). A power curve fit to the median diameter-discharge pairs of data resulted in significant positive relationships ($r^2 = 0.08$ to 0.52) at 24 of the study sites. The power curve relationship was not significant at six of the study sites.

Sand-size material is the major component of the bedload sediment. At 23 sites the predicted transport rate of the sand size particles (0.5-2 mm) is larger than predicted transport rates for all other size classes (<0.5, 2-8, 8-32, >32 mm) across the range of sampled discharges. At the remaining sites, the predicted sand transport rate is greatest up to some discharge, and then the transport rate of larger material becomes greater. To provide additional perspective on sediment sizes in transport, we include in table 10 the largest median diameter, the percentage of bedload samples with median diameters larger than sand (2 mm), and the corresponding minimum discharge, expressed as a ratio of bankfull discharge, when median diameters exceed 2 mm. For example, for bedload samples collected at the Selway River study site, while the largest median diameter was 55.0 mm, only 2.8 percent of the samples (two out of 72) had median diameters exceeding 2 mm and these occurred at or above discharges of $1.61Q_b$.

Summary

The web site spreadsheets and documents that accompany this report provide sediment transport and related data for 33 coarse-bed streams and rivers in Idaho. These sites span a large range of drainage areas, average annual runoffs, channel sizes, channel gradients, and substrate sizes. Our primary purpose is to make these data available to potential users.

Table 10. Information on size of bedload material for the study sites.

Study site	Largest particle			Median diameter					Particle size class with the largest transport rate
	Power eqn.[a] r^2	Trend[b]	Diameter b-axis[c] mm	Power eqn. r^2	Trend[b]	Largest median mm	Percent of samples with median >2 mm	Q/Q_b or $Q/Q_{1.5}$ ratio[d]	
Big Wood River	0.63	+	79	0.08	+	40.7	35.0	$0.29Q_{1.5}$	0.5-2 mm up to ~$1.25Q_{1.5}$; 8-32 mm and >32 mm at >$1.25Q_{1.5}$[e]
Blackmare Creek	nm		32-64	0.01	+[ns]	4.0	5.6	0.08	0.5-2 mm at all discharges
Boise River	0.37	+	62	0.05	+[ns]	35.8	2.4	0.96	0.5-2 mm at all discharges
Dollar Creek	nm		16-32	0.14	+	2.0	0		0.5-2 mm at all discharges
Johnson Creek	0.69	+	55	0.33	+	4.6	5.6	0.35	0.5-2 mm at all discharges
Little Buckhorn Creek	nm		8-16	0.13	+	1.9	0		0.5-2 mm at all discharges
Lochsa River	0.68	+	45	0.08	+[ns]	3.0	2.8	0.43	0.5-2 mm at all discharges
Middle Fork Salmon River	0.70	+	83	0.16	+	43.7	51.6	0.71 $Q_{1.5}$	0.5-2 mm up to ~0.71 $Q_{1.5}$; 8-32 mm and >32 mm at >$1.10Q_{1.5}$
North Fork Clearwater River	0.64	+	74	0.32	+	19.9	6.9	0.56	0.5-2 mm at all discharges
Salmon River nr Obsidian	0.40	+	72	0.29	+	10.6	38.0	0.90 $Q_{1.5}$	0.5-2 mm at all discharges
Salmon River nr Shoup	0.72	+	78	0.25	+	48.5	63.9	1.00 $Q_{1.5}$	8-32 mm and >32 mm at >$0.82Q_{1.5}$[f]
Salmon River bl Yankee Fork	nm		32-64	0.33	+	38.9	21.7	0.33 $Q_{1.5}$	0.5-2 mm up to ~$0.69Q_{1.5}$; 8-32 mm and >32 mm at >$0.79Q_{1.5}$
Selway River	0.75	+	82	0.29	+	55.0	2.8	1.61	0.5-2 mm at all discharges
South Fork Payette River	0.71	+	128	0.17	+	63.8	16.7	0.24	0.5-2 mm at all discharges
South Fork Salmon River	0.48	+	27	0.13	+	2.3	1.5	0.77	0.5-2 mm at all discharges
Squaw Creek (USGS)	0.73	+	66.5	0.25	+	10.3	8.7	0.64	0.5-2 mm at all discharges
Thompson Creek	0.75	+	68.5	0.20	+	7.1	2.4	0.31	0.5-2 mm at all discharges
Valley Creek	0.59	+	141	0.12	+	18.5	34.5	0.26	0.5-2 mm up to ~$1.29Q_b$; 2-8 mm >1.29 Q_b
West Fork Buckhorn Creek	nm		16-32	0.11	+	2.5	14.1	0.20	0.5-2 mm at all discharges
Cat Spur Creek	nm		25				18.0	0.17	<2 mm[g]
Hawley Creek	nm		32-64	0.12	+	9.8	12.9	0.39	0.5-2 mm at all discharges
Johns Creek	0.27	+	22	0.01	-[ns]	5.3	3.6	2.00	0.5-2 mm at all discharges
Little Slate Creek	0.46	+	30	0.05	+[ns]	17.5	1.7	0.43	0.5-2 mm at all discharges
Lolo Creek	0.05	+[ns]	55	0.00	-[ns]	10.2	14.3	0.16	0.5-2 mm at all discharge[h]
Main Fork Red River	0.53	+	60	0.17	+	38.9	5.7	0.08	0.5-2 mm at all discharges
Rapid River	0.42	+	62	0.16	+	37.2	20.5	0.09	0.5-2 mm up to ~$0.64Q_b$; >32 mm at >$0.64Q_b$
South Fork Red River	0.70	+	49	0.26	+	3.2	5.9	0.31	0.5-2 mm at all discharges
Squaw Creek (USFS)	nm		64-128	0.34	+	5.9	9.7	0.50	0.5-2 mm up to ~2.27 Q_b; 2-8 mm >2.27 Q_b
Trapper Creek	0.63	+	41	0.33	+	3.7	3.5	0.29	0.5-2 mm at all discharges
Fourth of July Creek	0.75	+	40	0.52	+	3.1	5.1	0.45	0.5-2 mm at all discharges
Herd Creek	0.70	+	60.5	0.41	+	9.7	19.4	0.09	0.5-2 mm up to ~$1.30Q_b$; 2-8 mm >$1.30Q_b$
Marsh Creek	0.59	+	66	0.18	+	23.4	38.8	0.13	0.5-2 mm at all discharges

[a] nm = largest particle not measured at this study site.
[b] + represents a trend of increasing size with discharge; - represents a trend of decreasing size with discharge; ns = not significant at alpha = 0.01.
[c] At study sites where the largest particle diameter was not measured, the largest size class represented in the samples is shown.
[d] Ratio of the lowest discharge to either bankfull or the 1.5 year recurrence discharge when the median diameter of a bedload sample was >2 mm.
[e] A few exceptions occur at lower discharges; refer to web-site data files and graphs.
[f] Only two of the 61 bedload samples were at discharges < $Q_{1.5}$.
[g] Limited data and a few exceptions occur.
[h] A few exceptions occur; refer to web-site data files and graphs.

Streamflow at all of the study sites is dominated by the melting of snow and flows typically peak in April, May, or June. Average annual runoff for the study watersheds ranges from 3.7 to 36.3 inches in response to large differences in average annual precipitation. Average annual discharge averages 0.21 of bankfull discharge (range 0.11-0.40). The bankfull discharge for most of these sites is a relatively frequent event with an average recurrence frequency of about 1.5 years.

Since a significant snowpack develops at all of these sites, a large proportion of the annual runoff occurs during a relatively short period of time, typically during the spring and early summer. Discharges equal to or larger than the bankfull discharge, on average, occur 3.3 percent of the time (12.1 days/year) and account for 19.7 percent of the annual streamflow. Discharges less than the average annual discharge, on average, occur 75.0 percent of the time (273.9 days per year) and account for 31.6 percent of the annual streamflow. The remaining 48.7 percent of the streamflow is associated with discharges between Q_a and Q_b that, on average, occur 21.7 percent of the time (79.3 days per year).

Bankfull discharge increases with increasing drainage area and average annual precipitation. Width, average depth, average velocity, and gradient at bankfull discharge are strongly related to both bankfull discharge and drainage area. However, bankfull discharge is the better predictor since it incorporates differences in precipitation inputs not reflected in drainage area.

The channel bed at all the study reaches is armored. The D_{50} of the surface material was larger than the subsurface material and the ratio of the surface to subsurface median diameters ranged from 1.9 to 7.2 indicating the presence of an armor layer. Armoring has been linked to sediment supply being less than the ability of the stream to transport that load (Dietrich and others 1989).

Both bedload and suspended sediment transport increases with stream discharge. The relationships between sediment transport and discharge using the log-log model (equation 1) resulted in statistically significant (alpha=0.01) models for all sites for both total bedload and suspended sediment transport. The exponents in the power function form of the model (equation 2) exhibit a very wide range from 1.489 to 5.749 (average 2.711) for total bedload transport and 1.362 to 3.997 (average 2.289) for suspended sediment transport. Emmett and Wolman (2001) state that a principal factor influencing the value of the exponent in the bedload transport equation is sediment supply limitation due to both the availability and mobility of bed material. They suggest that supply limitations can occur due to a streambed armor layer of large particles and that large bedload transport rates cannot occur until the armor layer is disturbed.

At most sites, the suspended sediment transport is larger than the bedload transport over the entire range of discharges when sediment transport was measured. At bankfull discharge, suspended sediment transport makes up the majority of the sediment load for all but five study sites. In general, as watershed size increases, suspended sediment accounts for an increasing percentage of the total sediment in transport.

The value of the exponent in the sediment transport power equations exerts much control over the range of flows most responsible for sediment transport. As the exponent increases, a larger proportion of the sediment load is associated with higher discharges that occur a smaller portion of the time. On average, discharges equal to or larger than bankfull discharge transport 61.5 percent of the bedload sediment. Discharges less than average annual discharge only transport about 3.8 percent of the bedload sediment. The remaining 34.7 percent of the bedload is transported by discharges between average annual discharge and bankfull discharge.

The size of bedload material being transported also increases with discharge. At all sites where the largest particle in the bedload sample was measured, there was a positive relationship between particle size and discharge. At most sites there was also a positive relationship between the median size of the bedload sample and discharge; however, these relationships were often very weak. Sand size material is a major component of the bedload sediment and at 23 of the study sites the transport rate of the sand is larger than rates for any other size class across all measured discharges. This is in agreement with Leopold's (1992) observation for gravel-bed streams that the largest portion of the bedload is sand.

Observations and measurements of transport of coarse material using painted rocks and bedload traps and the measurements of the largest particle in the bedload samples suggest that at most sites coarse material (often about the median size of the bed material) is moved at discharges near or slightly above bankfull discharge. This is in general agreement with the findings of others (Andrews 1984; Ryan and Troendle 1996).

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