MORPHOLOGY OF HIGH GRADIENT STREAMS AT DIFFERENT SPATIAL SCALES, WESTERN CASCADES, OREGON

Gordon E. Grant

U.S. Forest Service
Pacific Northwest Research Station
3200 Jefferson Way
Corvallis, Oregon 97331 U.S.A.

Abstract

The channel and valley-floor morphology of high-gradient streams is commonly expressed at several spatial scales. In this paper, a taxonomy of channel and valley floor features is proposed to improve understanding of processes and landforms in steep streams and to provide a common framework for stream descriptions. This taxonomy is based on field studies in two streams draining the western slopes of the Cascade Range in Oregon, U.S.A. At the finest scale (10^{-1} - 10^{0} channel widths), step-pool sequences formed by large boulders oriented transverse to the channel axis dominate channel structure; these features appear to form in response to flow perturbations such as antidunes during bedload transport events. An important scale from the standpoint of hydraulics and sediment transport is the channel unit scale (10^{0} - 10^{1} channel widths). Pool, riffle, rapid, and cascade channel units (in order of increasing bed slope) have non-overlapping slope ranges and particle sizes, and can be distinguished in the field based on hydraulic criteria and step structure. Channel units display non-random sequence and spacing in response to both fluvial mechanisms and exogenous controls, such as bedrock or source areas for large boulders along the channel margin. Formation of channel units is poorly understood but may be a steep stream analog to bar formation.

Distinctive channel and valley floor morphology is also expressed at the reach scale (10^{2} - 10^{3} channel widths). Reach structure varies in response to the degree of constraint imposed by large-scale landslides, resistant bedrock, or alluvial fans. The ratio of valley floor width to active channel width is an important index for distinguishing the organization of channels at this scale. Recognition of these varying scales is important for understanding longitudinal variations in sediment transport and storage, stratifying research sampling, designing effective measures for erosion control, and analyzing the structure of biological communities.

Introduction

Increasing land use in mountainous areas in both developed and undeveloped countries has prompted investigations of high-gradient streams, i.e. those with bed slopes greater than 2%. These streams differ from lowland streams in several important respects. Hydraulics of high gradient streams are strongly affected by large boulders and woody debris which create bed roughness on the same scale as channel depth or even width, leading to high energy losses, upper regime flow, and disrupted velocity profiles. Lowland channels, in contrast, have roughness due primarily to bedforms and bars, and hydraulics characterized by lower regime flow (Bathurst 1978). Interactions between hillslopes and channels in mountain streams influence stream and valley morphology; sediment transport is intimately linked with hillslope processes in terms of both supply rate and delivery mechanisms. Non-fluvial emplacement of bed material by landslides and debris flows results in channels containing bed particles which resist transport; consequently, geomorphically effective events from the standpoint of both sediment transport and channel structure occur infrequently (Scott and Gravlee, 1968; Nolan and others, 1987; Hayward, 1980; Grant, 1986; Best and Keller, 1986). In contrast, lowland streams are often separated from valley walls by extensive floodplains and terraces and geomorphically effective events occur relatively frequently (Pickup and Warner, 1976; Wolman and Gerson, 1978).

There has been comparatively little research on channel morphology of high-gradient mountain streams. In the United States, population centers are generally far removed from mountainous areas and, until recently, there has been little impetus to study erosion processes in steep channels. Over the past twenty years, however, intensive utilization of mountain areas for timber, recreation, hydroelectric power, and municipal water, and concern over degradation of fisheries and wildlife habitats has focussed the need to analyze structure and processes in high-gradient streams. Researchers in the U.S. have emphasized field measurements of stream morphology in natural channels, as exemplified by several recent studies (Bathurst, 1987; Hayward, 1980; Grant and others, in review).

In Japan, steep boulder-bed streams are commonly called 'torrential bed channels'. Their proximity to densely populated areas has resulted in loss of life and property when floods and debris flows sweep down these channels. While the need to understand dynamics of steep streams is pressing, extensive modification of channels by sabo engineering and control structures has made it difficult for Japanese scientists to examine morphology of streams in their natural state. Notable exceptions to this are the work of Sawada and others (1983, 1985) and Ashida and others (1981) at Ashiaraidani basin in the Japan Alps and investigations of steep stream processes on Hokkaido by several researchers (Nakamura, 1986; Nakamura and others, 1987; Kishi and others, 1987). Most Japanese researchers have emphasized flume studies (Ashida and others, 1976; 1984; 1985; 1986 a, b; Haseguawa, 1988) while only a few comparable flume studies have been reported in the English literature (Judd and Peterson, 1969; Whittaker and Jaeggi, 1982; Bathurst and others, 1983).

Progress in investigating high-gradient streams has been hindered by lack of a sound conceptual framework for analyzing stream morphology. What is needed in part is a taxonomy of morphologic features that can be used to classify stream structure, characterize changes in stream morphology in response to floods, debris flows, and landslides, and analyze morphogenetic processes in steep channels. Stream morphology can be viewed as being hierarchically organized (Frissell and others, 1986; Kishi and others, 1987; Grant and others, in review) and this concept has been employed to classify streams from an ecological perspective (Kani, 1944, 1981; Mizuno and Kawanabe, 1981).

In this paper, I present a topographic classification system for bed features and valley floor landforms at several spatial scales, drawing on field studies from two streams located in the Western Cascade Range of Oregon, U.S.A. Recognition of these varying scales is important for understanding longitudinal variations in sediment transport and storage, stratifying research sampling, designing effective measures for erosion control and analyzing the structure of biological communities.

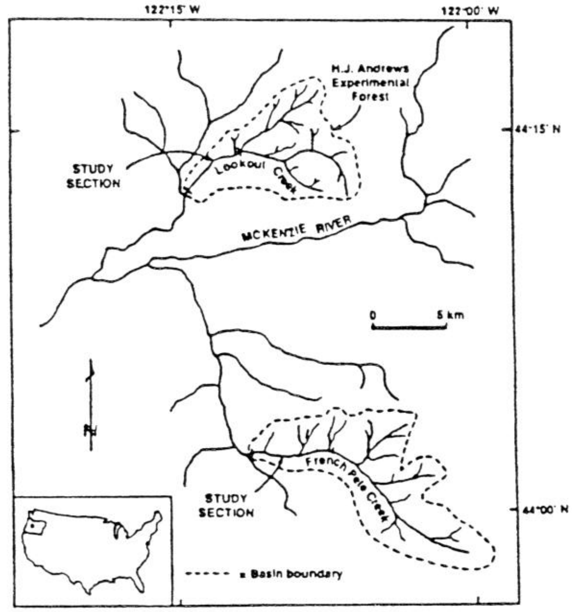

Fig. 1. Location of Lookout and French Pete Creek study reaches.

Description of streams studied

The two streams studied, Lookout Creek (LOC) and French Pete Creek (FPC), are located within the western Cascade physiographic province, a deeply-dissected terrain underlain by volcanic rocks of late Oligocene to late Pliocene age (Fig 1). Both streams flow through west-trending, steeply-walled valleys (hillslope gradients greater than 70% are common), which are densely vegetated in mature (100-200 year old) and old-growth (>200 year old) Douglas fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*) with scattered western red cedars (*Thuja plicata*). Mean annual precipitation in the study area is approximately 2500 mm with most precipitation falling between November and April. A transient snow zone exists between 400 and 1500 m elevation and floods generally occur as a consequence of rapid snowpack melting during rain-on-snow events.

TABLE 1. DRAINAGE BASIN CHARACTERISTICS FOR THE TWO STUDY BASINS

	French Pete Creek	Lookout Creek
Drainage area (km^2)	83.4	67.6
Mean basin elevation (m)	1300	1200
Average channel gradient		
Entire basin (%)	4.3	3.8
Study section (%)	3.8	2.2
Average unvegetated channel width (m)	18.1	18.1
Mean annual discharge (m^3/s)	3.5	3.6
Median bed partical size (cm)	20	13

The two basins are comparable in size, elevation, and mean annual discharge; however, the gradient of the study reach in FPC is 1.7 times that of LOC (Table 1). FPC drains a virtually pristine basin while the LOC basin has been commercially harvested for timber over the past 40 years. Most of this activity, however, is concentrated on hillslopes away from the stream channel and has had minimal effect on stream morphology. Both streams experienced major channel changes, streamside landslides, and debris flows during the December 1964 flood, an event with an approximate 100-year recurrence interval (Waananen and others, 1971).

The beds of both study sections are very coarse and paved with cobbles and boulders up to 2 meters or greater in diameter. Bed material is derived from alluvial fans, bedrock, glacial deposits, and colluvium. Channels also contain abundant coarse woody debris distributed above, within, and alongside the high water channel (Harmon and others, 1986; Lienkaemper and Swanson, 1987).

Classification and characteristics of channel features

The longitudinal profile of mountain streams has a staircase-like structure apparent at several different scales, and conveniently expressed in terms of the channel width. At the finest scale, the channel is dominated by steps composed of the largest boulders in the stream interspersed with pools approximately 0.4 to 0.8 channel widths in length (Fig 2). Taken together, the steps and intervening pools create *step-pool sequences* (Whittaker and Jaeggi, 1982; Ashida and others 1984, 1986 a,b). Kishi and others (1987) refer to this scale of variation as the 'rib' scale, a term also used by others (McDonald and Bannerjee, 1971; Koster, 1978). This scale also corresponds to the 'Aa' type of channel defined by Kani (1944, 1981).

Step-pool sequences are, in turn, interspersed by larger pools, generally 1.0 to 4.0 channel widths in length (Fig 2). I have termed this the *channel unit* scale of variation; it corresponds to what Kishi and others (1987) term 'swells' and is similar to the Bb type of channel described by Kani (1944, 1981). Four different types of channel units can be distinguished based on their geometry, degree of step development and hydraulic characteristics; these are discussed in the section on channel units.

Lengths of stream channel 10^2 to 10^3 channel widths long are termed *reaches*. Reaches can be defined either by their longitudinal profile (steep versus gentle gradient), their planform morphology (wide or narrow valley floor in relation to channel width) or by the type of marginal constraint imposed by valley wall features (earthflow-constrained, bedrock-constrained, unconstrained, etc.). As discussed in the section on reaches, these factors are often inter-related.

Field work in the two Oregon streams has highlighted aspects of channel morphology at these various scales. Here, I examine these scales in detail to emphasize the distinctiveness of different levels in this spatial hierarchy and to explore linkages among scales.

Step-pool scale

This is perhaps the best recognized and most studied scale of organization of mountain streams and is best observed at low flow. Step-pools are formed by lines or ribs of boulders oriented transverse to the direction of flow; steps partially or fully span the low-flow channels, and some can be traced across adjacent unvegetated surfaces, as well. Steps are generally composed of several large boulders oriented with their long axes transverse to the flow

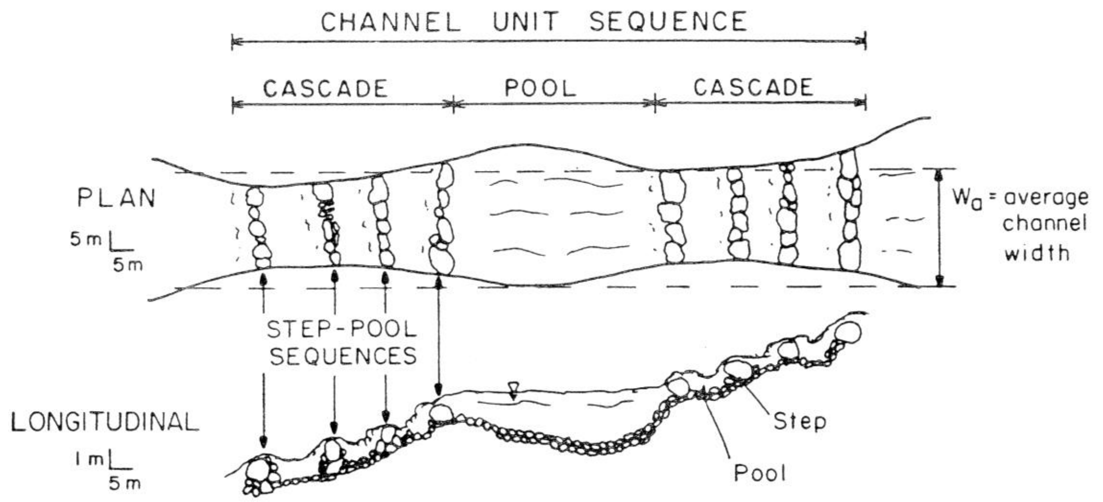

Fig. 2. Schematic diagram of channel morphology at the step-pool and channel unit scales.

direction and intermediate axes parallel to flow or gently dipping upstream at angles of 5 or less, so that the vertical rise of the step is approximately equal to the short axis. Smaller boulders and cobbles are imbricated against these larger framework boulders in a manner similar to cluster bedforms (Brayshaw, 1985).

Measurements of step height, inter-step distance, and intermediate diameters of the five largest boulders making up the step were made for 31 steps in four rapids and three cascades in both LOC and FPC. Step height is the difference between the average of 5 or more measurements of bed elevation taken immediately upstream and downstream of the step. Boulders creating steps were similar in size in all units sampled, averaging 1.1 m, which places them among the largest boulders in both streams. Step heights were also similar in all sites, ranging from 0.13 to 0.29 m, averaging 0.22 m. Consistency in step height appears to result from similarity in size and shape of particles forming steps. Inter-step spacing varies inversely with channel slope (Fig 3), a finding consistent with earlier work (Judd and Peterson, 1969; McDonald and Bannerjee, 1971; Koster, 1978; Hayward, 1980; Whittaker, 1987a). Control of step spacing by gradient can be explained in light of the similarity in size of particles creating steps. Since step height is constant, an increase in bed slope must result in closer-spaced steps over a given channel length if most of the drop is accounted for in steps.

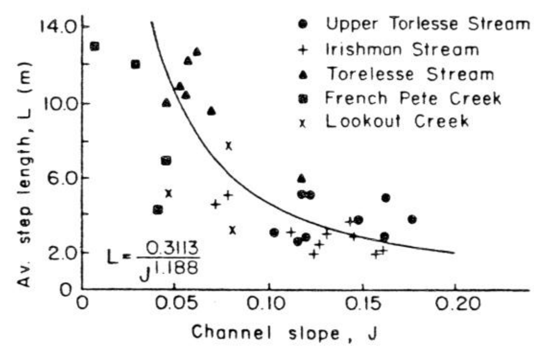

Fig. 3. Plot of step length versus channel slope; data points and curve for Torlesse and Irishman streams from Whittaker (1987).

Flume experiments have shown that steps form due to bed deformation in response to supercritical flow phenomena including antidunes (Ashida and others, 1984; 1985; 1986a,b; Kishi and others, 1987; Hasegawa, 1988) and hydraulic jumps (Whittaker and Jaeggi, 1982). Paleohydraulic reconstruction of discharges required to entrain the largest size particles in steps using the method of Costa (1983) confirms that flow conditions are near critical when incipient motion for step particles occur. Recurrence intervals for these flows for French Pete Creek vary from greater than 100 years to less than 1.5 years, but generally range from 5-10 years (Table 2). Thus, step-pools represent a type of 'relict bedform'

TABLE 2. CALCULATED HYDRAULIC VARIABLES AT INCIPIENT MOTION FOR STEP PARTICLES, FRENCH PETE CREEK

Unit Type	D_{84} (m)	Dmax (m)	R (m)	Qcrit (cms)	Recurrence Interval (years)	Froude Number
Cascade	0.9	2.4	1.6	250	>100	0.9
Cascade	0.3	2.2	0.7	60	3	1.3
Pool	0.6	1.2	1.1	80	6	0.9
Rapid	0.5	2.1	1.0	90	9	1.0
Rapid	0.3	1.2	0.6	30	<1.5	1.1
Rapid	0.5	1.2	1.0	110	21	1.0
Rapid	0.6	2.2	1.1	70	4	1.0

Abbreviations used: D_{84}: Size fraction for which 84% of bed particles are finer; Dmax: Size of maximum particle sampled; R: Calculated hydraulic radius at incipient motion of bed; Qcrit: Calculated critical discharge at incipient motion of bed.

(Allen, 1968) formed under low-frequency, high regime flows and stable under more moderate discharges.

Steps can also occur in high-gradient streams due to non-alluvial features, notably resistant bedrock outcrops and large woody debris. In small, headwater streams, logs and other debris oriented perpendicular to the channel can account for up to 80% of the total vertical change in elevation in a reach (Swanson and others, 1976; Keller, 1979).

Channel unit scale

High-gradient streams exhibit a characteristic variation of channel depth and gradient at the scale of one to several channel widths; channel units are regions of macroscopically uniform flow and form within this scale of variation (Fig 2). They are somewhat analogous to pool-and-riffle forms observed in low gradient streams (Leopold, Wolman, and Miller, 1964, p. 203-215; Keller and Melhorn, 1978) but differ in several important respects: they lack a well-defined association with alternate or point bars; they exhibit a broader range of forms; and their distribution within a stream is strongly affected by exogenous influences, such as the location of source areas for coarse sediment and bedrock.

Four major types of channel units can be identified, based on their hydraulic, geometric, and sedimentologic characteristics. Although channel units may define a continuum of bed features, individual unit types represent distinct modal tendencies within this continuum that are readily recognized and classified in the field. Criteria used to distinguish units in the field are as follows:

Pools are areas of sub-critical, tranquil flow with few small-scale hydraulic jumps or free-surface instabilities, and with high relative submergences (ratio of particle size D_{84} to flow depth h). At low-flow, width of pools is commonly greater at their downstream than upstream ends. Greatest depths in pools are commonly located just downstream of their upstream boundaries.

Riffles are areas of sub-critical flow modified by local free-surface instabilities and small hydraulic jumps over bed roughness elements. Water surface typically has a rippled appearance; depths are shallower, and velocities greater than in pools at low flow. While individual boulders or boulder clusters may be present, they are not organized into ribs. Only 5-10% of the water-surface area exhibits supercritical phenomena such as hydraulic jumps or standing waves at low flow.

Rapids are channel units distinguished from riffles on the basis of: (1) greater percentage of stream area (15-50%) in supercritical flow; (2) organization of boulders into step-pool sequences; and (3) steeper gradients. The planform of both riffles and rapids is generally straight, so upstream width equals downstream width.

Cascades are steep (average gradients of 6.4 and 5.2% in FPC and LOC, respectively) channel units comprised of well-defined step-pool sequences. Cascades have greater than 50% of stream area in supercritical flow. Flow in cascades tends to be convergent; the ratio of upstream to downstream active channel width was 1.3 and 1.4 in FPC and LOC, respectively.

Non-overlapping bed slope ranges for each type of unit indicated that slope breaks occur as discrete populations in both streams (Fig. 4). Although mean slopes of pools, rapids, and cascades differ significantly by site, 95% confidence limit bars show little or no overlap between sites, suggesting that unit-slope ranges are site-independent. On average, each unit type represents roughly a 2.5-fold increase in slope over the next lower gradient type. Average slopes for pools, rapids, and cascades are remarkably consistent with slope data for segments of ephemeral channels in the Dead Sea area as reported by Bowman (1977) (Fig. 4). He also

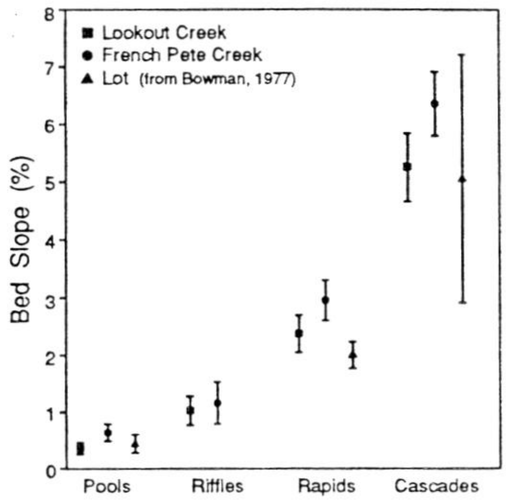

Fig. 4. Bed slope with 95% confidence limits for Lookout and French Pete Creek, Oregon and Lot basin, Israel.

showed that channel slopes in steep, coarse-bed stream channels occur as distinct populations, creating stepped-bed morphology.

Channel units also show distinctive particle size variations, although the contrast is stronger for French Pete Creek than Lookout Creek (Fig. 5). This may be due to the larger median size of all bed material in French Pete Creek than in Lookout Creek (Table 1). Since the largest material is preferentially deposited in steeper units (rapids and cascades), a higher proportion of large bed material in the creek will tend to accentuate the differences in particle size between low and high gradient units.

The origin of channel units is poorly understood. Kishi and others (1987) and Hasegawa (1988) attribute 'swell' formation to both antidunes and bars. Certainly, the scale of these features is much closer to bars than antidunes. Pool-to-pool spacings in LOC and FPC were examined to compare spacing of units in boulder bed streams with unit spacing observed in low gradient rivers where unit spacing is often determined by the frequency of bar formation. The data generally support the hypothesis of a tendency towards regular spacing, although spacing is less than the 5-7 channel widths that reported for low gradient streams (Keller and Melhorn, 1978). Frequency distributions of pool spacing in Lookout Creek, for example, peak between 2-4 active

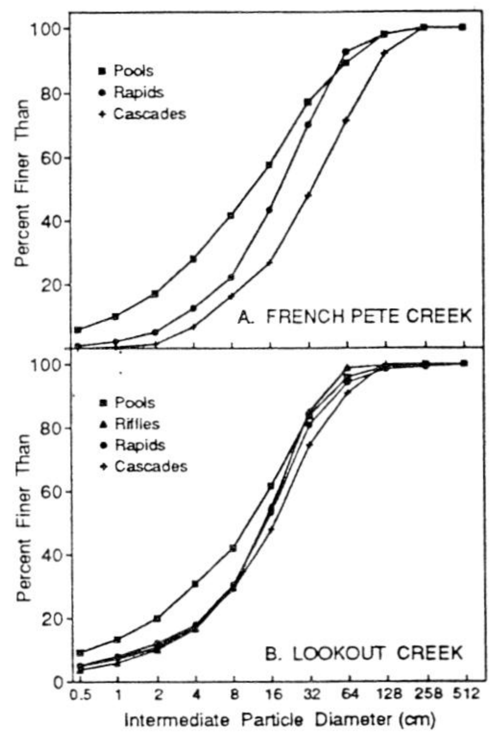

Fig. 5. Particle size distributions for French Pete and Lookout Creek channel units.

channel widths (mean = 4.0) (Fig. 6). Pool spacings are more irregular in FPC; frequency distributions are bimodal with a primary peak at 3 and a secondary peak at 6 channel widths, but inter-pool distances range as high as 45 channel widths. Some of this variability may result from uneven distribution of large roughness elements such as logs, bedrock, and boulders. These roughness elements often have lengths and diameters on the same scale as channel width and can thus restrict or induce unit formation at irregular intervals (Lisle, 1986).

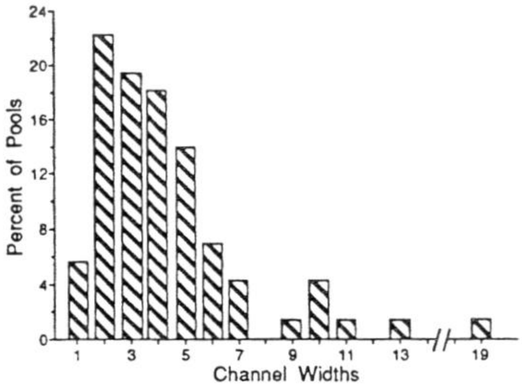

Fig. 6. Frequency distribution of pool-to-pool spacings, Lookout Creek.

Grant and others (in review) argue that unit formation may result from bunching of large particles during bedload transport events which, according to kinematic wave theory, will promote further deposition of large particles (Langbein and Leopold, 1968). Differences in the relative mobility of large and small particles within a mixture may also promote longitudinal sorting of bed particles (Iseya and Ikeda, 1987). Additional field and laboratory observations of bed morphology development under high transport conditions will be necessary to resolve unanswered questions of how stepped bed morphology arises at the channel unit scale.

Reach-scale characteristics

Step-pools and channel units comprise two levels of the spatial hierarchy. At the next broader level, these features are organized into a set of 'reach-types', defined by the type and degree of lateral constraint imposed open the channel by the valley walls (Fig. 7a). Reaches encompass both the active channel and surfaces, floodplains, and terraces lateral to the channel. They can be distinguished as *unconstrained* or *constrained* depending on whether the valley floor width index (VFWI), defined as the ratio of total valley floor width to active or high-water channel width, is greater or less than three (Fig 7b). Constrained reaches result where: 1) bedrock outcrops in the valley wall or along the channel margin; 2) active or dormant earthflows impinge directly on the channel; or 3) alluvial fans constructed on the valley floor restrict the valley width. All types of constrained as well as unconstrained reaches are observed along Lookout Creek (Fig 7).

Reaches differ in terms of: 1) channel unit structure; 2) disturbance regime; and 3) structure and composition of streamside vegetation. Most constrained reaches tend to have a greater proportion of their length in pools and cascades than unconstrained reaches (Table 3). Channels in constrained reaches are often dominated by short cascade-pool-cascade-pools sequences in contrast to unconstrained reaches where long riffles and rapids dominate. Higher frequency of pool-forming elements, such as bedrock outcrops and large boulders, along constrained reaches promotes formation of pools. Input of large boulders and wood along earthflow toes results in more cascade units and a steeper longitudinal profile (Fig. 7c). Reaches constrained by alluvial fans have anomalously few pools and cascades, in part because of the relative paucity of both large boulders and bedrock in the channel (Table 3); this is due to the nature of alluvial fan development. Large fans which can constrain the channel only occur where the valley is sufficiently wide to permit deposition of coarse material from tributaries on the valley floor and bedrock outcrops are generally not observed in wide valleys. Furthermore, within-fan sorting of material supplied from tributaries leads to boulder deposition near the fan apex and finer sediment deposition near the distal margins of fans in proximity to channels. Hence, few boulders and little bedrock are visible in channels along alluvial fan constrained reaches.

Disturbance regimes also differ by type of reach. Active input of sediment and organic debris from

TABLE 3. CHARACTERISTICS OF REACHES SHOWN IN FIGURE 7, LOOKOUT CREEK.

Reach	Reach-Type[1]	Average VFWI[2] (m/m)	Average Channel Slope(%)	Channel Length in Pool (%)	Channel Length in Rif+Rap[3] (%)	Channel Length in Cascades (%)
A	Constrained-brck	1.2	1.9	39	32	29
B	Unconstrained	2.7	2.0	19	57	24
C	Constrained-erflw	1.3	2.7	32	28	40
D	Unconstrained	6.8	2.0	25	60	15
E	Constrained-a. fan	2.7	2.4	7	76	17
F	Unconstrained	5.5	2.3	26	59	15

[1] Abbreviations used: brck = bedrock; erflw = earthflow; a. fan = alluvial fan

[2] VFWI = valley floor width index: the ratio of valley floor width to active channel width.

[3] Rif+Rap = total of channel length in riffle and rapid channel units.

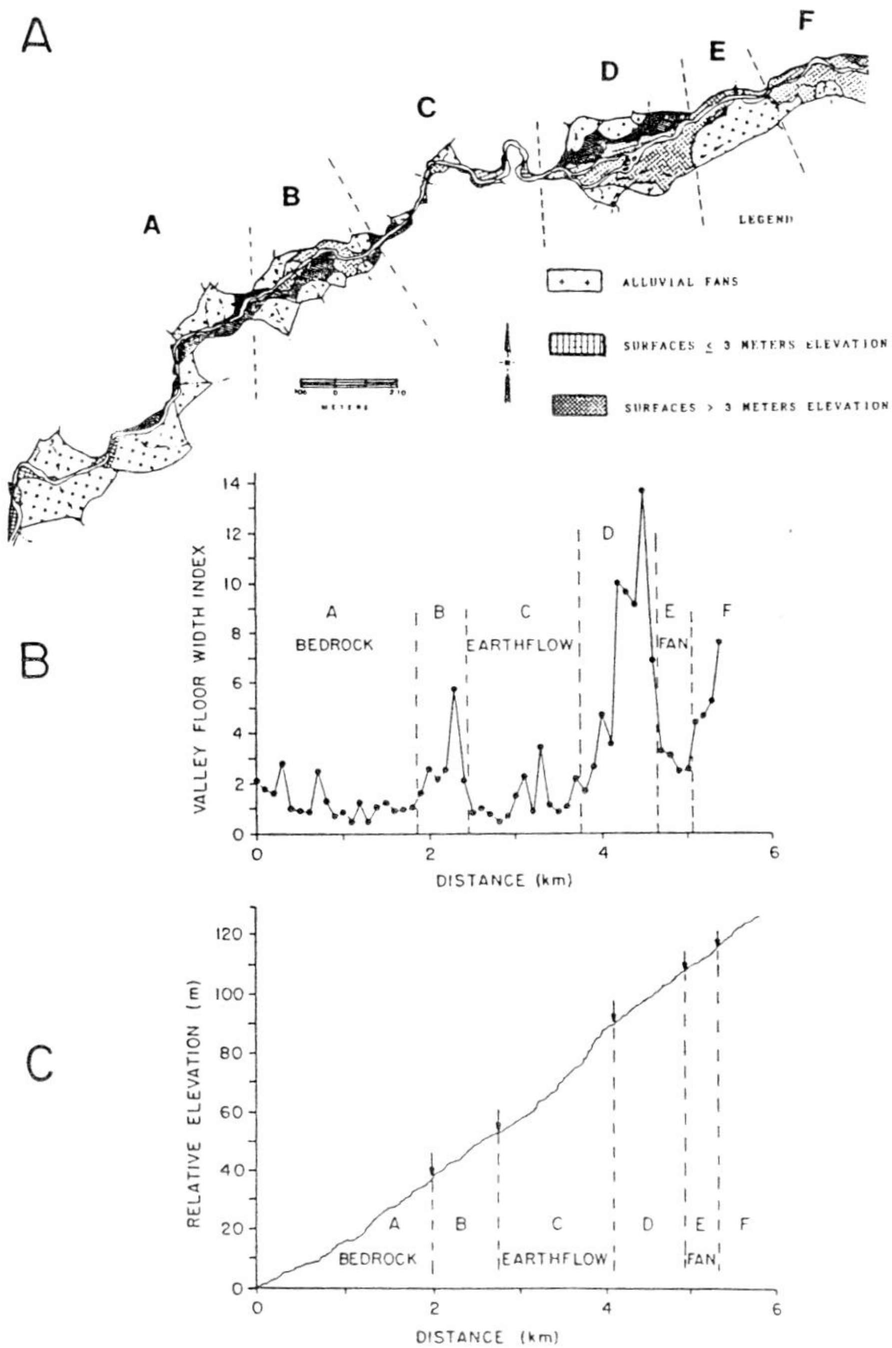

Fig. 7. Map of reaches and associated reach geometry along 5.5 km study area, Lookout Creek; 7A: planview of reaches and associated valley floor landforms; 7B: distribution of valley floor width index by reach type; 7C: longitudinal profile of the channel by reach type.

debris sliding occurs where channels are constrained by active earthflow or landslide complexes (Swanson and others, 1985). The earthflow constraining reach C along Lookout Creek has been inactive over at least the past 7000 years; however the steeper, narrower channel adjacent to the earthflow complex results in higher bed shear stresses during flood events than in the unconstrained reach immediately upstream. Despite this, the greater opportunity for the channel to expand over low surfaces in the unconstrained reach coupled with the finer texture of bed material, and presence of multiple channels results in much higher frequency of lateral channel change than in the constrained reach. Debris flow deposition is also a disturbance mechanism in unconstrained reaches whereas the narrower channel and steeper channel gradients in constrained reaches tend to promote transportation of debris flow material.

Because of the higher frequency of lateral channel movements, unconstrained reaches have wider zones of herbaceous and non-woody vegetation bordering the channel and greater distances to coniferous vegetation. This has biological implications in that detrital and light input to these reaches is substantially different than in constrained reaches.

Implications of the spatial classification

Recognition of the different scales on which morphologic features in high mountain streams are expressed is important from several perspectives. First, the scales give clues as to the processes responsible for the morphogenesis of features. The spacing of successive step-pools, for example, is scaled by fractions of a channel width (Figs. 2,3); hence, origin of step-pools is linked to hydraulic processes occurring at the same scale, such as antidunes and hydraulic jumps. The length of channel units, on the other hand, is scaled by multiples of channel width (Fig. 2), the same scale as bar formation. One might therefore conjecture that formation of channel units is a steep stream analog to alternate bar formation in lower gradient streams. This is a plausible mechanism as Bathurst and others (1983) have shown in flume experiments that the domain of bar formation includes the range of slopes observed in mountain streams. Although the processes responsible for channel unit formation are not fully understood, the scale of the feature demands that different mechanisms than those responsible for formation of individual step-pools be considered.

Since channel and valley morphology often control rates of both water and sediment movement, consideration of appropriate scales is also important from the standpoint of understanding spatial differences in rates of transport processes. Step-pools, for example, are important morphologic features in mountain streams from the standpoint of both flow resistance and sediment transport. Higher drag forces over stepped beds results in greater rate of energy expenditure per unit channel length than in unstepped beds (Peterson and Mohanty, 1960; Bowman, 1977; Bathurst and others 1983; Khashab, 1986). Sediment transport rates also differ between stepped and unstepped beds. The small pools between steps provide storage sites for fine sediment transported during low to moderate discharges. Sediment transport rates during a particular storm event are therefore dependent on the available storage capacity of these pools as well as on the absolute magnitude of the discharge. Antecedent storage volume in pools has been shown to influence sediment rating curves in both field studies (Ashida and others, 1976; Sawada and others, 1983, 1985) and flume experiments (Ashida and others, 1986; Whittaker, 1987 a,b).

Spatial dependence of sediment transport rates has also been shown at the channel unit scale. Differences in shear stresses between riffles and pools during flows competent to move bed material result in scour in pools and deposition in riffles during high flows and the reverse during more moderate flows (Jackson and Beschta, 1982).

Differences in sediment of transport rates at the reach scale have not been documented. Where reach-controlling agents change the channel gradient, such as in the steep reach adjacent to the earthflow along Lookout Creek (Fig 7c), both water and sediment transport rates may be expected to increase. This is offset, however, by increased hydraulic resistance due to delivery of large boulders. Reaches also vary systematically in terms of rates of sediment supplied to the channel. Rates are highest along reaches bordered by active earthflows, moderate along unconstrained reaches, where the channel may be isolated by its floodplain from hillslope delivery but unconsolidated fluvial deposits are readily available for transport, and lowest in bedrock-controlled reaches where both channel storage and hillslope delivery are low.

One implication of this is that appropriate scales within the spatial hierarchy must be considered when developing research strategies to measure water and sediment transport. At a minimum, measurement sites need to be stratified with respect to channel unit and reach scales. Reach-scale morphology also needs to be considered when designing erosion control structures, since transport rates, channel pattern, and disturbance processes vary by reach-type.

Finally, since geomorphic structure and processes strongly influence the structure and composition of both terrestrial and aquatic communities in riparian zones, this spatial hierarchy provides a way of understanding the organization of biologic systems. This fact was recognized by the Japanese ecologist Kani (1981) who wrote (p. 113):

> "In different environments are to be found different communities of organisms, which have different sets of ways of living. When the world is divided into smaller and smaller parts, each part becomes more and more particular and specific. The organisms in one little world live in a way different from those in another. However, in similar habitats are to be found similar lives, beyond space and time. Therefore, to classify habitats would be the same as to classify the ways of living in the organismic communities there. The classification would reflect the similarities and differences among the ways of lives."

Research in the United States has confirmed Kani's view and shown that a geomorphic classification provides a useful means for analyzing and interpreting differences in riparian vegetation, stream invertebrates, and fish communities in mountain areas.

References

Allen, J.R.L. (1968): The nature and origin of bed-form hierarchies, Sedimentology, v. 10, p. 161-182.

Ashida, K., Takahashi, T., and Sawada, T. (1976): Sediment yield and transport on a mountainous small watershed. Bull. Disas. Prev. Res. Inst., Kyoto Univ., v. 26, Part 3, No. 240, p. 119-144.

Ashida, K., Takahashi, T., and Sawada, T. (1981): Processes of sediment transport in mountain stream channel. Erosion and Sediment Transport in Pacific Rim Steeplands. I.A.H.S. Publ. No. 132, p. 166-178.

Ashida, K., Egashira, S., and Ando, N. (1984): Generation and geometric features of step-pool bed forms. Annuals, Disas. Prev. Res. Inst., Kyoto Univ., No. 27 B-2, p. 341-353.

Ashida, K., Egashira, S., Sawada, T., and Nishimoto, N. (1985): Geometric structures of step-pool bed forms in mountain streams. Annuals, Disas. Prev. Res. Inst., Kyoto Univ., No. 28 B-2, p. 325-335.

Ashida, K., Egashira, S., and Nishimoto, N. (1986a): Sediment transport mechanism on step-pool bed form. Annuals, Disas. Prev. Res. Inst., Kyoto Univ., No. 29 B-2, p. 377-390.

Ashida, K., Egashira, S., and Nishino, T. (1986b): Structure and friction law of flow over a step-pool bed form. Annuals, Disas. Prev. Res. Inst., Kyoto Univ., No. 29 B-2, p. 391-403.

Bathurst, J.C. (1978): Flow resistance of large-scale roughness, Journal of the Hydraulic Division, ASCE, v. 104, No. HY12, p. 1587-1603.

Bathurst, J.C. (1987): Critical conditions for bed material movement in steep, boulder-bed streams. Erosion and Sedimentation in the Pacific Rim. I.A.H.S. Publ. No. 165, p. 309-318.

Bathurst, J.C., Graf, W.H., and Cao, H.H. (1983): Bedforms and flow resistance in steep gravel-bed channels, *in* Sumer, B.M., and Mller, A., eds., Mechanics of Sediment Transport, Balkema, Rotterdam, Netherlands, p. 215-221.

Best, D. W., and Keller, E.A. (1986): Sediment storage and routing in a steep boulder-bed, rock-controlled channel, *in* DeVries, J., ed., Proceedings of the Chaparral Ecosystems Research Conference, May 16-17, 1985, Santa Barbara, California, California Water Resources Center Report No. 62, University of California, Davis, p. 45-55.

Bowman, D. (1977): Stepped-bed morphology in arid gravelly channels, Geological Society of America Bulletin, v. 88, p. 291-298.

Brayshaw, A.C. (1985): Bed microtopography and entrainment thresholds in gravel-bed rivers, Geological Society of America Bulletin, v. 96, p. 218-223.

Costa, J.E. (1983): Paleohydraulic reconstruction of flash-flood peaks from boulder deposits in the Colorado Front Range, Geological Society of America Bulletin, v. 94, p. 986-1004.

Frissell, C.A., Liss, W.J., Warren, C.E., and Hurley, M.D. (1986): A hierarchical framework for stream habitat classification: viewing streams in a watershed context. Environmental Management v. 10., no. 2, p. 199-214.

Grant, G.E. (1986): Downstream effects of timber harvest activities on the channel and valley floor morphology of western Cascade streams. [PhD. dissertation]: Baltimore, Maryland, Johns Hopkins University, 363 p.

Grant, G.E., Swanson, F.J., and Wolman, M.G. (in review): Morphology and morphogenesis of boulder-bed streams, western Cascades, Oregon. Submitted to Geological Society of America Bulletin.

Hasegawa, K. (1988): Morphology and flow of mountain streams. Hydraulic Engineering Series 88-A-8, Hydraulic Committee, Japanese Society of Civil Engineers, p. 1-22. (in Japanese).

Hayward, J.A. (1980): Hydrology and stream sediments in a mountain catchment, Tussock Grasslands and Mountain Lands Institute Special Publication No. 17, Canterbury, New Zealand, 236 p.

Iseya, F., and Ikeda, H. (1987): Pulsations in bedload transport rates induced by a longitudinal sediment sorting: a flume study using sand and gravel mixtures, Geografiska Annaler, v. 69 A-1, p. 15-27.

Jackson, W.L., and Beschta, R.L. (1982): A model of two-phase bedload transport in an Oregon Coast Range stream, Earth Surface Processes and Landforms, v. 7, p. 517-527.

Judd, H.E., and Peterson, D.F. (1969): Hydraulics of large bed element channels, Report No. PRWG17-6, Utah Water Research Laboratory, Utah State University, Logan, Utah, 115 p.

Kani, T. (1944): Ecology of torrent-inhabiting insects. Furukuwa, H.(ed.) Insects, I. Kenkyu-sha, Tokyo, p. 171-317. (In Japanese).

Kani, T. (1981): Stream classification in "Ecology of torrent inhabiting insects (1944)": An abridged translation". Physiol. Ecol. Japan. v. 18, p. 113-118.

Keller, E.A., and Swanson, F.J. (1979): Effects of large organic debris on channel form and fluvial processes, Earth Surface Processes, v. 4, p. 361-380.

Keller, E.A., and Melhorn, W.N. (1978): Rhythmic spacing and origin of pools and riffles. Geological Society of America Bulletin, v. 89, p. 723-30.

Khashab, A.M.E. (1986): Form drag resistance of two-dimensional stepped steep open channels. Canadian Journal of Civil Engineering, v. 13, p. 523-527.

Kishi, T., Mori, A., Hasegawa, K., and Kuroki, M. (1987): Bed configurations and sediment transports in moutainous rivers. In: Comparative Hydrology of Rivers of Japan: Final Report, Japanese Research Group of Comparative Hydrology, Hokkaido University, Sapporo, Japan, p. 165-176.

Koster, E.H. (1978): Transverse ribs: their characteristics, origin, and paleohydraulic significance, *in* Miall, A.D., ed., Fluvial Sedimentology, Memoir 5, Canadian Society of Petroleum Geologists, Calgary, Alberta, p. 161-186.

Langbein, W.B., and Leopold, L.B. (1968): River channel bars and dunes - theory of kinematic waves, U.S. Geological Survey Professional Paper 422-L, 20 p.

Leopold, L.B., Wolman, M.G., and Miller, J.P. (1964): Fluvial Processes in Geomorphology. W.H. Freeman, San Francisco, 522 p.

Lisle, T.E. (1986): Stabilization of a gravel channel by large streamside obstructions and bedrock bends, Jacoby Creek, northwestern California. Geological Society of America Bulletin, v. 97, p. 999-1011.

McDonald, B.C., and Banerjee, I. (1971): Sediments and bed forms on a braided outwash plain. Can. Journal of Earth. Science, v. 8, p. 1282-1301.

Mizuno, N., and Kawanabe, H. (1981). A topographical classification of streams, with an introduction of the system widely used in Japan: I. Reach type, stream zone, and stream type. Verh. Internat. Verein. Limnol. Bd. 21, p. 913.

Nakamura, F. (1986): Analysis of storage and transport processes based on age distribution of sediment. Transactions of the Japanese Geomorphological Union, v. 7-3, p. 165-184.

Nakamura, F., Araya, T., and Higashi, S. (1987): Influence of river channel morphology and sediment production on residence time and transport distance. Erosion and Sedimentation in the Pacific Rim, International Association of Hydrological Sciences Publication No. 165., p. 355-364.

Nolan, K.M., Lisle, T.E., and Kelsey, H.M. (1987): Bankfull discharge and sediment transport in northwestern California. Erosion and Sedimentation in the Pacific Rim, International Association of Hydrological Sciences Publication No. 165., p. 439-449.

Peterson, D.F., and Mohanty, P.K. (1960): Flume studies of flow in steep, rough channels. Journal of the Hydraulics Division, ASCE, v. 86, No. HY9, p. 55-76.

Pickup, G. and Warner, R.F. (1976): Effects of hydrologic regime on magnitude and frequency of dominant discharge. Journal of Hydrology, v. 29, p. 51-75.

Sawada, T., Ashida, K., and Takahashi, T. (1983): Relationship between channel pattern and sediment transport in a steep gravel bed river, Zeitschrift fur Geomorphologie, N.F. Suppl.-Bd 46, p. 55-66.

______ (1985): Sediment transport in mountain basins. *In* Proceedings of the International Symposium on Erosion, Debris Flow, and Disaster Prevention. Sept. 3-5, 1985, Tsukuba, Japan. Tokyo (publisher unknown). p. 139-144.

Scott, K.M., and Gravlee, G.C. (1968): Flood surge on the Rubicon River, California - hydrology, hydraulics, and boulder transport, U.S. Geological Survey Professional Paper 422-M, 40 p.

Swanson, F.J., Lienkaemper, G.W., and Sedell, J.R. (1976): History, physical effects and management implications of large organic debris in western Oregon streams, U.S. Forest Service General Technical Report PNW-56, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, 15 p.

Swanson, F.J., Graham, R.L, and Grant, G.E. (985): Some effects of slope movements on river channels, *in* Proceedings of the International Symposium on Erosion, Debris Flow, and Disaster Prevention. Sept. 3-5, 1985, Tsukuba, Japan. Tokyo (publisher unknown). p. 273-278.

Waananen, A.O., Harris, D.D., and Williams, R.C. (1971): Floods of December 1964 and January 1965 in the far western states - Part I, Description: U.S. Geological Survey Water-Supply Paper 1866-A, 265 p.

Whittaker, J.G. (1987a): Sediment transport in step-pool streams, *in* Thorne, C.R., Bathurst, J.C., and R.D. Hey, eds., Sediment Transport in Gravel-Bed Rivers, John Wiley and Sons, Ltd. Chichester, England, p. 545-579.

Whittaker, J.G, (1987b): Modelling bed-load transport in steep mountain streams, *in* Erosion and Sedimentation in the Pacific Rim, International Association of Hydrological Sciences Publication No. 165, p. 319-332.

Whittaker, J.G. and Jaeggi, M.N.R. (1982): Origin of step-pool systems in mountain streams, Journal of the Hydraulics Division, ASCE, v. 108, No. HY6, p. 758-773.

Wolman, M.G., and Gerson, R. (1978): Relative scales of time and effectiveness of climate in watershed geomorphology. Earth Surface Processes, v. 3, p. 189-208.

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—砂防学会ワークショップ—

荒廃渓流における地形変化と堆積土砂の制御

Workshop on "Channel Geomorphological Change and Sediment Control at Devastated River"

1988年10月13日　静岡大学

ワークショップ編集委員会

まえがき

砂防学会では、砂防学に関する研究をさらに活性化させるために、昭和６３年度から公募方式により、ワークショップの設置を奨励援助することになった。これは砂防学に関係する若い研究者が自主的にワークショップを主宰し、意欲あふれる独創的研究を推進していくことを側面から援助していこうとするものである。

本年度は６つのワークショップを援助し、それぞれ活動を開始して貰っている。ここで論文集として纏められたものは九州大学丸谷知己氏が主宰する”荒廃渓流における地形変化と堆積土砂の制御”というテーマで静岡大学で１０月１３日に行われたワークショップに提出された報告である。ワークショップにおいて、大変興味ある諸問題が討議され、それだけでも砂防学の発展に大いに意義があったが、更にこのような立派な論文集を自主的に纏め上げられたことは、公募方式によるワークショップ活動の推進母体である研究開発委員会として、大変喜ばしいことと思っている。

このワークショップは荒廃渓流の渓床を地学的な見方で論議していこうという主旨と理解しているが、砂防学の基本の一つをなす分野であり、今後更に継続して研究を発展して戴きたいと考えている。あえて研究開発委員会としての希望を述べさせて貰えば、渓床変動論のもう一つの見方として土砂水理学を基礎とする方向があり、この方の研究に携わる若い研究者とも相互に議論される機会を作られると非常に意義深い成果が得られるのではないかと思う。

ともあれ、この論文集は砂防学発展に十分寄与するだけではなく、研究開発委員会が意図するところをよく理解されたものであり、他のワークショップの進め方にも大変参考になるものと思う。主宰者の丸谷氏を始め、論文執筆者、ワークショップ開催に精力的に努力された静岡大学大村寛氏をはじめとする諸兄に深い敬意を表します。

昭和６３年１０月１３日

砂防学会開発研究委員会

委員長　　片岡　順

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