Field verification of predictive bedload formulas in a coarse bedload mountain stream
by Nicholas Bugosh

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Earth Sciences
Montana State University

Abstract:
Field verification of the applicability of bedload predictive formulas to coarse-bedload high-gradient mountain streams has received relatively little study as compared to similar work in sand bed streams. This study attempted to verify the applicability of two types of predictive bedload formulas, a discharge type and a tractive force type, to Squaw Creek, a coarse bedload high-gradient mountain stream. The Schoklitsch (1934) formula was chosen as a discharge type and the Meyer-Peter and Muller (1948) formula was selected as a tractive force type. The predictions of these formulas were also compared to predictions generated from Bagnold's simple theoretical expression for unit stream power.

Discharge, water surface slope, bed slope, water density, bedload particle size and bedload quantity were measured instantaneously during the 1983 and 1984 bedload transport events. A technique, which proved very successful, was developed for simultaneously measuring water surface and bed slope. The appropriate parameters were substituted into the formulas and the resulting predicted quantity of bedload was compared to the quantity actually measured in the stream. Field observations of channel features and changes in channel morphology were made to enable explanations for any variance between predictions and measurements.

The catastrophic dispersal of an old log jam in the study reach was observed and recorded during the 1983 bedload event. The dispersal of this log jam and the resulting instantaneous changes in stream power parameters had greater effect on bedload in Squaw Creek than any other parameter studied. Approximately 730 metric tons of bedload passed through the study reach during the twenty-three day 1983 bedload event. Thirty percent of this bedload moved in a three day period and is directly attributable to the burst of the log jam.

The Schoklitsch formula predictions were closest to measured values. The complex Meyer-Peter and Muller formula yielded predictions very similar to those of the simple stream power expression. The formulas overpredicted bedload in Squaw Creek by approximately two orders of magnitude. One order of magnitude of the overprediction can be attributed to sampling and analysis error. The remaining order of magnitude overprediction is attributed to the formulas' inability to account for variance in sediment supply, sediment storage and spatial and temporal variations in bedload transport in a high-gradient coarse-bedload stream.

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APPROVAL

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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June 10, 1988
Date

Henry L Parsons
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Date May 18, 1988

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ABSTRACT

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CHAPTER 1

INTRODUCTION

Purpose and Scope

Coarse bedload in high-gradient (slope(S) >0.01) mountain streams has received little study (McPherson, 1970; Hollingshead, 1971; Milhous and Klingeman, 1973; Nanson, 1974; Laronne and Carson, 1976; Ackers and White, 1980; Parker, Klingeman and McClean, 1982; Custer and others, 1987; Reid and Frostick, 1987) as compared to bedload in sand-bed streams. Although others have studied bedload, their works have been largely confined to sand-sized particles in flumes and low-gradient streams. These workers have proposed many theories to describe bedload, as well as theoretical and empirical formulas to predict quantity of bedload a stream is capable of transporting. Verification of the applicability of this groundwork to coarse (gravel through boulder) sediment, high-gradient streams has only begun in earnest by a few workers in the last two decades (Shulits and Hill, 1968; White, Milli and Crabbe, 1975). The apparent neglect is due in part to sampling difficulties. The tremendous stream power necessary to transport pebble, cobble, and boulder size particles makes sediment sampling extremely difficult and hazardous (Novak, 1957; Hubbell, 1964).

The purpose of this work is to: (1) measure stream power parameters in a high-gradient coarse bedload stream; (2) measure quantity of bedload; (3) attempt to verify applicability of some existing bedload transport formulas to such a stream; and (4) to offer explanations for variance between the predicted bedload and measured bedload to serve as the basis for further refinement of these models.

Site

Squaw Creek is a major tributary of the West Gallatin River, one of three headwater streams (West Gallatin River, Jefferson River, Madison River) which converge to form the Missouri River. The study site is in Gallatin County, Montana about 38.4 kilometers south of Bozeman (Figure 1). The study site is at the confluence of Squaw Creek and the West Gallatin River (latitude 45°26'28" N, longitude 111°13'20" W, in SE 1/4, Sec. 33, T.4 S., R.4 E., Montana) in hydrologic unit 10-02-00-08. Table 1 summarizes some of the quantifiable physiographic and hydrologic characteristics of the area.

Climate and Vegetation

The climate is typical of sub-alpine to alpine areas at high latitudes. Snow cover is intact most of the year with mid-June through late October being clear of snow in most of the lower part of the basin. Precipitation averages 81.8 centimeters (cm) for the drainage. The mean basin altitude is 2,268 meters. The great relief, as well as the northern and southern exposures, contribute to great variety in vegetative types. The basin is mostly heavy forest, but large areas with southern exposures support mainly sagebrush and juniper. The forest types vary from aspen in the foothills to Douglas

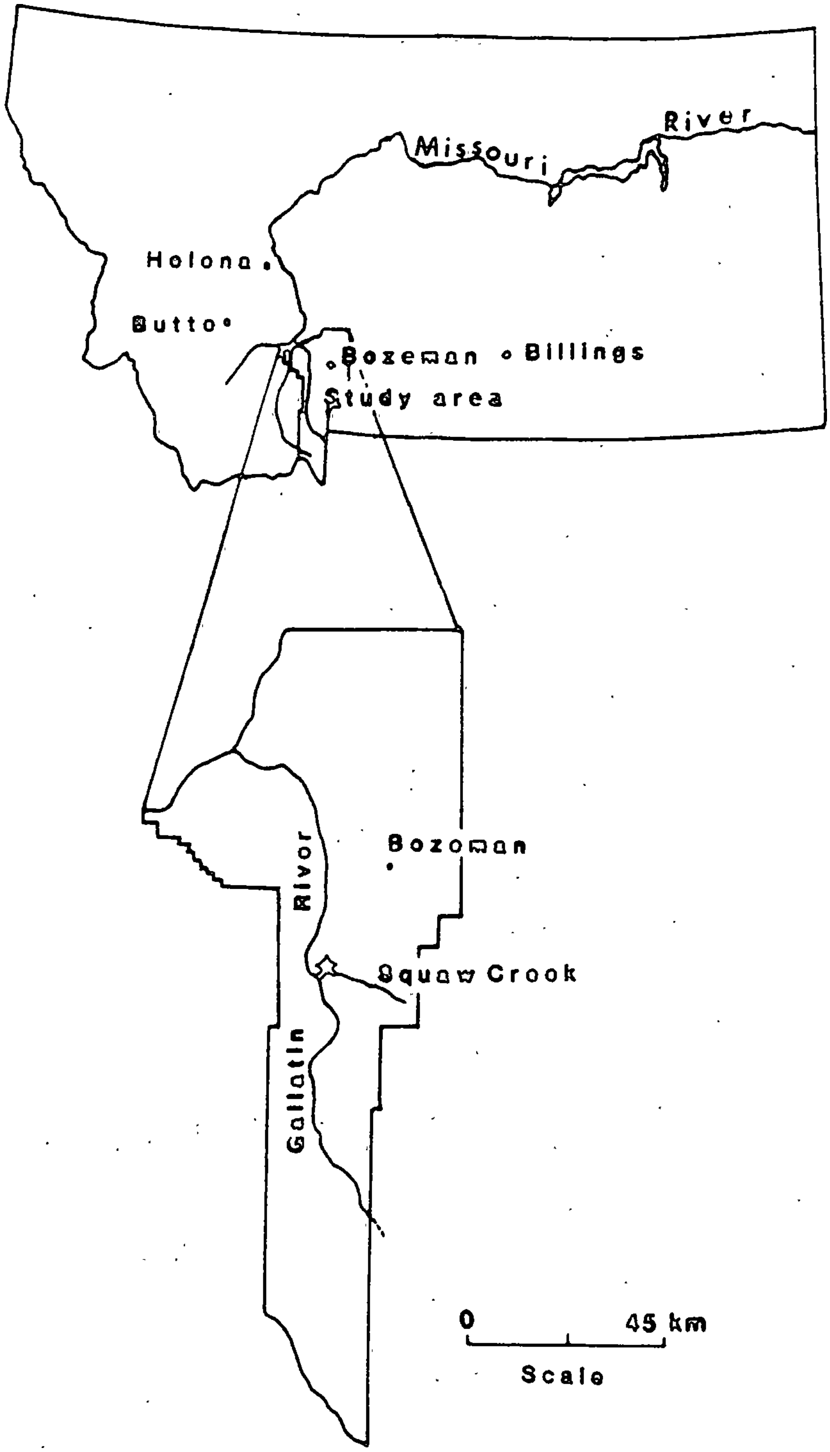

Figure 1. Location map of study area, Squaw Creek, Gallatin County, Montana. The study location is represented by the star.

fir in the sub-alpine zones to Engleman spruce. Typical forest understory plants are blue huckleberry and grouse whortleberry.

Table 1. Physiographic and hydrologic characteristics of Squaw Creek study site.

Drainage basin area	105.7 square kilometers (km^2) (40.4 square miles (mi^2))
Relief	1520.0 meters (m) (4.987 feet (ft))
Mean basin slope	25.0°
Stream order (Strahler)	4, based on U.S.G.S. topographic quadrangle
Total stream length	103.6 kilometers (km) (64.4 mi)
Main channel length	22.0 km (13.7 mi)
Mean particle size (d_{50}) armor	94 millimeters (mm) (Dunne and Leopold, 1978)
Mean particle size (d_{50}) bar	43.3 mm (Folk, 1980)
Mean particle size (d_{50}) bedload (76.2 mm H-S)	8.5 mm (average 1983 and 1984) (Folk, 1980)
Pcp (snow)	45.7 centimeters (cm) (18.0 in)
Pcp (rain)	35.6 cm (14.0 in)
Bankful discharge ($Q_{1.5}$)	5 cubic meters per second (m^3/s) (176.55 ft^3/s)
Width ($Q_{1.5}$)	8.6 m (28.2 ft)
Depth ($Q_{1.5}$)	0.3 m (1.0 ft)
Lag time (snow melt)	7 hours (hr) (peak arrives at site 20:00 hr)
Lag time (rain)	1.5 hr
Q average annual flow	1.1 m^3/s (38.7 cubic feet per second) (ft^3/s)
Q peak flow 1959-1975	8.5 m^3/s (298.3 ft^3/s)

Hydrologic Characteristics

Table 1 gives some of the quantifiable hydrologic characteristics of Squaw Creek. Some qualitative description of Squaw Creek is appropriate because it is the very nature of high gradient mountain streams which has both limited the amount of research done on them and frustrated successful application of many bedload formulas to them.

Most of the year Squaw Creek is a calm, clear mountain stream moving little, if any, sediment load. Through most of the water year it is about 0.3 m deep and 7.62 m wide at the study reach. The bed is a jumble of boulders, cobbles, pebbles, sand, beaver dams and log jams. Squaw Creek flows, in its 22.0 km length, from greater than 3,048 m above mean sea level at the head of the basin to 1,676 m at the mouth. Each spring from about mid-May to mid-June the character of the stream changes suddenly.

As the warm days melt the snowpack, discharge increases dramatically - two to threefold in a 48-hour period. For example, from 24-26 May, 1983 discharge on the rising limb of the hydrograph rose from 2.0 to 5.0 m^3/s. Flow over the boulder and cobble strewn bed becomes extremely turbulent and, though less than 0.6 m deep, it becomes unwadable. Due to the very steep slope, the discharges present are capable of transporting the cobble and boulder size bed material. The author has witnessed cobbles (approximately 150 mm in diameter) bouncing 0.3 m above the water surface! It is this high energy, explosive nature of high-gradient mountain streams that makes bedload sampling both difficult and hazardous.

CHAPTER 2

METHODS AND MATERIALS

Site Preparation

The study reach contains a United States Forest Service (U.S.F.S.) stream gaging station (Squaw Creek Bible Camp). The U.S.F.S. gaging station was used on a cooperative basis during the research. It consists of a staff gauge and a Leupold-Stevens Type F Model 68 recording stream gauge mounted on a stilling well. The station is located at a bridge which crosses Squaw Creek allowing access to the camp. Immediately upstream of this bridge a wooden plank catwalk was installed across the stream to provide a platform which allowed repeatable, safe, point measurements of the study parameters during peak discharge.

Stream Power Parameters

Velocity

Stream flow velocity was measured from the catwalk with a General Oceanics velocity meter at 0.6 stream depth (United States Department of the Interior, 1982). Discharge measurements thus obtained were compared with U.S.F.S. measurements, which at low flows were made on a waded channel traverse downstream of the bridge with a Scientific Instruments Price AA current meter. During peak flow U.S.F.S.

measurements were made off the bridge with a current meter attached to a 75 pound Columbus weight suspended by cable, in accordance with standard hydrometric procedure (United States Department of the Interior, 1982).

Water Density

Water density was estimated using temperature and suspended sediment. Water temperature was taken using a hand-held mercury thermometer. Suspended sediment load was measured from the catwalk at 10 evenly spaced intervals using a hand-held DH-48 sampler (United States Department of the Interior, 1982). The sampler was dipped into the flow at each measurement point so that a cross-sectionally integrated sample representative of total suspended sediment transport was obtained. The water temperature was converted to pure water density using data tables (Weast and others, 1967). The suspended load (mg/l) was added to the pure water density to obtain the water density in the stream.

Slope

Bedslope and water surface slope were measured simultaneously (Figure 2). Stakes were driven into the right and left banks upstream of the bridge and also into the heavy bridge abutments at either end of the catwalk. Nylon cords were stretched taut across the stream at these two traverses. Leveling of the lines in 1983 was initially done with a Brunton hand-transit (compass). The compass was used because a catastrophic bedload event occurred during set-up and rapid installation was necessary to measure the passing event. The lines were later resurveyed horizontal by plane table and earlier measurements were adjusted to fit the more accurate survey. Nylon was chosen because of its stability in changing moisture conditions once the initial stretch is taken out. These lines provided fixed horizontal datum to which distance-to-bed and distance-to-water surface measurements could easily be made using a measuring stick. The measuring stick is placed into the stream and down to the bed perpendicular to the nylon datum line and water and bed surfaces. The distance from the bed and water surface to the datum line can be read simultaneously. While upstream measurements had to be made by wading, due to a lack of funds to construct another catwalk, the downstream measurements could be made from the catwalk at the bridge. The bed and water surface elevations (y_1 and y_2) and the distance between nylon datum lines (x) allowed easy calculation of bed and water surface slope ($S=y_2-y_1/x$). The slope measurements were taken at five longitudinal profiles along the channel. A similar method has also been used successfully by Bridge and Jarvis (1982).

Water surface slope measurements were checked using a water level method (Figure 3). Flexible plastic tubing, 7.9 m long and 1.6 cm diameter, was placed in the stream longitudinally and allowed to fill with water. The upstream end of the tube was then raised until its meniscus (x_1) was level with the water surface. The downstream end of the tube was then also raised vertically. Due to atmospheric pressure the meniscus at the downstream end of the tube (x_2) will rise to the same level as the upstream meniscus. The distance from the downstream meniscus to the water surface (y_2-y_1) is then measured as is the