AN ABSTRACT OF THE THESIS OF

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Title: Large Woody Debris and Channel Morphology of Undisturbed Streams in Southeast Alaska.

Abstract Approved: ____.
Robert L. Beschta

The characteristics and interactions of the riparian stand, large woody debris (LWD), and channel morphology were examined on five undisturbed, low gradient streams in southeast Alaska. One first-, two second-, one third-, and one fourth-order streams were studied. Stream morphology variables were measured systematically at fixed intervals of three to ten feet depending on stream size: 50-foot intervals were used for riparian forest measurements.

The percentage of alder comprising the riparian forest increased with stream size. The first- and second-order streams had alder comprising approximately 8% of the total basal area whereas, the fourth-order stream had 25%. Likewise, the percentage of LWD pieces consisting of alder increased from 12% in the two smallest first and second-order streams to 31% in the fourth-order stream. These findings, along with inspection of air photos indicate a

alternating "one sided" alder corridor exists along the largest stream.

The proportion of large woody debris pieces with rootwads in the channel increased from 2 and 6% in the two smallest first- and second-order streams to 32% in the fourth-order stream indicating the largest stream has recruited LWD from bank cutting and/or lateral channel migration. LWD oriented perpendicular (90°) to general stream flow was relatively frequent for all streams. No significant (alpha=0.05) linear relationship was found ($r^2<0.05$) between piece length and orientation to flow.

Channel morphology changed with stream size. For example, the length of stream with side channels and/or braided reaches increased from 1% in the first-order stream to 41% of stream length in the fourth-order stream. The overall percentage of pools averaged 57% and showed no changes with changes in stream size. However, the relative proportions of individual pool "morphological types" and "causal elements" did change with stream size. "Underflow pools" comprised less than 10% of the morphological types in the first-, second-, and third-order streams but increased to 17% in the fourth-order stream. Autocorrelations of the spatial distributions of stream morphological variables (i.e., depth and width) indicated that the streams are influenced by a wide variety of interacting factors and processes. Thus channel dimensions are characterized by high variability and an absence of "memory" or "repeatable" components.

A positive linear relationship (alpha<0.01, $r^2=0.23$) was found between LWD volume and the standard deviation of bankfull width. No such relationships were found for other stream morphological variables including thalweg depth, low-flow width, cross-sectional area, and width depth ratio, indicating other variables besides wood volume present are influencing variability in stream morphology, or that the effects of large woody debris upon channel morphology is not easily expressed by linear regression techniques.

Autocorrelations and frequency histograms of an upstream forested section, with instream LWD, and a downstream meadow section with no LWD, noncohesive soils and tidal effects, show that the meadow section had greater "memory" and less diversity in "morphological types" and "pool causal elements."

These results provide a quantitative assessment of several stream morphology variables for first- through fourth-order streams in southeast Alaska. Further research is needed to compare these results for undisturbed streams with streams influenced by management activities.

Large Woody Debris and Channel Morphology of Undisturbed Streams in Southeast Alaska

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LARGE WOODY DEBRIS AND CHANNEL MORPHOLOGY OF UNDISTURBED STREAMS IN SOUTHEAST ALASKA

INTRODUCTION

The influence of large woody debris (LWD) has upon channel morphology and stream habitat is currently an important issue to natural resource managers. Although debris can be beneficial for fisheries habitat (Dolloff 1983), there is debate on the amount, type, and configuration of LWD needed for various streams. The natural distribution of LWD in undisturbed streams is often assumed to provide the best fish habitat (Sullivan et.al. 1987) because fish have adapted to these conditions over time (Reiser and Bjornn 1979).

The purpose of this research is to study LWD characteristics and their effects on channel morphology in undisturbed streams. Specific objectives include:

1) Determine the spatial LWD distribution and its effect on stream morphology.
2) Evaluate localized effects of LWD upon the morphology of stream channels.

From spatial distributions of LWD and morphology, the hypothesis of whether increasing LWD volumes actually increases the diversity or variability in channel features (Keller and Talley 1979, and Hogan 1985) can be tested quantitatively. From these distributions, "signatures" (i.e., longitudinal values measured along a space continuum) of LWD volume and morphological features (i.e., depth, width, cross sectional area, pool type etc....) can be developed and compared to evaluate how they change with stream size. Eventually, studies on disturbed streams can compare their "signatures" with these to evaluate any changes associated with land use practices. From cross sections and longitudinal profiles the localized effects of selected LWD will be characterized, and correlated with size and shape of associated pools.

It is expected that LWD will be responsible for increasing variability in stream morphology. It is also expected that the results will vary between stream orders and the way in which LWD and other variables are expressed.

BACKGROUND

HISTORY

Until the last several decades forest management activities in the Pacific Northwest were often undertaken with little regard for fisheries impacts. After harvesting trees, slash was normally left where it fell clogging streams (Triska and Cromack 1980). Log driving and splash damming occurred in many northwest streams scouring them to bedrock (Sedell and Duval 1985). Snagging (removing LWD jams to improve navigation) occurred in most of the larger stream systems in Oregon, Washington, and British Columbia (Sedell and Luchessa 1982, Sedell and Duval 1985). The first attempts at managing LWD for fish consisted of LWD removal to decrease barriers to anadromous fish migration (Holman 1964, Helmers 1966, and Meehan et.al. 1969). This concern caused fishery biologists to recommend the removal of all LWD in many streams whether it blocked migration or not. In fact, stream cleanout is still practiced in some areas (Bisson et.al. 1987).

Recent studies have shown that fish populations decrease when LWD is removed (Bryant 1981, Toews and Moore 1982, Dolloff 1983). There is increasing agreement by fisheries research biologists that some LWD should be left in the stream, but questions related to which LWD species, lengths, diameters, volumes, and placements are needed for a range of stream sizes have not yet been answered.

LWD LOADING: PROCESSES AND PATTERNS

Process

Loading of LWD (the volume of large woody debris occurring per unit area or length of a stream channel) can be thought of as the result of an input-output process (Keller and Talley 1979). Such inputs and outputs can be episodic (occurring only infrequently) or chronic (occurring frequently) (Bisson et.al. 1987).

Large woody debris can enter a stream system as follows:

a) Mass soil movements from adjacent hillslopes

Keller and Swanson (1979) and Swanson et.al.(1987) indicate that the amount of LWD entering the stream system from mass soil movements is a function of slope, stability and shape of the stream valley. A stream in a V shaped valley with steep unstable slopes would have an increased chance of receiving LWD from this source. This process can have both episodic (slumps and debris avalanches during extreme meteorological events) and chronic (soil creep) components.

b) Tree Blow Down

The susceptibility to blowdown of a tree is a function of rooting depth and strength based on soil type, tree species,and tree vigor. Tree blowdown can occur chronically as trees weaken with age. However, the majority of trees blow down during a few wind storms (Swanson et.al. 1976).

c) Bank Erosion

This input process is a function of stream discharge and power (Beschta and Platts 1986) and stream mobility (the ability of a stream to move laterally across a valley bottom). This effect will often be combined with blowdown and mass movements (Bisson et.al. 1987). As a mass of soil slumps, slides, or creeps towards a channel the stream erodes the toe and recruits LWD. Tree rooting systems will often be weakened by bank cutting and the tree will blow over during wind storms. This process can be both episodic and chronic (Bisson et.al 1987). Sedell and Froggatt (1984) indicate that the Willamette River in Oregon historically recruited large wood from a corridor approximately four miles wide.

d) Floatation from upstream

The capability of a stream to transport LWD is a function of the streams discharge and the overall size and length of the LWD piece (Keller and Swanson 1979). LWD must also be dislodged from an upstream source, and the dynamics of this process are often complex.

e) Debris Torrent or Flow

This generally occurs mainly on high gradient streams in V-shaped valleys with unstable slopes (Swanson et.al. 1987). LWD that is found in a debris torrent is usually relatively small because the churning action of the flow breaks up the wood (Swanson et.al. 1987). This process is episodic, occurring only during low frequency storm events.

f) Logging Input

The amount of LWD contributed to a stream is a function of the felling techniques and rigor of post-harvest cleanup. Pieces that enter a stream from this process will generally be smaller and not have rootwads attached (Bryant 1980 and Hogan 1985). The pieces are also considered less "stable" and more likely to move (Hogan 1987 and Bisson et.al. 1987).

Once LWD has entered a stream, there are several mechanisms by which it can be removed:

a) Floatation from site

The capability of LWD to float is a function of its size (Toews and Moore 1982 and Bryant 1983). Length is perhaps the most important size characteristic as pieces that are longer than the stream width are considered more resistant to floatation (Bisson et.al. 1987). Other factors contributing to resistance to floatation include presence of a rootwad, and extent of anchoring or burial (Bisson et.al. 1987). Orientation perpendicular to flow (Bryant 1983) and a high percentage of LWD in the water will increase the chance of LWD floatation.

b) Decay

The rate of LWD decay varies with species, with hardwoods (deciduous species) decaying much faster on average than softwoods (conifers). The Sequoias, Redwoods, and Cedars have the slowest rates of decay and are the most stable (Grahamn and Cromack 1982, Maser et.al 1984). Decay rates are also a function of whether the wood is completely submerged, partially submerged, or terrestrial. Partially submerged LWD has the fastest rates of decay followed by terrestrial with submerged having the lowest rates (Triska and Cromack 1980). The rate also increases with increasing temperature (Grahamn and Cromack 1982). Decay and floatation are inter-related in exporting wood because decay can often destablize wood enough so it is transported downstream.

c) Lateral Channel Movement

As a stream meanders (i.e.,moves laterally), it abandons portions of channel and cuts new channels. This process causes a simultaneous loss and gain of LWD as channel shifts occur. This process does not fit the traditional input-output criteria but never the less it is important for relatively large low gradient channels.

d) Debris Cleanout During or After Logging

Sedell and Duval (1985) and Bisson et.al. (1987) both point out that unless instructed to do otherwise harvesting crews can remove significant amounts of LWD from streams. Historically, stream cleanout constitutes a dominant form of debris output in many streams.

Spatial Distribution (Patterns)

The spatial distribution of debris varies with stream size (Triska and Cromack 1980). LWD is often randomly placed along first order streams, but tends to be increasingly clumped and creates LWD dams in third- and forth order streams (Bilby and Likens 1980, Likens and

Bilby 1982, and Bisson et.al. 1987). In fifth order and larger streams LWD tends to be restricted to side margins and gravel bars (Sedell et.al. 1984). Most of these conclusions are inferred from LWD maps and aerial photos. To date there has been little quantitative work to determine the longitudinal distribution in different stream types and sizes.

OVERALL FUNCTIONS OF LWD

Once in the channel, LWD can affect a stream in several ways. In high gradient streams channel velocity and "unit stream power" is decreased by LWD creating a "stepped profile" (Heede 1972, Marston 1982, and Beschta and Platts 1986). In lower gradient stream systems LWD causes decreased velocity by causing form drag or frictional resistance. This is because the presence of large roughness elements cause potential energy to be dissipated in overcoming friction rather than in increasing the stream's velocity (Richards 1982).

LWD can also influence the storage and routing of sediment. Megahan (1982) and Bilby (1984) indicated that a significant amount of sediment is stored behind LWD dams and individual pieces. Wilford (1984) found that this storage effect can be extended to hillslopes and gullies. Beschta (1979) found that the removal of LWD from a stream can cause increased sediment and bedload transport until the stream reaches a new equilibrium.

Debris can also influence particulate organic matter routing and storage (Bilby and Likens 1980 and Likens and Bilby 1982). Speaker et.al. (1984) found that increased LWD in the channel increased the time it took for dye and leaves to route through a stream. Cederholm (1984) found that salmon carcasses were retained longer with increased levels of instream LWD volume. LWD retention is important because organic materials that are retained can be more completely processed by the stream biota, increasing the food base of the stream (Hynes 1975).

LWD also provides cover and generally influences rearing habitat for fish. During summer low flows, LWD in streams can provide shade (Meehan 1974). During high flow events, LWD can provide a refuge from winter high flow events (Bustard and Naver 1975 and Heifetz et.al. 1986). Bisson et.al. (1987) reports that LWD provide current breaks (areas of lower velocity) that are preferred habitat for fish. Dolloff (1983) indicates that debris may create a partitioning effect, visually isolating fish and increasing the carrying capacity of the stream.

When in large jams LWD may hinder or even block the migration of fish. This was once a major concern to fishery biologists but its significance was apparently overstated (Reiser and Bjornn 1979). Many blockages considered impassable when evaluated at low flows were passable at higher flows (Bryant 1983).

LWD AND CHANNEL MORPHOLOGY

Among other effects, LWD can create pools, affect the occurrence of side channels, and possibly increase variability of fish habitat.

Pools

Pools are an important component of fish habitat (Bisson et.al. 1987). During periods of elevated water temperatures in summer, some pools may provide thermal refuges that can aid fish (Beschta et.al. 1987 and Bisson et.al. 1987). Fish can also reside in layers in pools thus increasing carrying capacity (Allee 1982). Pools are also a preferred habitat for most age classes of coho salmon (Oncohynchus kisutch) (Hartman 1965 and Bisson et.al. 1982).

Even with no structural elements and uniform bed grain sizes, riffle-pool sequences will form in laboratory channels (Leopold et.al. 1964). These sequences represent a means of self adjustment by a stream in order to minimize the time rate expenditure of potential energy per unit mass of water (Yang 1971). In this case the formation of channel features is an endogenous (from within system or purely fluvial) process caused by water and bedgrain interactions at varying flow rates. The pools formed by this process tend to repeat along the stream's longitudinal profile every five to seven channel widths (Keller and Melhorn 1978). In natural stream systems there are other factors overlayed on this process such as variations in bed grain sizes (from clay particles to massive bedrock), the presence of large structural elements (LWD, boulders, rootwads etc...), the effects of animals (beaver dams), and anthropogenic factors. While variations in the combinations of these factors make the process of bed formation a complex subject, some generalizations can be made. Bed morphology is influenced by water flowing around structural elements such as LWD, boulders, or bedrock outcrops (exogenous factors). In small forested streams of the Northwest most pools are formed by these exogenous processes (Sullivan et.al. 1987). Similarly, Keller and Talley (1979) estimated that 50-90% of the pools in a small stream in California were associated with LWD.

Pools caused by endogenous (fluvial) processes can be characterized as follows (Figure 1).

a) Lateral scour pools are caused by the deflection of flow that occurs as a channel rounds a meander bend. If not constrained by channel banks, streams will meander or have sinuosity in response to the streams slope, discharge and sediment load (Leopold et.al. 1964 and Richards 1982).

b) Riffle-pool sequence pools as stated earlier are created by the interaction of flow and bed material.

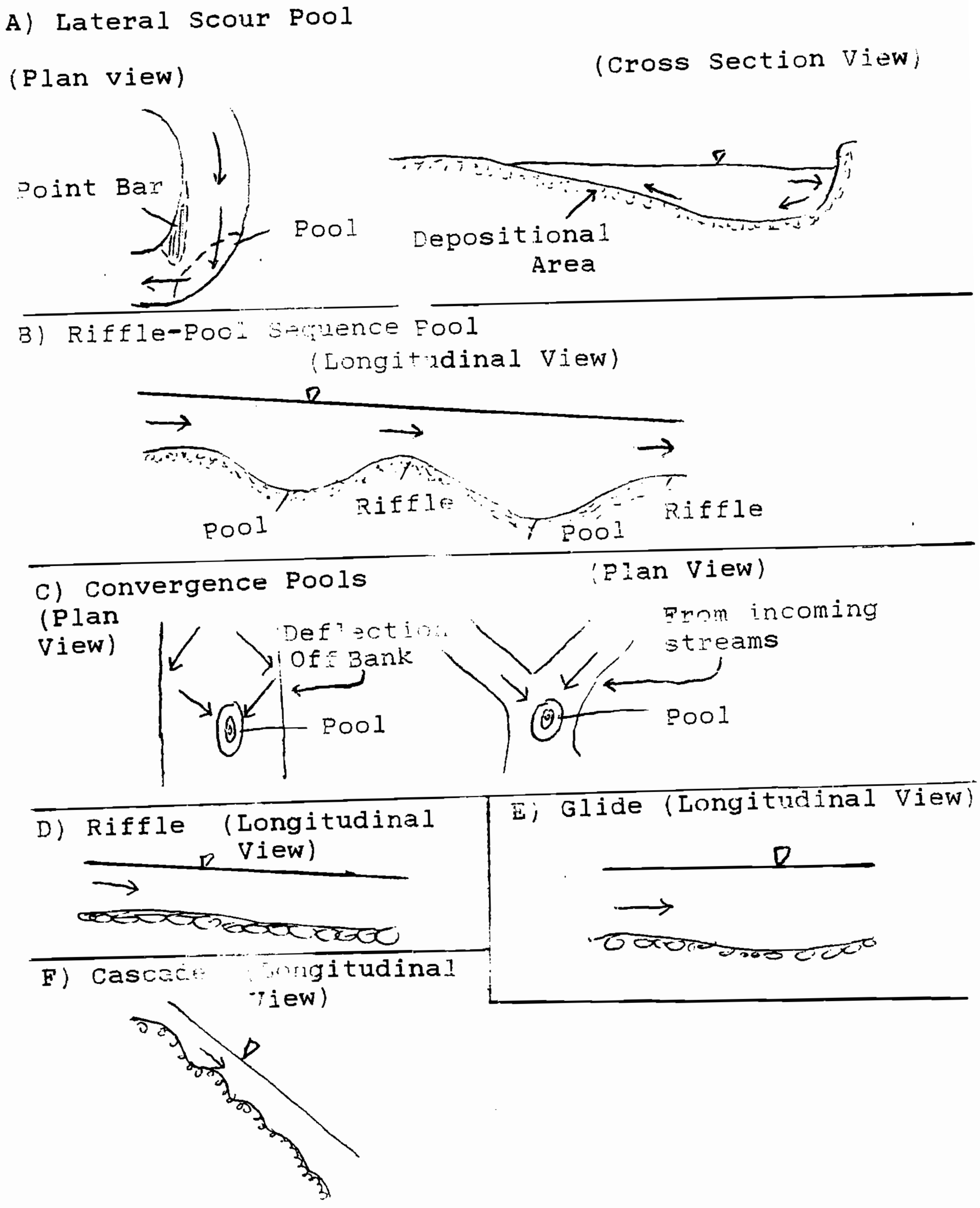


Figure 1. Endogenous pool types and other stream morphological features (adapted from Frissell et.al. 1985 and Beschta and Platts 1986).

c) Convergence pools are formed when flows converge due to entering streams or side channels or patterns in structural elements (Beschta and Platts 1986).

Exogenous pools (pools caused locally by large roughness elements) can be classified as follows (Figure 2):

a) Plunge pools are caused by water flowing over an obstruction, then dropping vertically increasing velocity, and scouring bed material immediately down stream (Frissell et.al. 1985, Beschta and Platts 1986).

b) Underflow or "submerged jet" pools are formed when water flows underneath an obstruction causing a convergence of flow under the obstruction (Beschta 1983). When water converges it gains velocity, thus increasing its capability to scour the channel and form a pool.

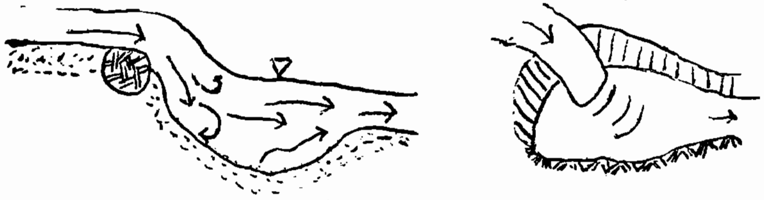
c) Defector pools are caused by water flow being deflected by an obstruction into a helical pattern that scours the channel adjacent to the obstruction.

d) Dam pools are caused by water backing up behind an obstruction (Frissell et.al. 1985). These pools can be formed in the main channel (primary pools) or along the channel side margins (secondary or backwater pools) (Bisson et.al. 1982, Keller and Melhorn 1973).

These pool types can be found in various combinations and degrees of effect which complicate classification. Lisle (1986) found that structural elements can reset sinuosity and thus affect the placement of lateral scour pools. Sullivan et.al. (1987) also concludes that structural elements (LWD) will offset riffle-pool sequences. In another example, convergence pools can be caused by both exogenous and endogenous processes, but was arbitrarily grouped into endogenous here.

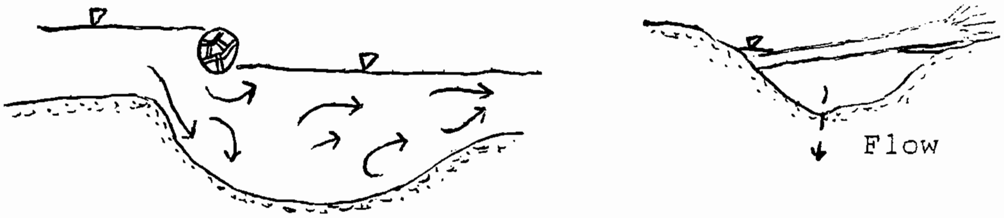
A) Plunge Pool

(Longitudinal View) (Plan view)



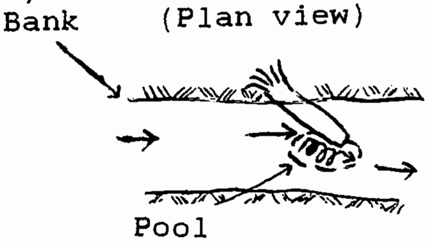
B) Underflow Pool

(Longitudinal View) (Cross Sectional View)



C) Deflector Pool

(Plan view)



D) Dam Pool

(Longitudinal View) (Plan view)

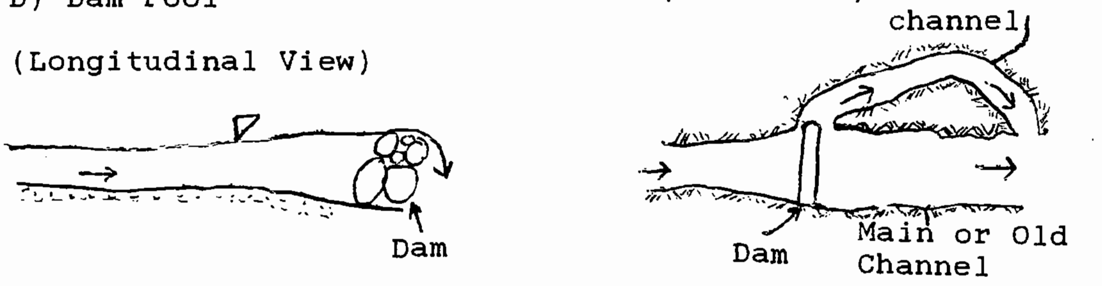


Figure 2. Exogenous pool types (adapted from Frissell et.al. 1985 and Beschta and Platts 1986).

Side channels

Side channels occur in wide or U-shaped valley bottoms where streams can move laterally (Swanson and Lienkapper 1982). Side channels often have lower velocities, better food sources, and better quality habitat for salmonids than are often found in the main stream channel (Sedell et.al. 1984). LWD enhances their formation by providing obstructions that deflects the flow against the channel banks (Zimmerman 1967). Side channels or braiding also occurs in streams with relatively high sediment loads and less stream power to carry sediments (Richards 1982); this effect is more frequent in low gradient streams (Swanson and Lienkapper 1982). The chance of side channel occurrence can also be decreased by LWD buttressing and stabilizing the banks (Keller and Talley 1979).

Habitat Diversity

In general the presence of LWD and other structural elements increases the variability of stream morphology (Hogan 1985). Keller and Talley (1979) speculated that increases in LWD also caused increases in width-depth ratios. Zimmerman (1967) indicated that a stream in a wooded section has more diversity than one in a meadow partly because LWD represented flow obstructions that caused streamflow to converge and diverge into stream banks which in turn caused backwaters. Sullivan et.al. (1987) concludes that "because of the presence of large obstructions in forest streams riffle-pool sequences are commonly irregularly spaced." This "irregularity" increases the variability in channel features and provides habitat diversity for salmonids.

Several authors contend that a high degree of habitat diversity is vital for salmonids. Components of habitat diversity include current velocity, water depth, cover, substrate type, proximity to food sources and pressure of competition (Bisson et.al. 1982). All these habitat components can be related to different channel features such as pools, riffles, and glides (Bisson et.al. 1982). Some can also be related to large structural elements in the stream such as LWD, boulders, brush, rootwads, and undercut banks (Bustard and Naver 1975).

Fish are characterized as habitat specialists (Sullivan et.al. 1987), yet their habitat requirements can differ during climatic seasons, life stages, and between fish types (Everest et.al. 1985). When all the needs of only a few types of fish are combined, a wide variety of habitat components and cover types are required (see Bisson et.al. 1982). For a given stream reach have an optimum productive capacity for a given mix of fish, there must be great variability in habitat types. Dolloff (1983) contends that because of differences in microhabitat utilization among fish species and age classes, there is greater production in more "diverse" stream reaches as more than one species can coexist without losing optimum values. However, when a stream has highly diverse habitat and fish are surrounded by abundant cover there can apparently be negative effects. For instance, Wilzbach and Hall (1985) contend that heavy cover decreases avaliable light and makes feeding more difficult.

METHODS

LOCATION AND CHARACTERISTICS OF STUDY STREAMS

The streams evaluated in this study are located on Chicagof Island in southeast Alaska approximately 70 miles southwest of Juneau, Alaska (Figure 3, Appendix A). All study streams flow into the Tenakee Inlet; four of the five principal study streams (Trap, Bambi, Beach, and East Fork Trap Creeks) flow into Trap Bay. The fifth stream (Kadashan River) is approximately 10 air miles west of Trap Bay.

A nearby raingage in Tenakee Springs recieves an average annual precipation of 66 inches (Sidle and Swanston 1982). The study watersheds, because of orographic effects and increased average elevation, probably receives more precipitation than this. Approximately 15% of the precipitation occurs in October, the wettest month (Water Resources Atlas for Alaska 1978). Most of the precipitation occurs as steady light to moderate rain with more snowfall occurring at higher elevations (Estep 1984).

The vegetation along the streams consists of an overstory of red alder (Alnus rubra), sitka spruce (Picea sitchensis), and western hemlock (Tusuga hetrophylla). The dense understory is dominated by devils club (Opoloponax horridum) with skunk cabbage (Lysichtum

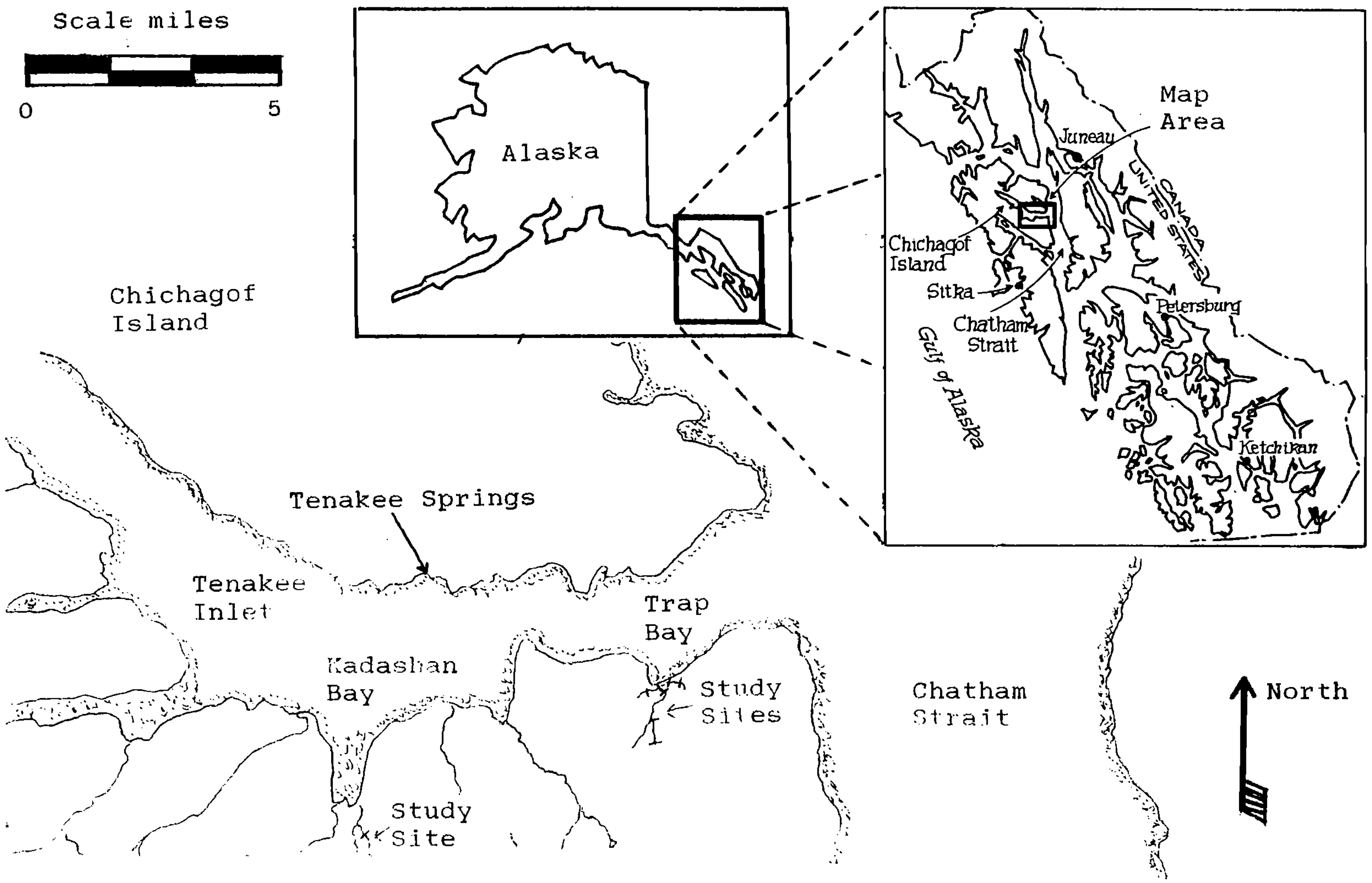


Figure 3. Location of Study Area.

americanum), blueberry and huckleberry (Vaccinium spp.), and salmonberry (Rubus spectabilis).

All streams flow through glaciated valleys. The Trap Bay streams are in a glacial cirque valley that is bounded by serrated ridges and a horn peak at the southern end (Estep 1984). Elevation ranges for the watersheds range from just above sea level to 3870 feet in Trap Bay and to 2650 feet in the Kadashan River Drainage (Table 1). The bedrock plays a lesser role in valley soil development than do the glacial tills that can be up to 1500 feet thick (Harris et.al. 1974). Headwater streams are often steep with channel slopes greater than 50%. Once streams drain into the valleys, their slopes moderate to less than 3% (Bryant 1984). Bambi and Beach Creeks originate in ridge top muskegs then flow over valley sidewall waterfalls to become valley bottom streams. East Fork Trap Creek originates from a cave in the side of the valley wall while Trap Creek and Kadashan River have a variety of sources depending on which tributary is traced.

The study streams vary in size from first to fourth order and have sediment sizes in the study reaches from clays to gravels. Bedrock and boulder outcrops are almost nonexistent in the study reaches. The streams have wide valley terraces and LWD input from debris torrents (flows) is almost nonexistent. There are coho (Oncorhynchus kisutch) and pink salmon (Oncorhynchus gorbuscha) and

Table 1. Stream and basin characteristics for study streams

Characteristic	Stream				
	Beach Cr.	Upper Bambi Cr.	E.Fk. Trap Cr.	Trap Cr.	Kadashan River
Stream Order[a]	1	2	2	3	4
Length of Study Reach (ft)	1100	1110	1500	5020	3000
Watershed Area (sq. miles)[a]	0.28	0.59	2.3	4.4	21.4
Low elevation watershed (ft)[a]	16	20	70	40	50
High Elevation watershed (ft)[a]	2020	2060	3870	3870	2650
Summer flow (cfs)[b]	0.7	1.4	10.9	17.4	41
Two year peak flow (cfs)[b]	53	105	260	470	2040
Stream Gradient (Percent)[c]	1.6	2.3	2.5	1.1	0.8
Average depth low flow (ft)[c]	0.8	0.5	1.6	1.9	2.8
Average width low flow (ft)[c]	9.8	6.1	21.0	34.1	57.9

a - Stream Order, watershed area, discharges, etc... determined at downsteam end of study reaches.

b - Discharges calculated from Water Resources Atlas for Alaska (1978).

c - Stream gradient, average depth, and average wetted-width were calculated from field measurements.

dolly varden char (Salvelinus malma) present in the Trap Bay streams (Bryant 1984). Kadashan River has these three species and steelhead trout (Salmo gairdneri). Beaver (Castor canadensis) and brown bear (Ursus americanus) are also present and active in both basins.

The watersheds are essentially "undisturbed" (no significant changes to the watershed due to human influence). The presence of several improved trails, a few cabins, some isolated "highgrading", and a short stretch of road with a bridge on the upper reaches of Kadashan River are the exceptions.

Studies on suspended sediment and bedload transport on Bambi Creek have been reported by Estep (1984), Estep and Beschta (1985), Sidle and Campbell (1985), and Campbell and Sidle (1985). Fish population studies have also been undertaken in all study reaches (Bryant 1984 for Trap Bay streams and unpublished work by Andy Dolloff for the Kadashan River). Mass movement studies in the Beach Creek Watershed have been reported by Sidle and Swanston (1982). Studies of riparian vegetation have also been undertaken (Alaback and Sidle 1986 and Sidle 1986).

FIELD METHODS

The field portion of the research involved measurements in four distinct phases: Phase 1-stream morphology, Phase 2-large woody debris characteristics, Phase 3-stand features, and Phase 4-localized channel effects.

Phase 1-Stream Morphology

Thalweg depth, low- and bankfull-flow width measurements were made using a leveling rod. These measurement were done at fixed intervals (lags) along the thalweg of the stream. The lag which varied from 3 to 10 feet depending on stream size, was determined by estimating channel bankfull width and dividing it by five. Initial estimates of channel width were imprecise and when the lag of a given channel is multiplied by five it usually does not give the calculated bankfull width (Table 2). At every tenth lag a detailed cross-sectional profile was measured. All depth measurements were referenced to the water surface. Stream slope was measured using an abney level.

Along some stream reaches the channel split into two or more channels. If the channel was separated at bankfull flow for more than 15 feet longitudinally, only the larger channel was measured and it was noted that the stream had a side channel. If the stream was separated at bankfull for less than 15 feet longitudinally both channels were measured and their widths were combined as if one channel and it was noted that the stream was braided. The confluence of tributaries was also noted.

Table 2. Longitudinal spacing (lag) of channel measurements in relation to bankfull width.

Characteristic	Stream				
	Beach Cr.	Upper Bambi Cr.	E.Fk. Trap Cr.	Trap Cr.	Kadashan River
Lag selected (ft)	3	3	5	5	10
Lag x 5 (ft)	15	15	25	25	50
Average bankfull width (ft)	16.1	15.1	28.9	42.1	85.1
Bankfull width to lag ratio	5.4	5.0	5.8	8.4	8.5

Stream features (riffle, glide and type of pool) were also noted for each measurement point (Figures 2 and 3). The classification of pools is the same as Figures 2 and 3 except the riffle-pool sequence pools and the convergence pools were grouped together and assigned the generic name "fluvial pools".

Large roughness elements (LWD, rootwads, and boulders) associated with pool formation were also noted.

Phase-2 LWD Measurements

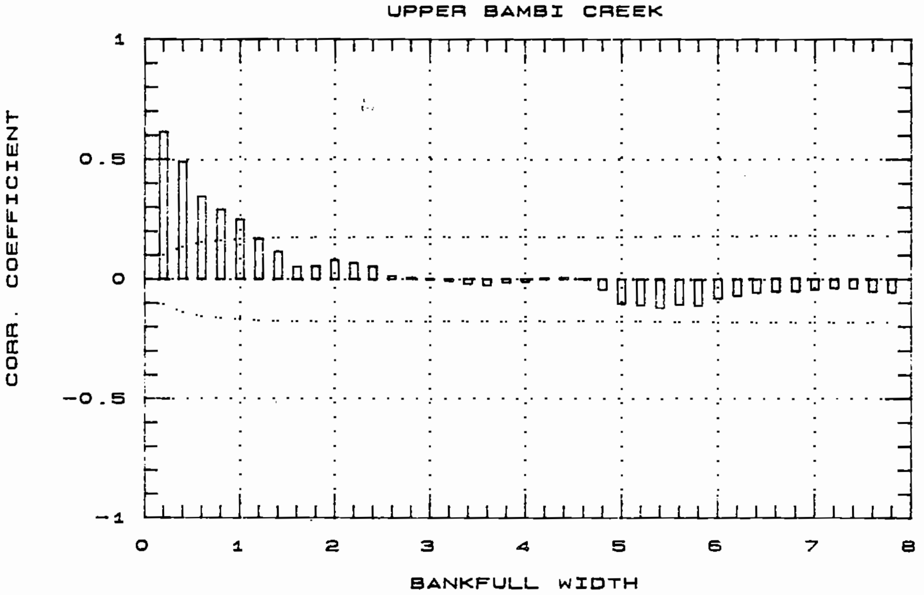
Along all the study reaches each piece of LWD over 8 inches in diameter and five feet long was identified as to species, location, and decay class (Table 3). The large end diameter, average diameter, and length were measured or estimated. Horizontal and vertical orientations of each piece to the stream were also determined (Figures 4 and 5). Measurements of horizontal and vertical orientation were often difficult to obtain because the LWD would often have a curved shape (i.e., sweep). In these cases a best guess was made after making measurements with protractors and clinometers. Exact measurements were often impossible due to the LWD being partially buried, underwater, and/or irregularly shaped due to decay.

The relative proportions of each debris piece within four "influence zones" was also determined (Figure 6). Zone 1 included that percentage of the debris in the

Table 3. A 5-class system of decay based on fallen Douglas Fir trees.a

Characteristics of fallen trees	Decay class I	II	III	IV	V
Bark	Intact	Intact	Trace	Absent	Absent
Twigs, 1.18 inches (3 cm)	Present	Absent	Absent	Absent	Absent
Texture	Intact	Intact to partly soft	Hard, large pieces	Small, soft blocky pieces	Soft and powdery
Shape	Round	Round	Round	Round to oval	Oval
Color of wood	Original color	Original color	Original color to faded	Light brown to reddish brown	Red brown to dark brown
Portion of tree on ground	Tree elevated on support points	Tree elevated on support points but sagging slightly	Tree is sagging near ground	All of tree on ground	All of tree on ground
Invading roots	None	None	In sapwood	In heartwood	In heartwood

a - From Maser et.al (1984)



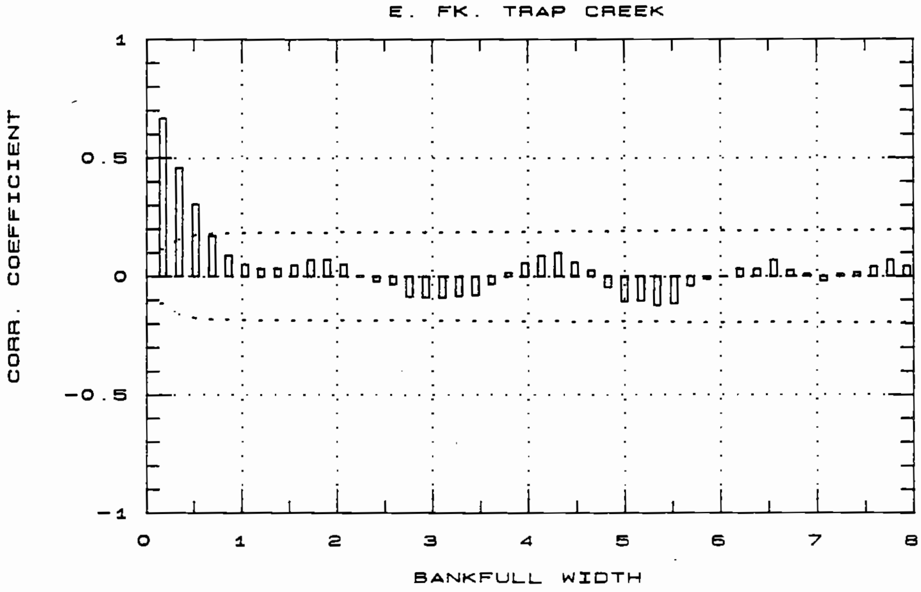


Figure 21. Autocorrelations in bankfull width with longitudinal distance for four of the five study streams.

(Plan view)

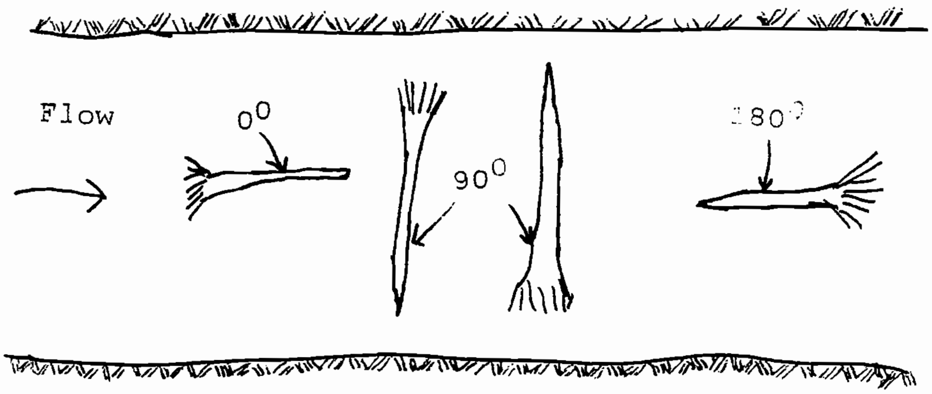


Figure 4. Horizontal orientation of Large Woody Debris to the Channel.

(Cross-sectional view)

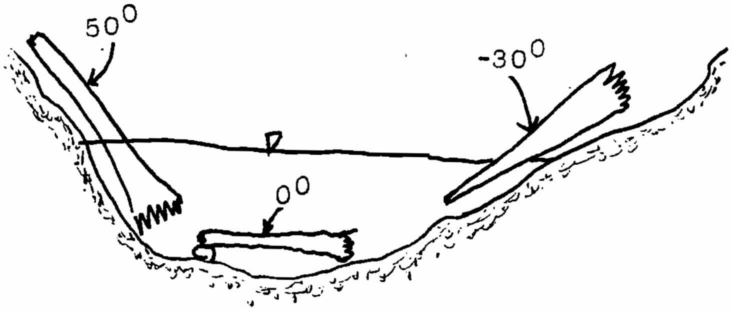


Figure 5. Vertical orientation (angle from horizontal) for Large Woody Debris.

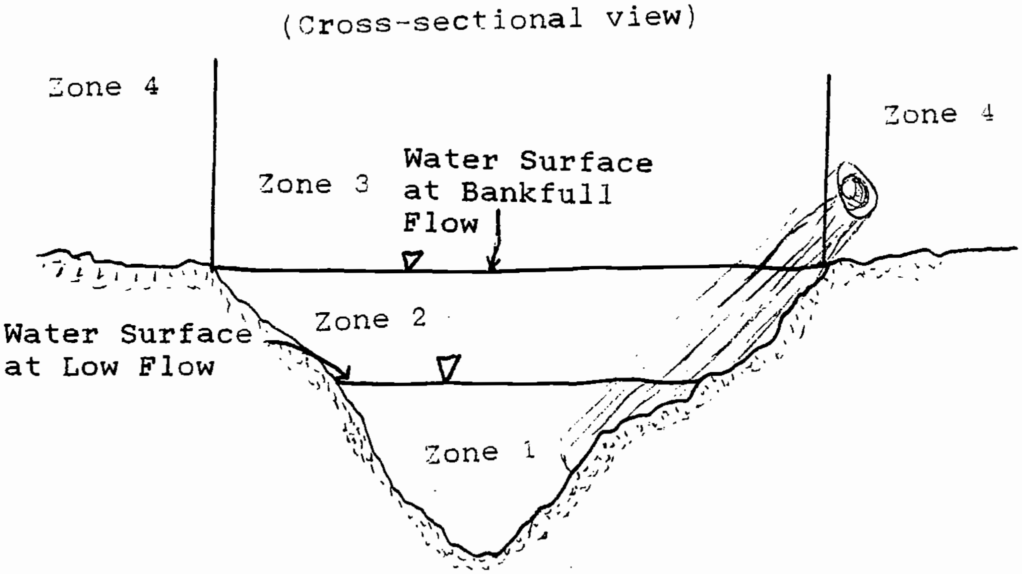


Figure 6. Large woody debris influence zones.

summer flow wetted cross-sectional area, Zone 2 in the bankfull flow wetted cross-sectional area, and Zone 3 in the area directly above Zones 1 and 2. Zone 4 includes the LWD outside Zones 1, 2, or 3. The LWD piece had to have some portion of itself in Zones 1, 2, or 3 in order to be counted. Each LWD piece was also characterized as being "grouped" or "ungrouped" based on whether the piece was in any way touching another piece. It was also noted whether LWD had it's rootwad in the channel or not and whether the debris was mostly-, partly-, or unburied.

Phase 3 Timber Cruising

At fifty feet intervals on alternating sides of the stream, the standing timber's species, stems per acre, and basal area was determined using a variable plot cruising method (Dilworth 1981). This was done using a 40 "BAF" (basal area factor) prism. If a tree was determined as "in", its DBH (diameter breast height) was measured to calculate stems per acre. If an "in" tree was dead and broken off and could not reach the stream if blown over, it was not counted. This was done to avoid counting stumps, that would not effect the stream in the future, for estimated basal area.

In variable plot cruising the BAF is normally based on a circular plot, but in this study only "half plots" were measured from the stream bank. To compensate, the angle of the side of the stream was also measured (Figure 7), and the corrected basal area and stems per acre were calculated by the following equation:

$$BA_{corr.} = BA_{meas.} \times \frac{360}{\text{Bank Angle}}$$

The bank angle measurement was often difficult to determine because of variable bank morphology. In cases where the bank was protruding or receding measurements were made at the estimated halfway point between protrusion and recession (Figure 7).

In areas where there was an island caused by a side channel the measurements were taken from a point on the side channel's outer bank unless the island was greater than fifty feet wide. In this case the measurement was simply taken as normal from the bankfull mark of the main channel.

Phase 4-Localized Channel Effects

At fourteen deliberately selected sites, cross-sectional stream measurements were obtained at 0.5 to 2.0 foot intervals to characterize the dimensions of different pools caused by LWD. The procedure was to use a tape and a leveling rod to measure depth at various distances from an anchor point both longitudinally and laterally. This would form a matrix that delineated pool shape. The size and position of debris in respect to this matrix was also determined.

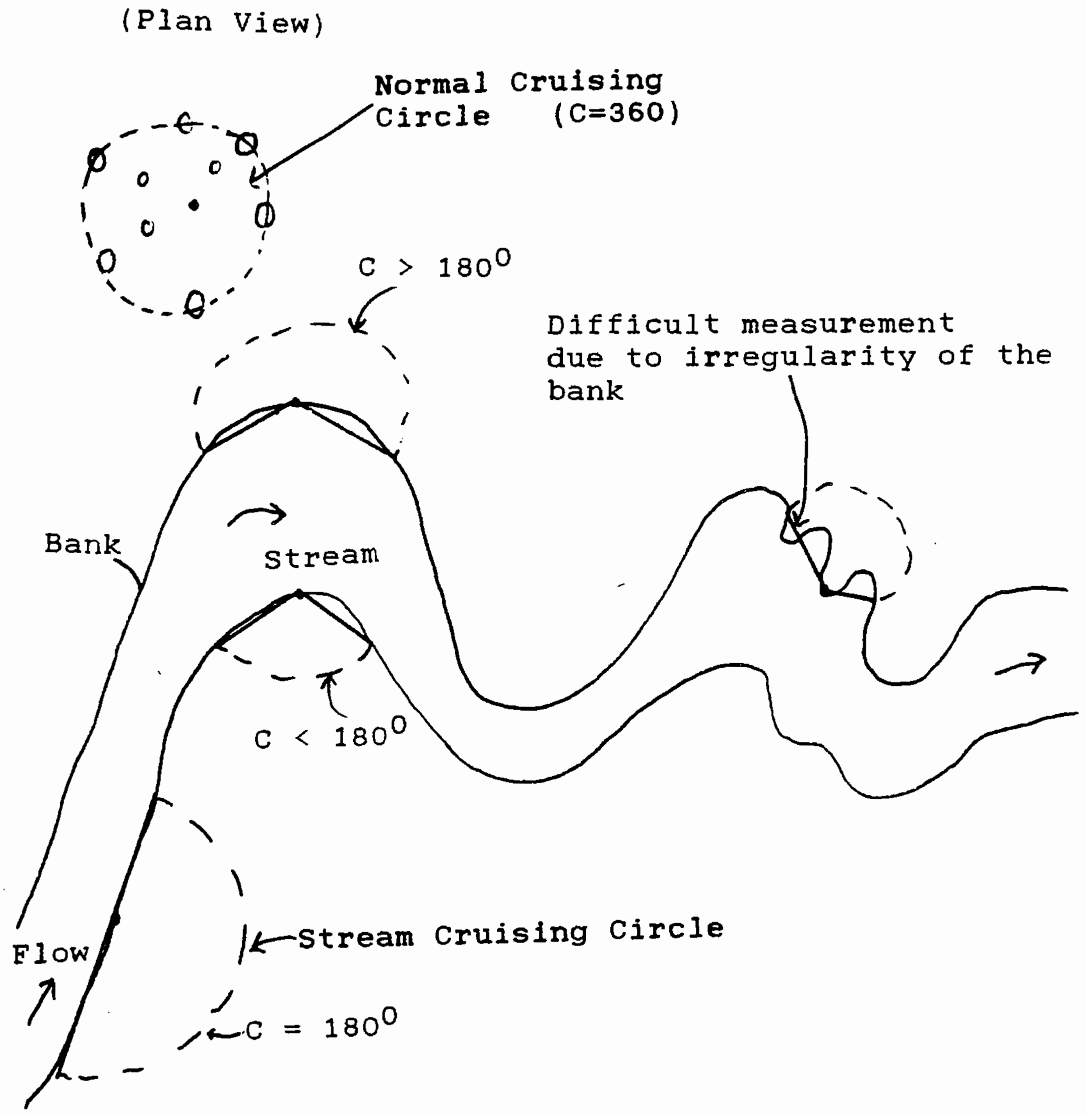


Figure 7. Measurement of bank angle (C) for variable plot cruising.

DATA ANALYSIS

The data analysis consists of computing and comparing summary statistics, frequency distributions, spatial distributions, regressions and time series analyses for the different streams. Almost all statistics were computed using the Statgraphics Statistical System (STSC 1986) for the IBM PC.

Summary statistics (i.e., mean, standard deviation, etc.) were initially calculated for each feature. The next step was to generate frequency distributions and test to see what kind distribution fits the data best using the Kolmogorov - Smirinov statistic (Appendix B). Where a variable significantly fitted (KS > 0.01) a lognormal distribution, as opposed to a normal distribution, log transformations of the data were performed for subsequent data analysis. Simple linear regression analysis (Neter et.al. 1983) was used to determine relationships in and between stream morphological features, debris, and stand characteristics. Significance levels were set at alpha= 0.05 (significant) and alpha= 0.01 (highly significant).

The spatial distribution of LWD and morphology was used to compare and contrast different sized streams.

Time series analytical methods were used in comparing "space series" for patterns in debris and morphological features. A "space series" is a sequence of values collected over a given space (Yevjevich 1972). These values can either be discrete (collected at distinct points) or continuous (collected without breaks) or an average of a discrete groups (Haan 1977). Spatial distributions (space series) can have deterministic components like trends, periods, and jumps and/or random components. In all instances, linear trends in data were removed prior to subsequent time series analysis.

Two important analytical methods for evaluating space series are autocorrelation (a variable string correlated against itself) and cross-correlation (a variable string correlated against another string). The shape of the correlogram can indicate trend, periodicity, and "memory" of the system (Haan 1977).

RESULTS AND DISCUSSION

The diversity of data provided an opportunity to undertake a wide variety of analyses. The results of these analyses have been divided into five sections: 1) riparian stand; 2) LWD; 3) stream morphology; 4) stand, LWD, stream and morphological interactions; and 5) localized effects of LWD.

RIPARIAN STAND

The three principal tree species present along the study streams were sitka spruce, western hemlock, and red alder. On all the streams spruce and hemlock comprised 75% or more of the basal area (Table 4).

Beach Creek had the second highest basal area (397 ft^2/ac.) and second lowest stems per acre (139 stems/ac.) (Table 4) indicating the presence of relatively large trees along this stream. East Fork Trap Creek had the second lowest basal area (325 ft^2/ac.) and the lowest stems per acre (136 stems/ac.) indicating a poor growing site and/or a high incidence of blowdown. From field observations and relatively high volumes of instream LWD (Table 5) it appears that East Fork Trap Creek had more blowdown than the other streams.

Table 4. Basal area and stems per acre for standing trees along the riparian zone.

Characteristic	Stream					
	Beach Cr.	Upper Bambi Cr.	E.Fk Trap Cr.	Trap Cr.	Kadashan River	Average
Stream Order	1	2	2	3	4	--
Basal Area/ac.						
Average (ft^2/ac)	397	308	325	408	302	348
Std.Dev. (ft^2/ac)	240	166	175	244	168	199
Stems/acre						
Average (#/ac)	139	190	136	241	152	172
Std. Dev. (#/ac)	106	161	123	225	156	154
Proportion of Total Basal Area						
Alder (%)	10	16	0	11	25	12
Spruce (%)	59	39	46	55	62	52
Hemlock (%)	31	44	54	34	13	36

Table 5. Large woody debris average volume, size and other characteristics for the five principal study streams.

Characteristic	Stream					
	Beach Cr.	Upper Bambi Cr.	E.Fk. Trap Cr.	Trap Cr.	Kadashan River	Average
Stream Order	1	2	2	3	4	--
Total Volume/ Str. Len. (ft^3/ft)	4.0	3.9	6.5	6.0	11.4	6.4
Zone 1+2 Vol./ Str. Length (ft^3/ft)	0.8	0.8	2.4	2.6	6.8	2.7
Avg. Volume/ Piece ($ft^3/Pi.$)	53	51	52	58	108	64
Avg. Large Diameter(in.)	21	18	20	21	26	21
Average Piece Length (ft.)	26	22	22	24	30	25
Total Vol./ Bankfull Flow Surface Area (ft^3/ft^2)	0.25	0.26	0.22	0.14	0.13	0.20
Zone 1+2 Vol./ Bankfull Area (ft^3/ft^2)	0.047	0.053	0.083	0.061	0.080	0.065
Zone 1 Vol./ Wetted Area (ft^3/ft^2)	0.026	0.042	0.057	0.044	0.060	0.046

The basal area and stems per acre measurements had relatively high standard deviations (Table 4). The apparent random nature of blowdown and the offsetting effect of channel meanders caused considerable variation in basal area (Figure 8) and stems per acre measurements. Variation increased as streams would flow through marshes and muskegs with no trees, yet a few feet downstream or upstream the stream would be surrounded by heavy timber.

The percent basal area for alder was relatively high along Kadashan River in relation to the other streams (Table 4). From interpretation of air photos it appears that a one-sided alder corridor that alternates from side to side is being formed on the inside, of meander bends along the Kadashan River (Figure 9). As a channel cuts laterally along the outside of a meander bend, deposition occurs along the inside and the inside area is eventually abandoned by the active channel. On these abandoned sites brush and alders appear before the coniferous trees as an earlier stage of a succession. To test this hypothesis, the bank angle measurements (Figure 7) were regressed against total basal area, stems per acre, and basal areas for the given tree species. For the Kadashan site, it was expected that the outside of meander bends (angle measurements > 180, Figure 7) would have larger basal area measurements than the ones on the inside of meander bends. No significant results were found for any of the streams

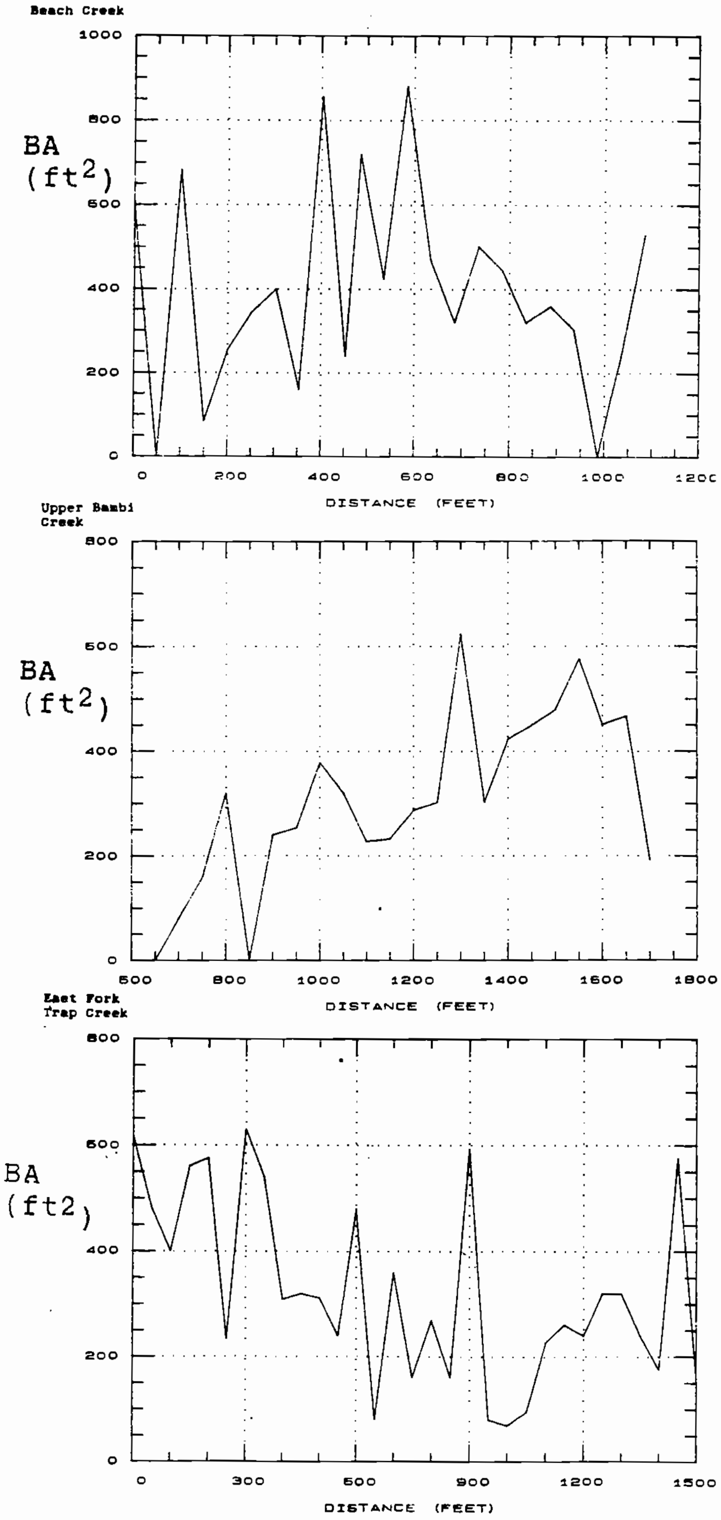


Figure 8. Basal area per acre (BA) with longitudinal distance for the five study streams.

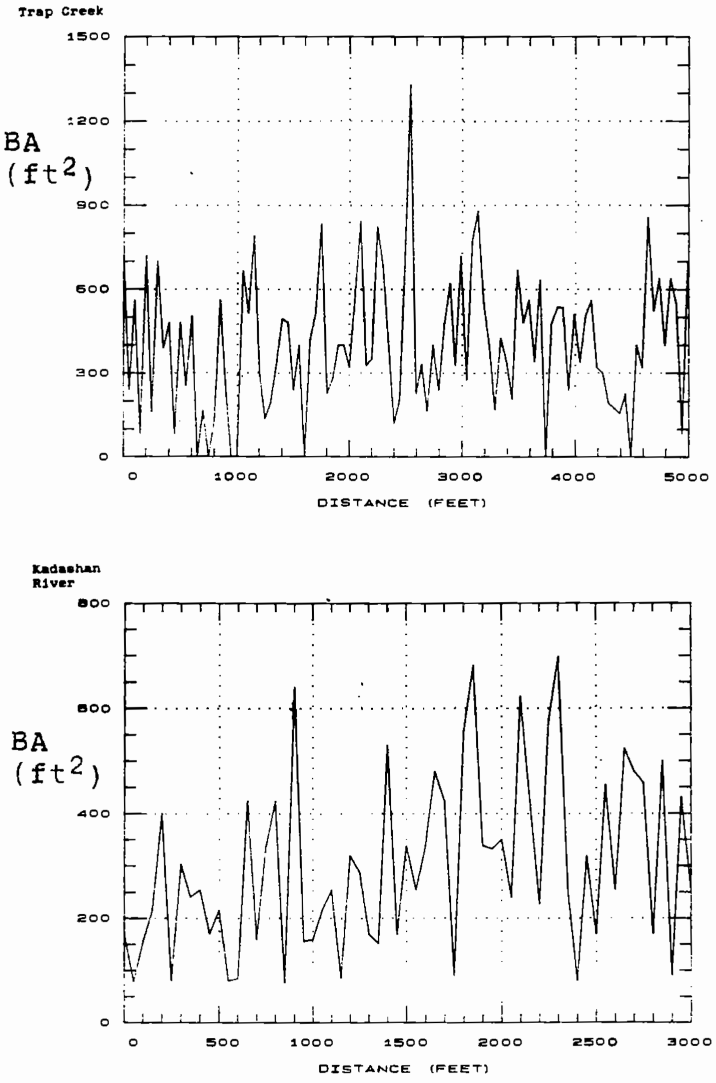


Figure 8. Continued.

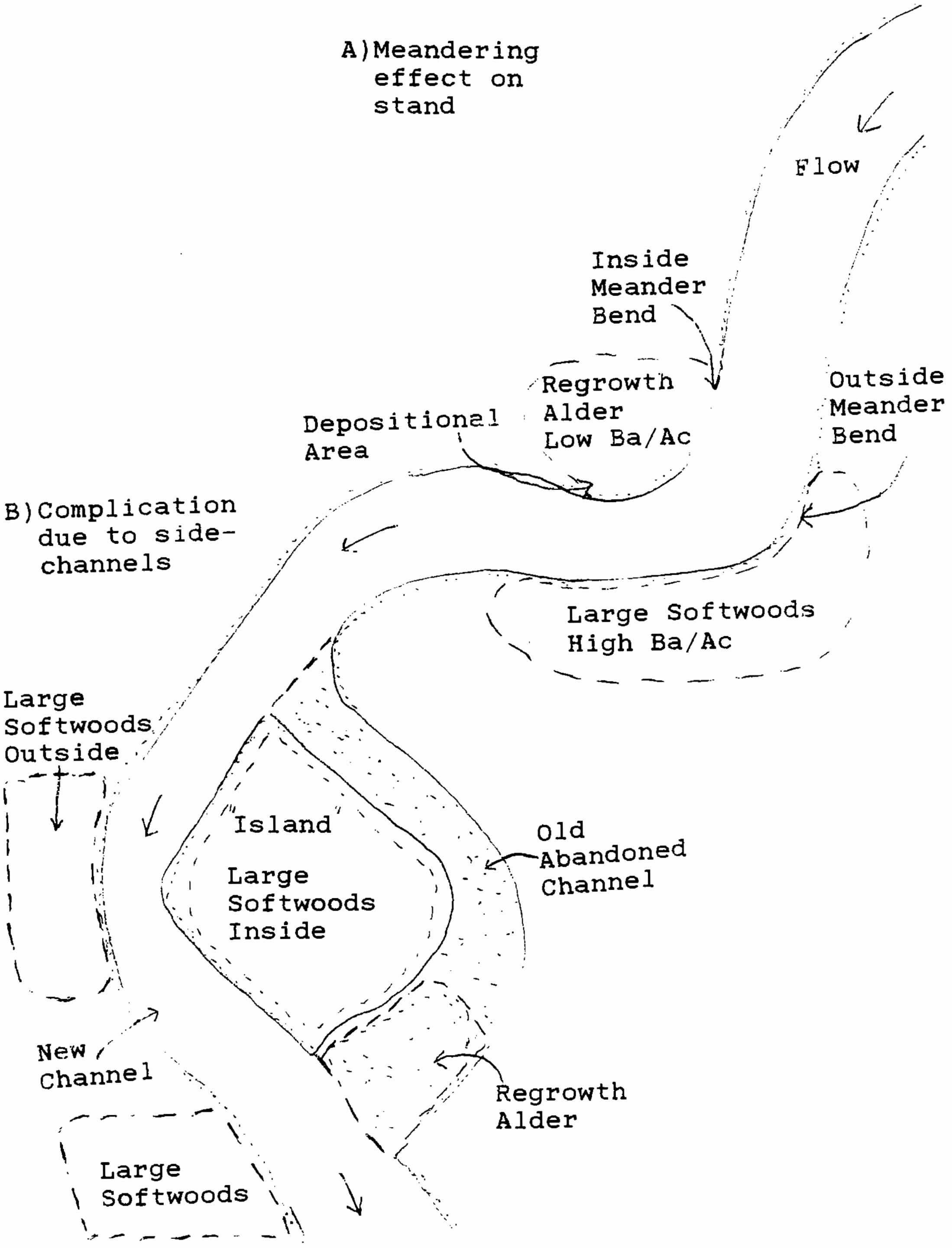


Figure 9. Plan view of meandering effect on stand composition and the complicating factor of side channel formation.

and for all the streams r^2 values were below 5%. High variability in the measurements and the complicating factor of side channel formation (Figure 9) may have been factors that precluded the occurrence of any linear relationship.

LWD

Characteristics

The variation in LWD volume with stream size depended on the method used to summarize volume measurements (Table 5). If total volume (for all four zones, Figure 6) per stream length was used, debris volume increased with increasing stream size. For example, with a change from third to fourth order total volume increased from 6.0 ft^3/ft to 11.4 ft^3/ft (Table 5). When total volume was divided by bankfull flow surface area, the two smaller streams had the larger volumes (Table 5). When Zone 1+2 volume was divided by bankfull flow surface area, East Fork Trap Creek had the greatest volume (0.083 ft^3/ft^2) and the larger streams had greater volume than the smaller streams (Table 5).

The apparent "flip-flop" in LWD volume/stream size trend between methods of measurement is because the LWD is typically found in different influence Zones (Figure 6) as stream size changes. For instance the amount of LWD in Zone 1 varies from 6% to 7% in the two smallest streams up to 28% in the largest stream (Table 6). Volume percentage in Zone 1+2 increases from 21% in the first order stream to 60% in the fourth order stream (Figure 10). The amount of wood in Zone 4 decreases from 56% in the smallest stream to 12% in the largest stream (Table 6).

There are several reasons why these trends occur. In the two smallest streams, average bankfull width is under 17 feet (Table 2) so that most LWD recruited by blowdown or bank erosion would land on the streambanks. Average piece length (26 and 22 feet for Beach and Bambi Creeks respectively) exceeds bankfull width which often causes LWD to be suspended above the estimated bankfull level of the stream. By falling on the streambanks, debris can also break, which explains the smaller volumes and lengths per piece in the smaller streams (Table 5). In the larger and wider streams (Trap Creek and Kadashan River) LWD can fall directly into the channel due to wider bankfull widths (42 and 85 feet, respectively) (Table 2). These widths typically exceed average piece lengths. Also, with more stream surface area even the larger LWD pieces can lie completely within Zones 1 and/or 2. Zone 1+2 LWD volume, because it is the fraction of LWD that interacts with water and creates channel features, is probably a better index of LWD volume than total LWD volume.

The LWD piece size distributions also indicated that LWD piece volumes increased with increasing stream size

Table 6. Percentage of large woody debris volume in the different influence zones for the five study streams.

Zones	Streams					
	Beach Cr.	Upper Bambi Cr.	E.Fk. Trap Cr.	Trap Cr.	Kadashan River	Average
Stream Order	1	2	2	3	4	--
% Zone 1	7	6	18	25	28	17
% Zone 2	14	13	19	18	32	19
% Zone 3	23	40	33	34	28	32
% Zone 4	56	41	30	23	12	32

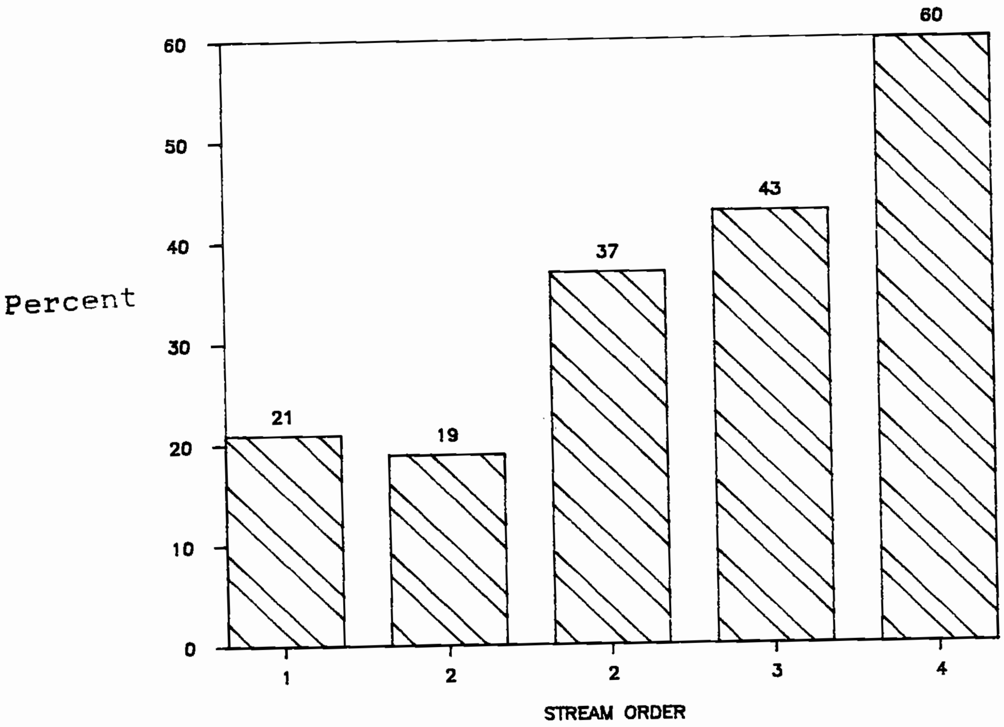


Figure 10. Percentage of total large woody debris in Zone 1+2 with increasing stream size for the five study streams.

(Table 7). On all streams most pieces were clustered between 0 and 100 cubic feet and the distributions were lognormal, but Kadashan River's distribution had a relatively greater number of pieces in the larger size classes (Table 7).

The proportion of LWD with its rootwad in the channel increased with increasing stream size (Table 8, Figure 11). One possible reason for this increase is that larger streams may have more debris recruitment due to local bank erosion. LWD entering the stream by streambank erosion would have their rootwads along the channels edge and the flow could easily divert around it causing the rootwad to be in the channel. A second cause could be that larger channels have a greater ability to move laterally. In either case the relative percentage of rootwads in the channel may be an indicator of a lack of streambank stability and/or a streams capability to move laterally and recruit LWD.

There is no apparent trend in LWD grouping with changes in stream size (Table 8), however field observations indicated the types of debris groups varied with stream size. In the first- and small second-order stream LWD was grouped in clusters due to episodic blowdown events and LWD pieces were scattered randomly, in some cases barely touching. In the larger second- and third-order streams LWD was grouped in clusters from

Table 7. Relative frequency of large woody debris by volume of individual pieces.

	Streams					
	Beach Cr.	Upper Bambi Cr.	E.Fk. Trap Cr.	Trap Cr.	Kadashan River	Average
Stream Order	1	2	2	3	4	--
Piece Volumes(ft^3)			Relative Frequency			
0-25	0.52	0.60	0.48	0.50	0.31	0.48
26-50	0.10	0.08	0.25	0.19	0.23	0.17
51-100	0.23	0.16	0.14	0.14	0.18	0.17
101-200	0.10	0.08	0.09	0.10	0.14	0.18
201-400	0.05	0.08	0.03	0.06	0.08	0.06
401-800	0	0	0.01	0.01	0.04	0.01
801-1200	0	0	0	0	0.02	0.01

Table 8. Large woody debris placement, species, and age characteristics for the five study streams.[a]

Characteristic	Stream					
	Beach Cr.	Upper Bambi Cr.	E.Fk. Trap Cr.	Trap Cr.	Kadashan River	Average
% Rootwads in the Channel	2	6	24	24	32	18
% Debris Grouped	67	58	52	68	53	60
% Debris not Buried	59	94	72	67	79	74
% Debris Alder	12	12	4	16	31	15
% Decay Groups 4 or 5 (advanced decay)	47	47	51	49	54	50
Vertical Orien. (Deg.) Average	-1.5	0.1	2.6	1.0	-0.2	0.4
Std.Dev.	0.7	11.1	14.0	8.4	5.5	7.9

a - On a large woody debris piece percentage basis.

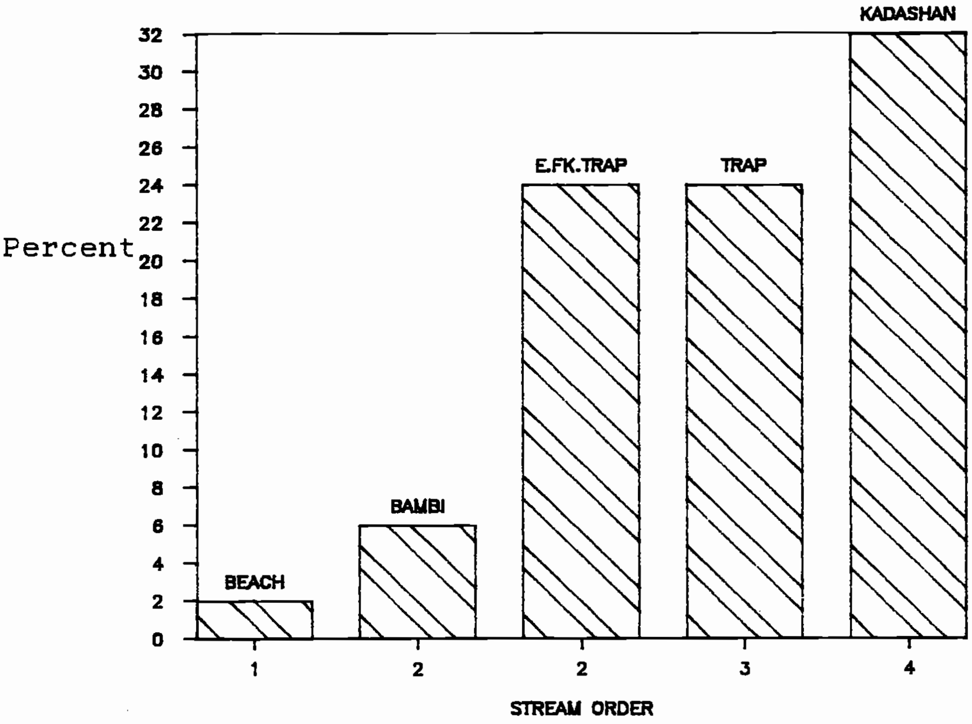


Figure 11. Percentage of large woody debris pieces with rootwad in the channel for the five study streams.

blowdown and in LWD jams caused by floated debris. In these streams, debris jams of LWD pieces were tightly packed against an obstruction which often was a relatively large LWD piece. In the fourth order stream, LWD seemed to be primarily grouped in debris jams with clusters from blowdown having a lesser role. There was no apparent trend in degree of burial and decay classes between streams (Table 8). The proportion of Alder comprising the total amount of LWD in and near the stream was greatest for the Kadashan River (Table 8). This agrees with the findings from the riparian stand section and indicates that the alder corridor along Kadashan River provides alder to the stream.

The LWD's vertical orientation in relation to stream flow (Figure 5) was close to 0 degrees for all streams with high standard deviations (Table 8). The LWD's horizontal orientation in relation to the channel (Figure 4) was found to cluster around 90 degrees for all streams (Figure 12). There is little difference between ungrouped and all LWD in evaluating these figures. Also the percentage of LWD at or below 80 degrees orientation did not increase or decrease with increasing stream size (Figure 13). These results suggest that the majority of LWD in these study streams has not been moved by fluvial activity. According to Hogan's (1985) interpretation of Figures 5.10 and 5.11, "moved" LWD has an "even"

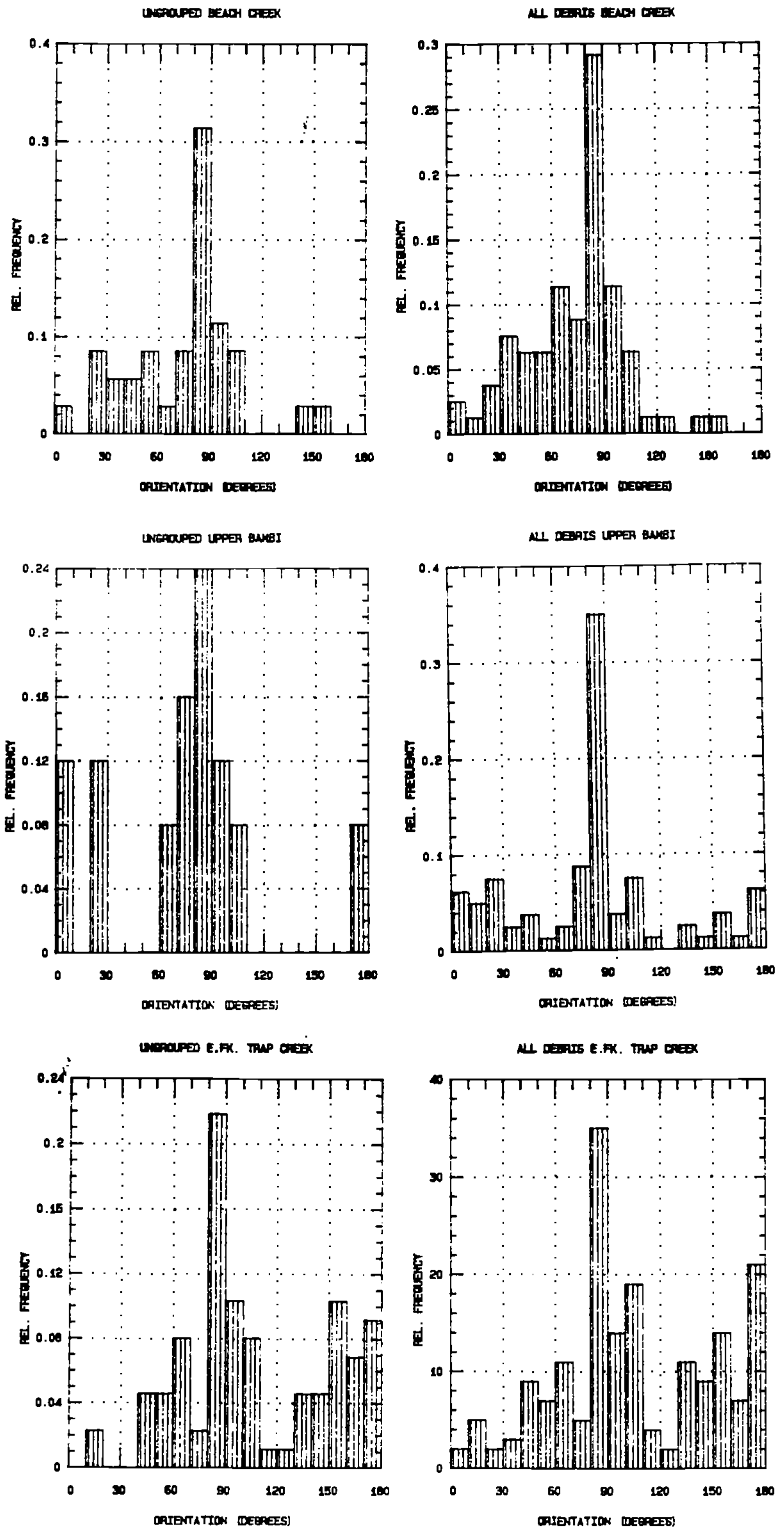
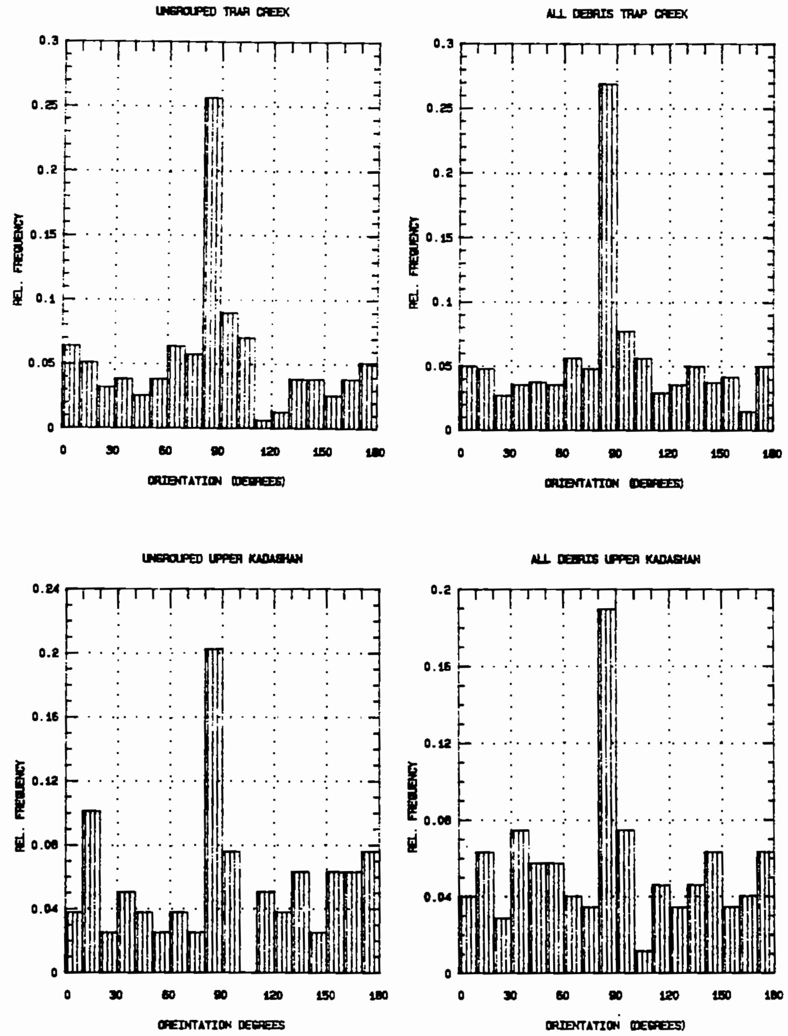


Figure 12. Relative frequency histograms of a) ungrouped and b) all large woody debris pieces for Beach, Upper Bambi, and E. Fk. Trap Creek.



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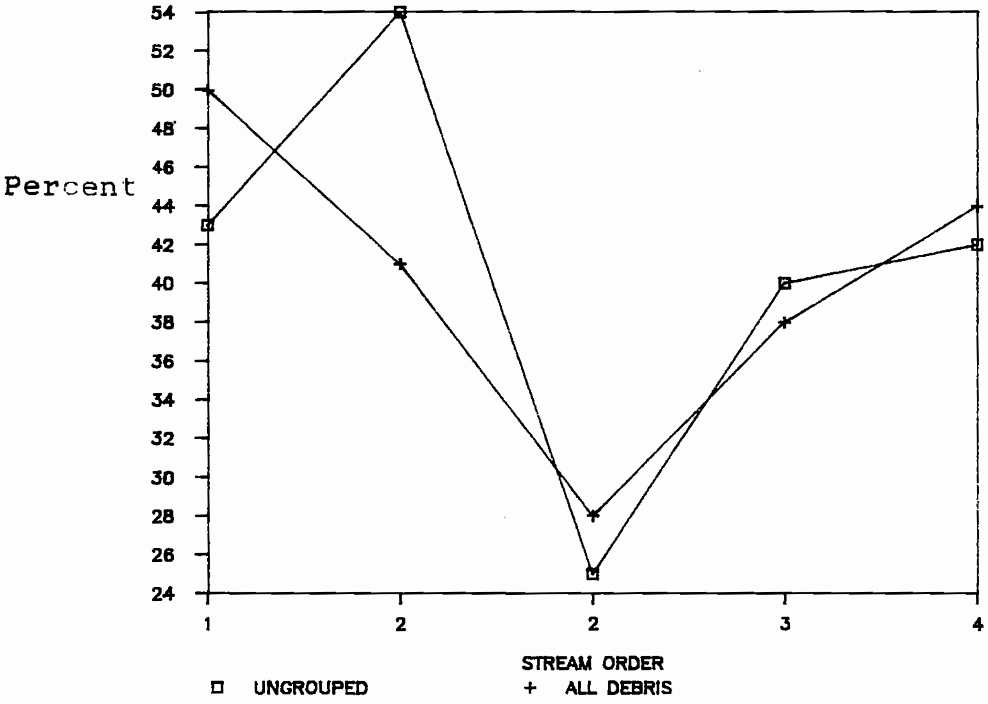


Figure 13. Percent of large woody debris pieces that have horizontal orientations between 0 and 80 degrees for the five study streams.

distribution as opposed to "unmoved" LWD that has a "peaked" distribution similar to Figure 12. While all study streams have peaks in their distributions it is important to note that the Kadashan River has the lowest peak and from this it can be inferred that it has the most LWD movement.

These results indicate that LWD orientation changes little with increasing stream size for first- to fourth-order streams. Furthermore, many of the trees apparently fall perpendicular to the stream (peak values clustering around 90 degree orientations in the study streams). This latter result agrees with the findings of Hogan (1987). One possible reason why this occurs could be because the streamside branches of riparian trees receive greater light and would have increased growth and greater weight than branches facing the forest side that would cause a tilting of the tree towards the stream. Another reason could be that stream bank erosion weakens trees and causes them to "slump" or progressively lean towards the stream.

For all the study streams, there was no significant linear relationship between LWD piece length and horizontal orientation (Table 9). In every case the r^2 was less than 10 percent. While length may be an important factor in determining orientation and stability in other streams (Bisson et. al. 1987), these results indicate that such relationships were apparently masked in

Table 9. Horizontal orientation (degrees) verses length for ungrouped large woody debris.

Stream	Regression Results				
	No. Pts.	Regress. Slope (Deg/Ft)	Regress. Inter-cept (Degree)	r^2	Prob-ability Level
Beach Creek	35	0.39	65	0.10	0.07
Bambi Creek	28	0.50	62	0.02	0.47
E. Fk. Trap Creek	91	-0.25	112	0.01	0.29
Trap Creek	163	0.13	81	<0.01	0.68
Kadashan River	89	0.55	68	0.03	0.12

this study by other factors such as degree of burial, relative proportion of LWD in the channel, position in stream (i.e., riffle, pool, etc...), and associations with other LWD pieces.

Spatial Distributions

The longitudinal occurrence of LWD volume (Figures 14 and 15) is highly variable for all five study streams. It is important to note that there are extended reaches of zero volume on Beach and Bambi Creek that are not found on the other streams. Otherwise, each stream has locations of relatively high and low volumes. Along with visual differences in the spatial distributions of LWD volumes, the way in which these distributions are formed are different as indicated previously in the section on LWD grouping.

STREAM MORPHOLOGY

Characteristics

The three smaller streams were steeper than the two larger streams (Table 10). There was an increase in the proportion of side channels and braiding with increased stream size (Table 10, Figure 16). Larger streams have an increased capability to erode channel banks, shift laterally, and form side channels. The East Fork Trap Creek though smaller and steeper than Trap Creek had a

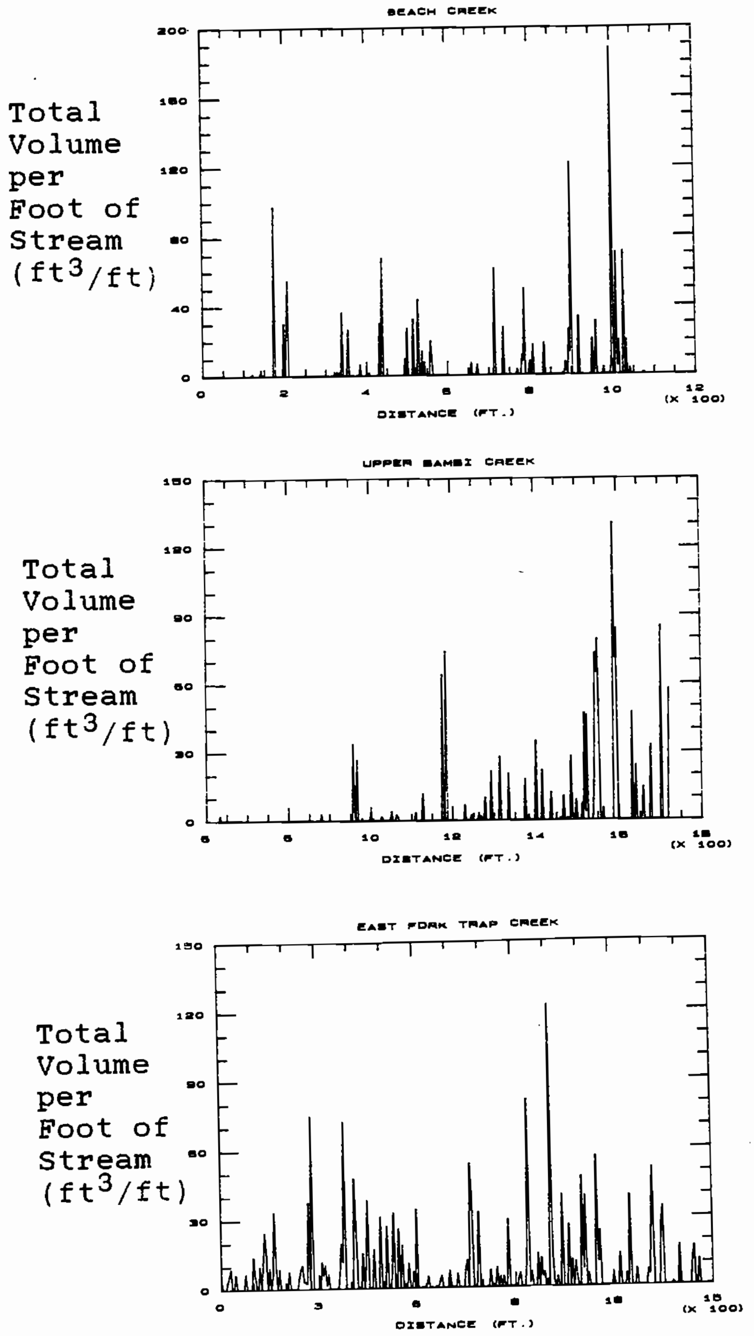


Figure 14. Longitudinal distribution of total large woody debris volumes for the five study streams.

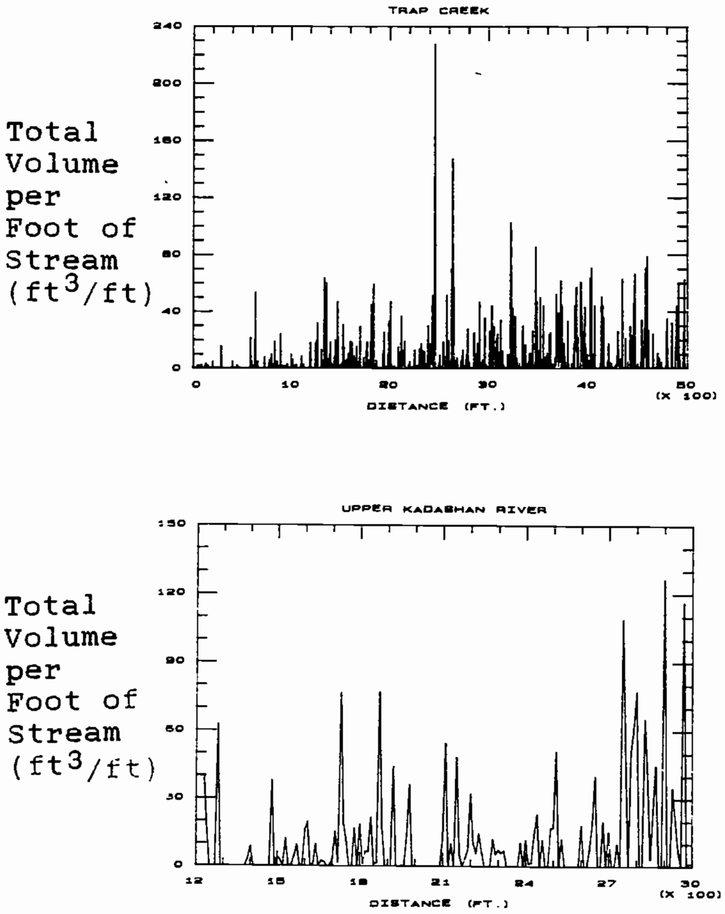


Figure 14. Continued.

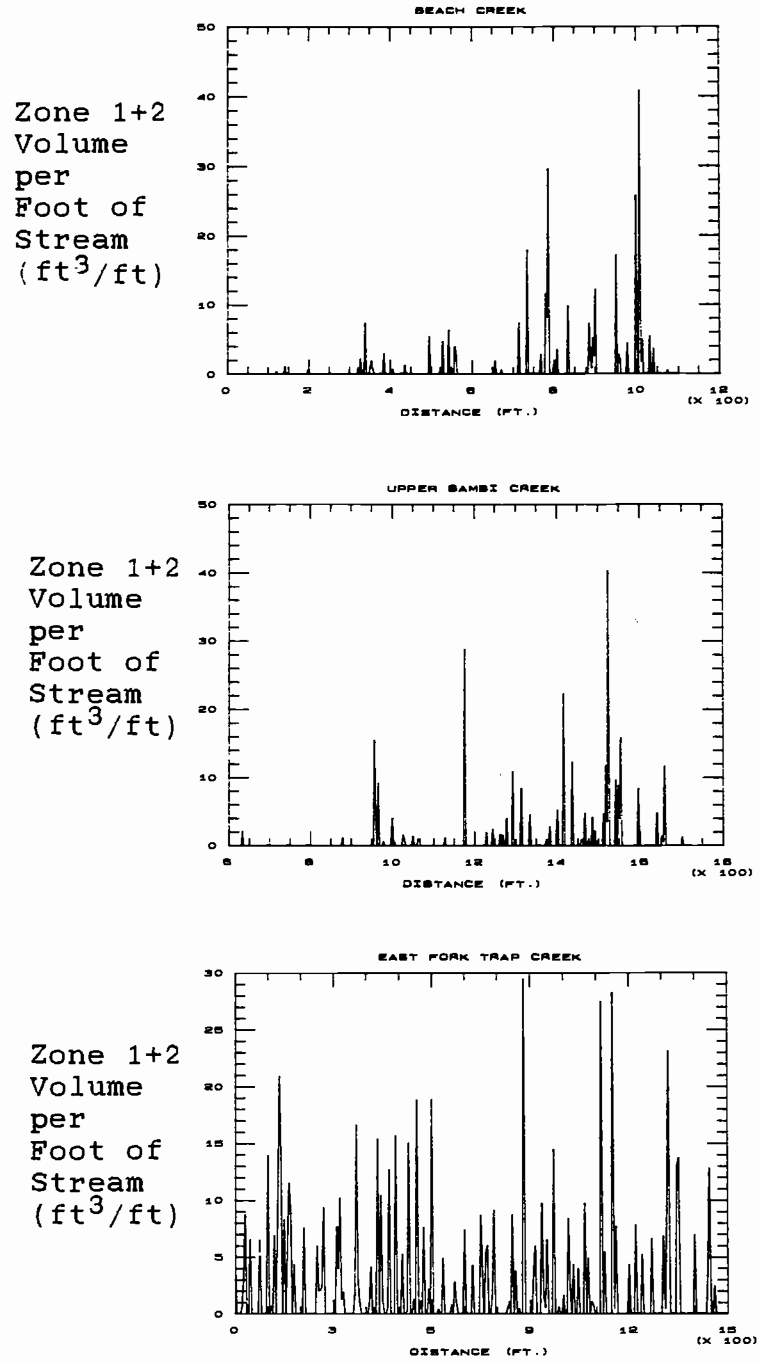
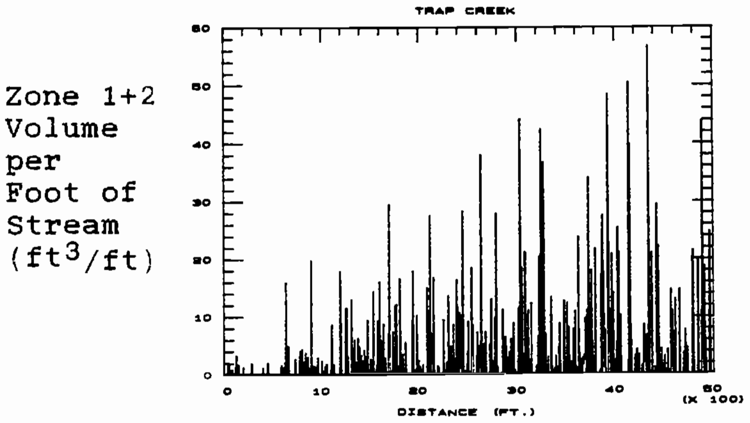


Figure 15. Longitudinal distribution of Zone 1+2 large woody debris volumes for the five study streams.



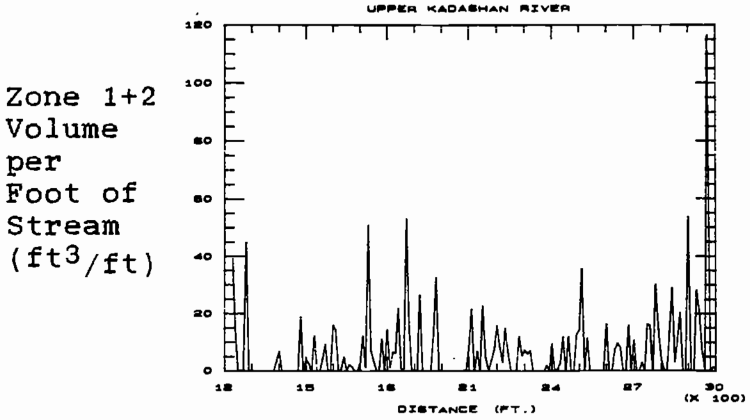


Figure 15. Continued.

Table 10. General morphological characteristics of the five study streams.

Characteristic	Streams					
	Beach Cr.	Bambi Cr.	E. FK. Trap Cr.	Trap Cr.	Kadas-han River	Aver-age[a]
Stream Order	1	2	2	3	4	--
Length of Study Rea.(ft)	1098	1113	1500	5020	3000	--
Avg. Thalweg Depth (ft)	0.8	0.5	1.6	1.9	2.8	1.5
Avg. Low-Flow Width (ft.)	9.8	6.1	21.0	34.1	57.9	25.8
Avg. Bankfull flow Width (ft.)	16.1	15.1	28.9	42.1	85.1	37.5
Avg. Slope (%)	1.6	2.4	2.5	1.1	0.8	1.7
Side Chan. (%)	0	4	27	29	33	19
Braided (%)	1	3	8	4	8	5
Pools (%)	57	33	60	70	65	57
Width/Dep. Ratio (ft/ft)[b]	15	20	15	21	24	19
Number Tributaries	0	1	2	9	1	--

a - Unweighted numerical average of the five study streams.
b - Using low-flow wetted conditions.

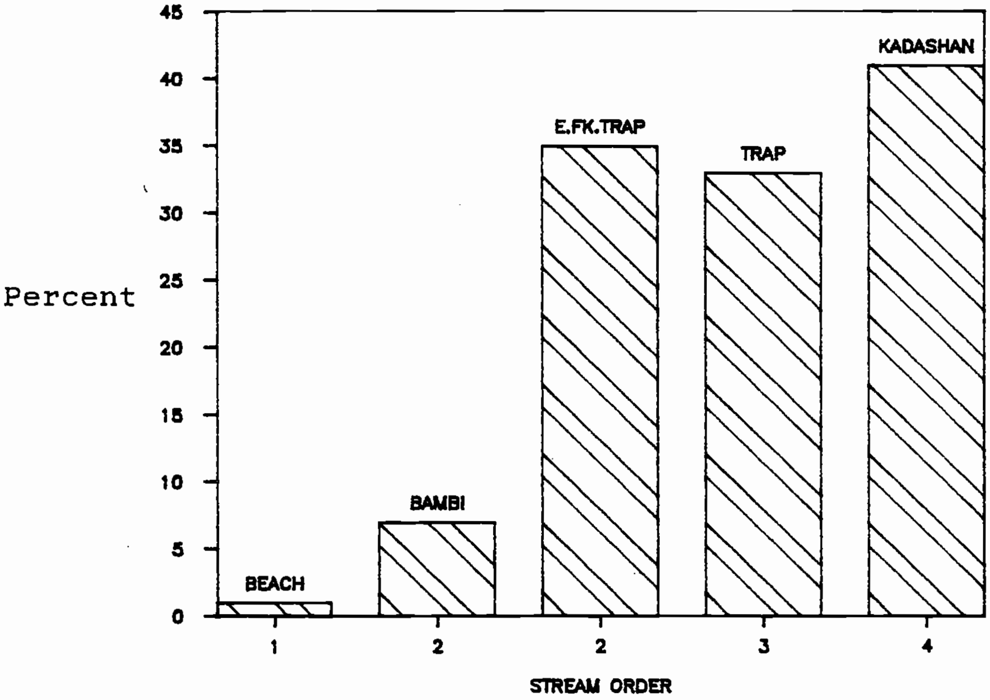


Figure 16. Percent of stream reaches with side-channeling and/or braiding at for the five study streams.

greater proportion of side channels and/or braiding (35 to 33 percent) (Figure 16). The East Fork also had the greatest amount of Zone 1+2 LWD volume per bankfull flow surface area. The increased LWD volume in the channel may be causing the East Fork to split more than the main channel even though the East Fork has less flow.

There is no general trend in percentage of pools with increasing stream size; however, Upper Bambi Creek (2nd Order Stream) has the lowest pool percentage (Table 10). Beach Creek, a similar sized stream with less average LWD per surface area (Table 5), has almost twice the percentage of pools as Upper Bambi Creek (Table 10). This indicates that simply having more LWD volume in the stream will not always insure an increased proportion of pools.

Average width-depth ratios changed little with increasing stream size (Table 10). There was only a small increase in the two larger streams.

Tributaries played a relatively small role in channel formation along the study reaches as there were only a small number of them (Table 10). In Trap Creek there was only one tributary for every 500 feet of stream length. In the Kadashan River there was only one tributary in 3000 feet of stream. All the tributaries along the study reaches with one exception (West Fork Trap Creek) were small 1st order streams that were almost dry in the summer months.

There were several distinct morphological types (Figures 1 and 2) along the thalweg of the study streams (Figure 17). The relative proportions of each type changed with changing stream size. For instance "underflow pools" (Figure 1) were found in less than 10 percent of the points for the four smaller streams, but on the Kadashan River underflow pools comprised 17 percent of the types and were second only to riffles in percentage present (Figure 17). The proportion of "deflector pools" in East Fork Trap and Trap Creek had percentages over 20%, but in the two smallest streams this proportion dropped to less than 11% (Figure 17). The differences in morphological types could be because of the differences in Zone 1+2 LWD volume and piece size with increases in stream size (Figure 10).

There were also several types of "large roughness elements" associated with pool formation (Figure 18). In these situations a pool was formed, at least in part, by flowing water being deflected by such elements. The fluvial process pool forming element indicates that the pool formed independently of any observable roughness element. Except for Upper Bambi Creek, LWD is the predominate element associated with pool formation. In Trap Creek and the Kadashan River almost 50% of all

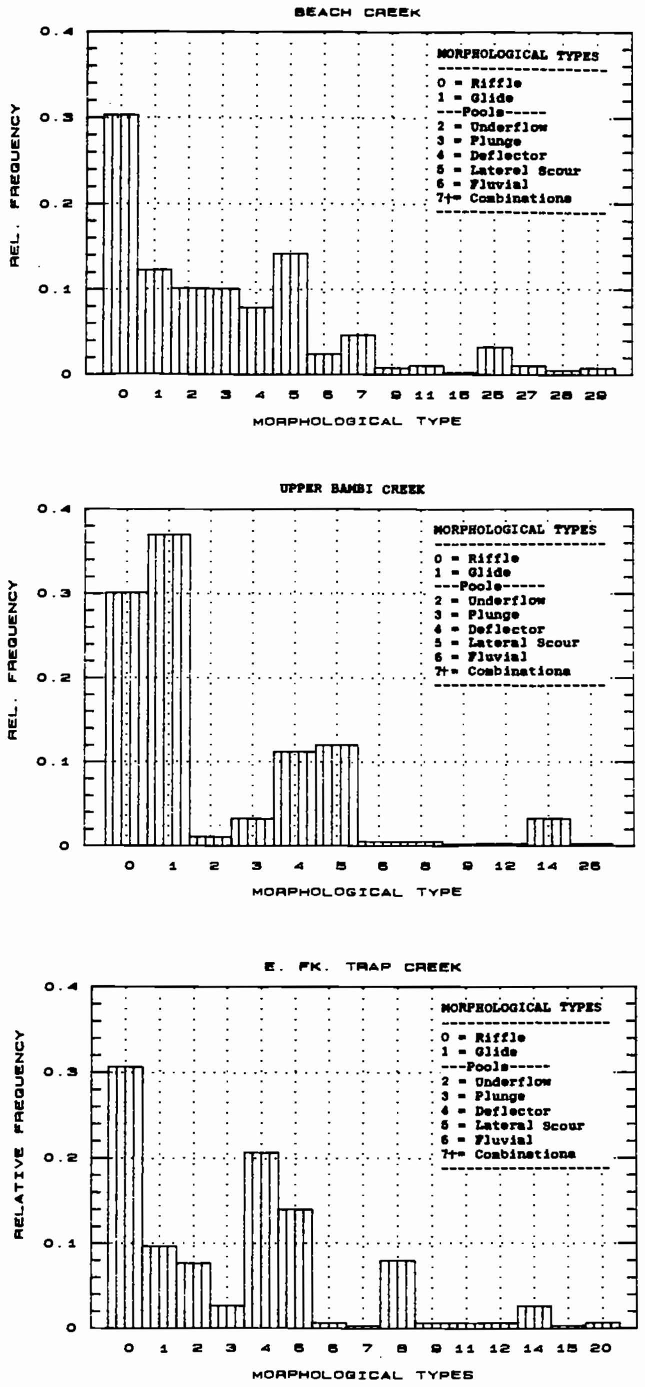
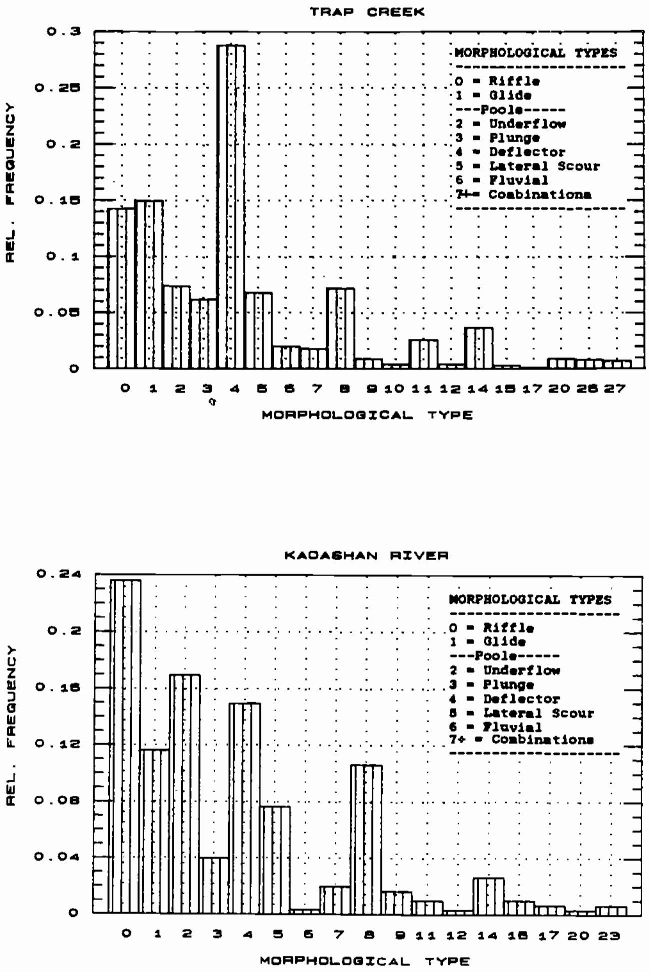


Figure 17. Relative frequency histograms of morphological types for the five study streams.[a]

[a] - All morphological types including combinations are listed in Appendix C.



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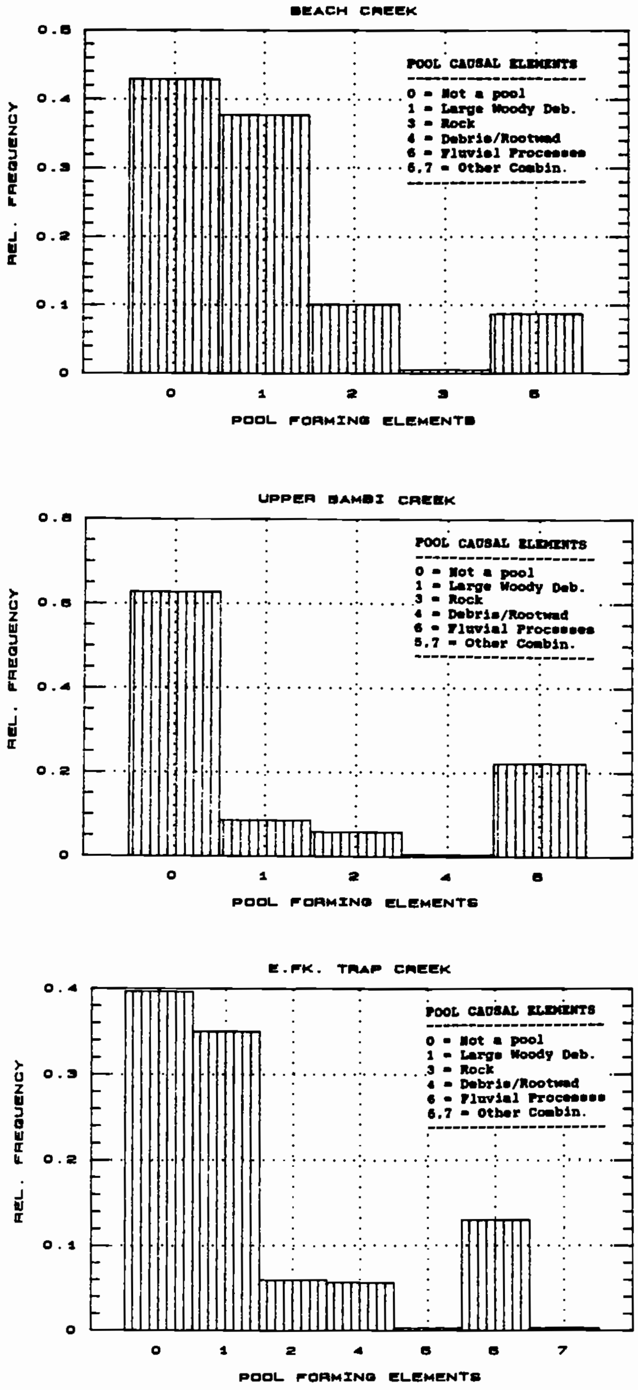
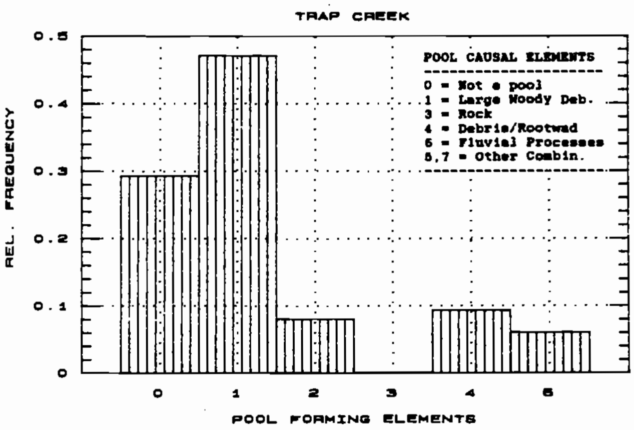


Figure 18. Relative frequency histograms of pool causal elements for the five study streams^a

a - All pool causal elements including combinations are listed in Appendix C.



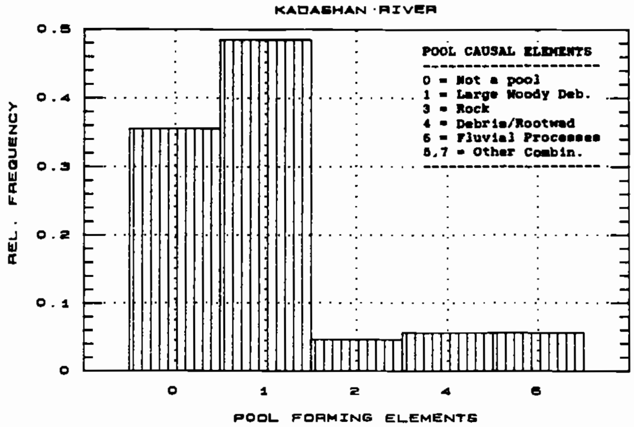


Figure 18. Continued.

morphological types are pools associated with LWD (Figure 18).

The relative importance of pool forming elements was different with different streams (Figure 18). For instance, the percentage of rootwads and/or debris rootwad combinations being associated with pool formation was 9-10% in Beach, East Fork Trap Creek and the Kadashan River, 3% in Upper Bambi Creek, and 18% in Trap Creek.

Cross-Sectional Area Index

Cross-sectional area was calculated from stream cross sections by two methods. The first method was to enter detailed cross-sectional measurements into a computer program for calculating the overall cross-sectional area. A second method referred to as the three point method, used thalweg depth and wetted width measurements from which cross-sectional area was calculated based on the formula for an equilateral triangle:

$$\text{Area} = 1/2\ B \times H$$

Where B = Base (Water surface wetted width)
H = Height (Thalweg Depth).

The needed data for the 3-point method was available at each measurement location, but information for the detailed method was obtained only at every tenth measurement location. If the second method provided a reliable index of cross-sectional area then cross-sectional area could be calculated for every measurement location. A regression analysis was performed between the two methods for common measurement locations to evaluate the usefulness of the 3-point method. Several linear and log transformed regressions were performed all having highly significant relationships (Appendix D). An almost one-to-one relationship was found when all the streams were combined (Figure 19) indicating that the 3-point method does provide a reasonable index for cross-sectional area.

Spatial Series Results

Autocorrelations in depth, bankfull width, cross-sectional area, and width-depth ratio as well as cross-correlations for width verses depth were performed for all five study streams. These analyses are based on the assumption that spatial data can be substituted for temporal data and analyzed with time series techniques. In every case each variable string was log transformed because most variables fitted a lognormal distribution. Linear trends were removed from each data set.

"Memory" and "repeatability" are important characteristics when evaluating the shapes of relationships shown in correlograms (Figures 20-24). Memory is defined here as the influence adjacent measurements have on one another. For instance if thalweg depth is great at one point it will also tend to be deep

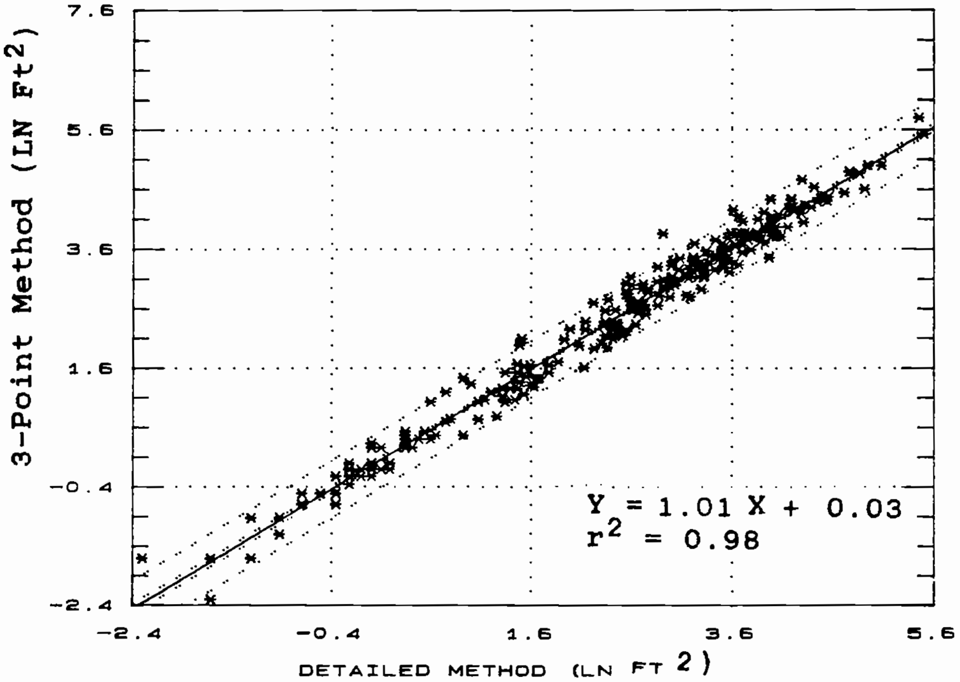


Figure 19. Scatterplot with fitted regression line for the three point method verses the standard detailed measurement method for determining cross-sectional area.

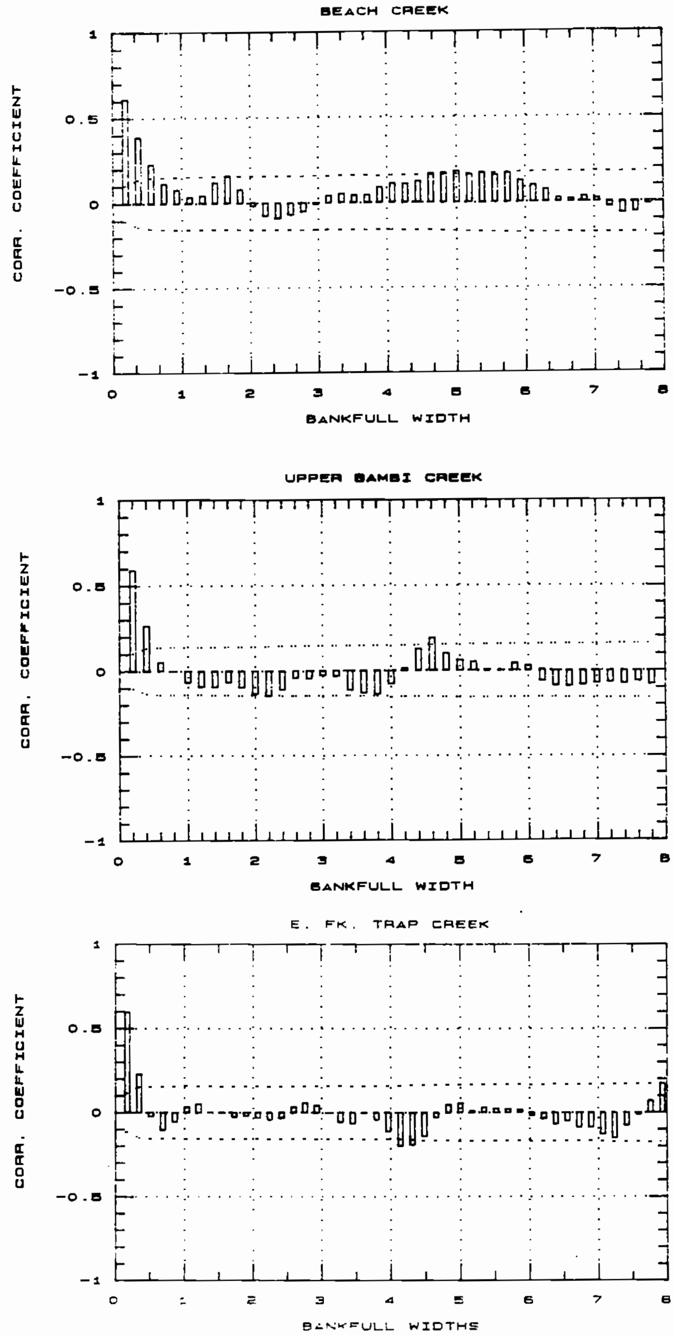


Figure 20. Autocorrelations in depth with longitudinal distance for the five study streams.

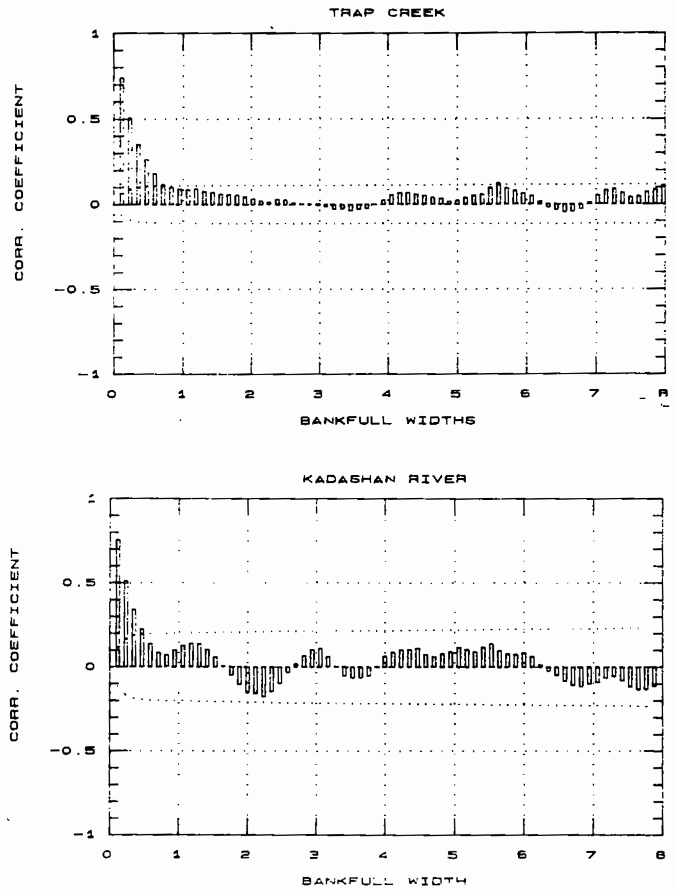
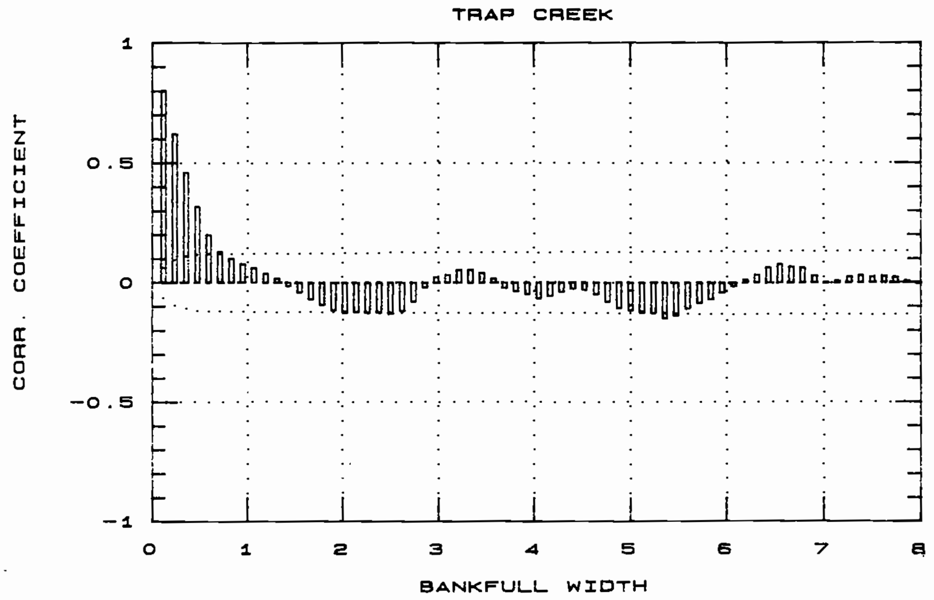


Figure 20. Continued.



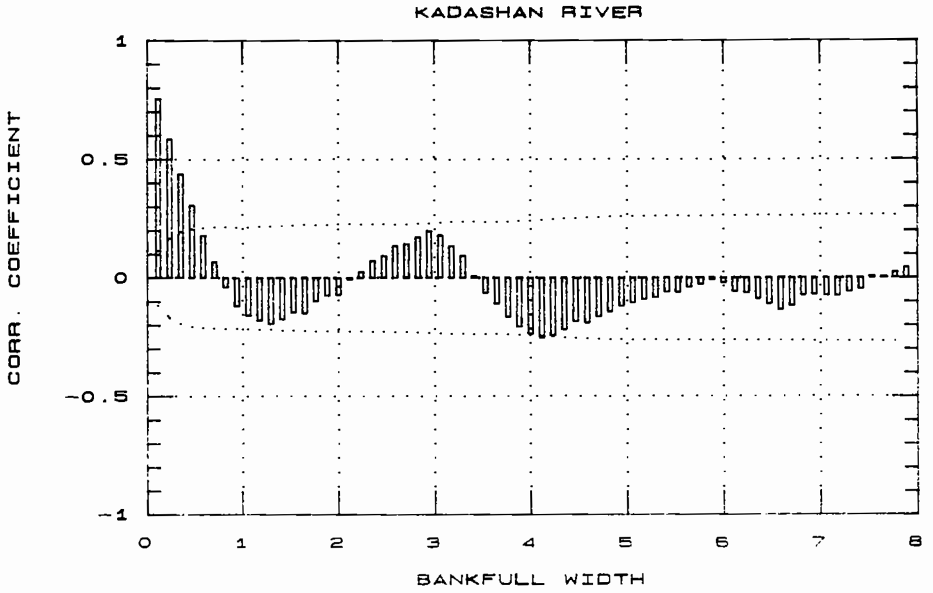


Figure 21. Continued.

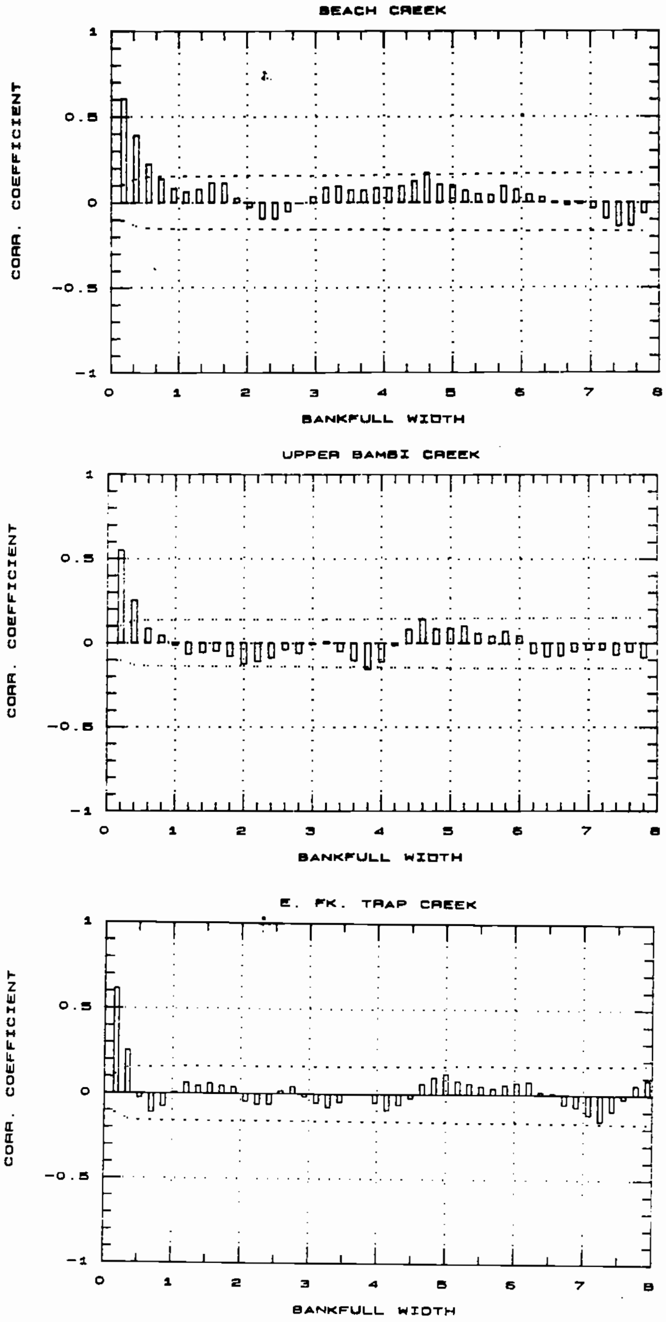


Figure 22. Autocorrelations in cross-sectional area with longitudinal distance for the five study streams.

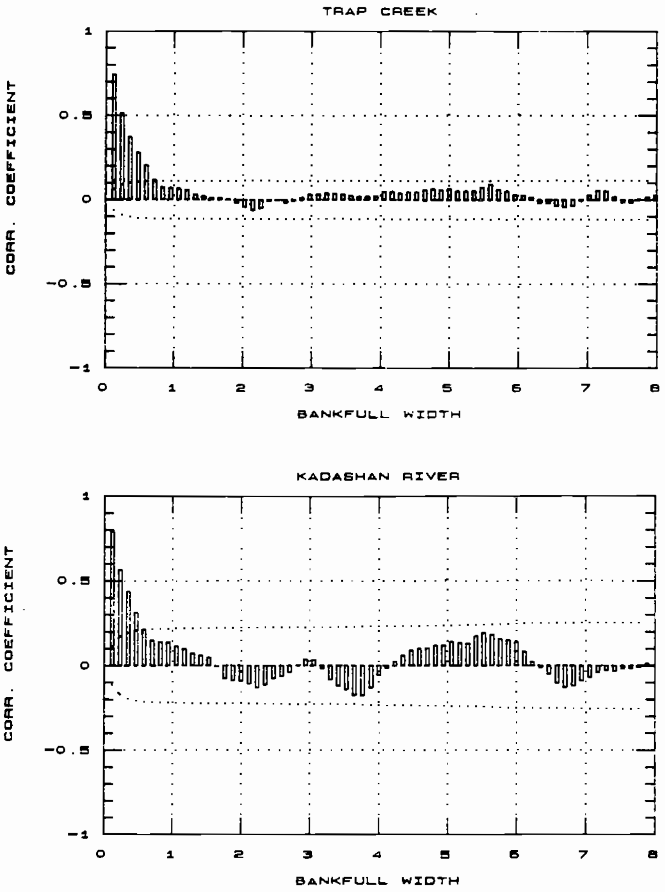


Figure 22. Continued.

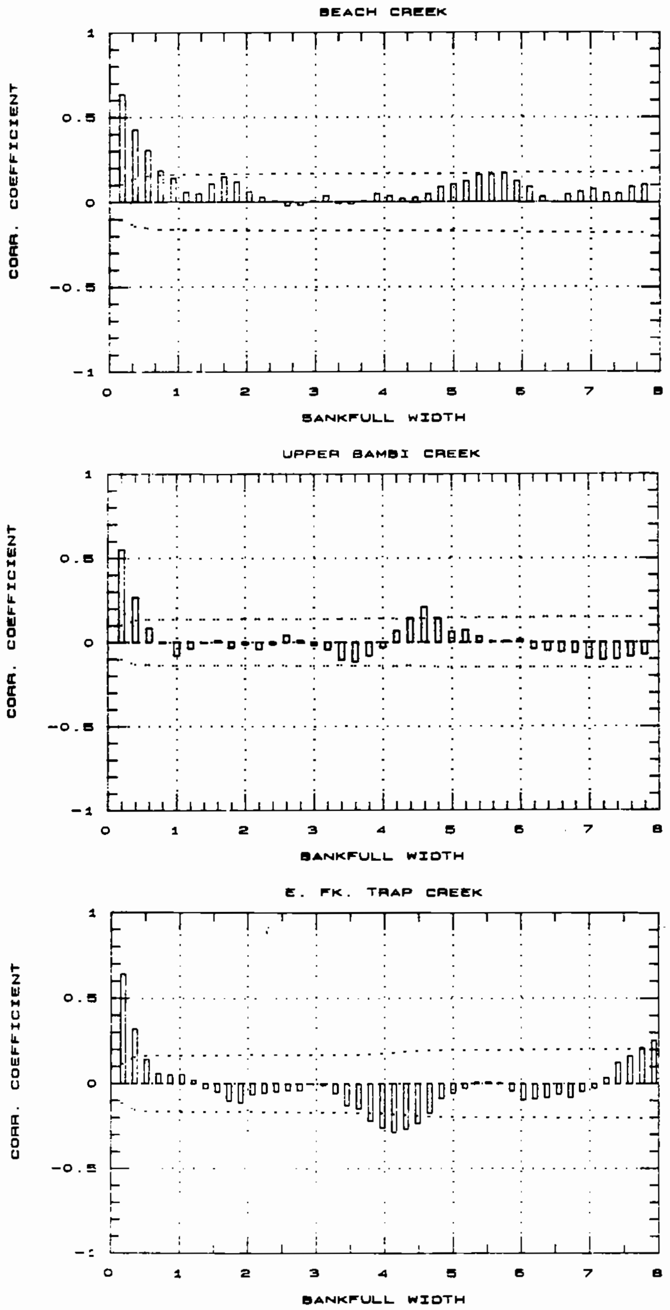


Figure 23. Autocorrelations in width/depth ratio with longitudinal distance for the five study streams.

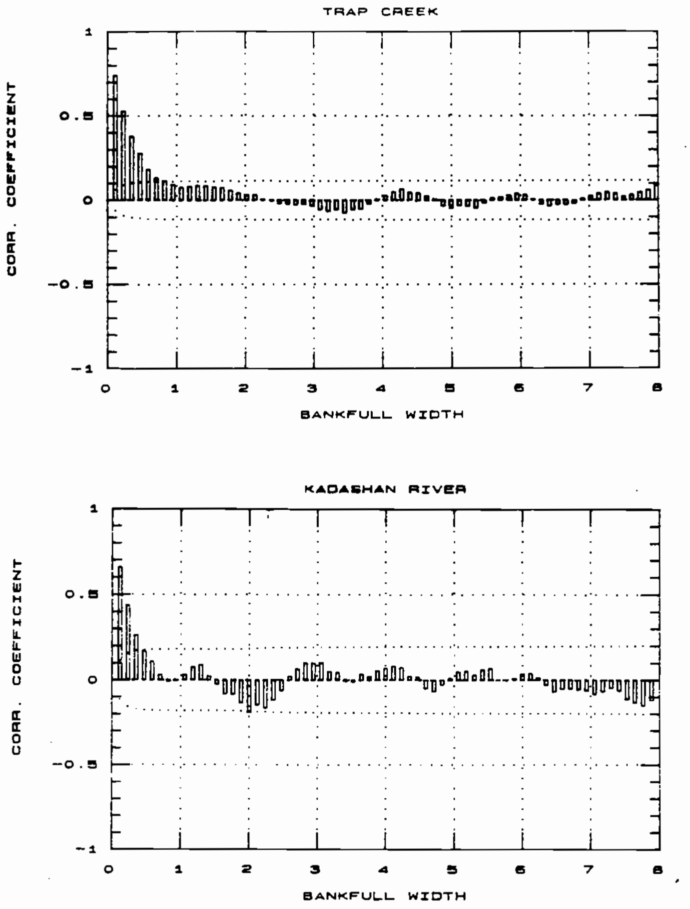


Figure 23. Continued.

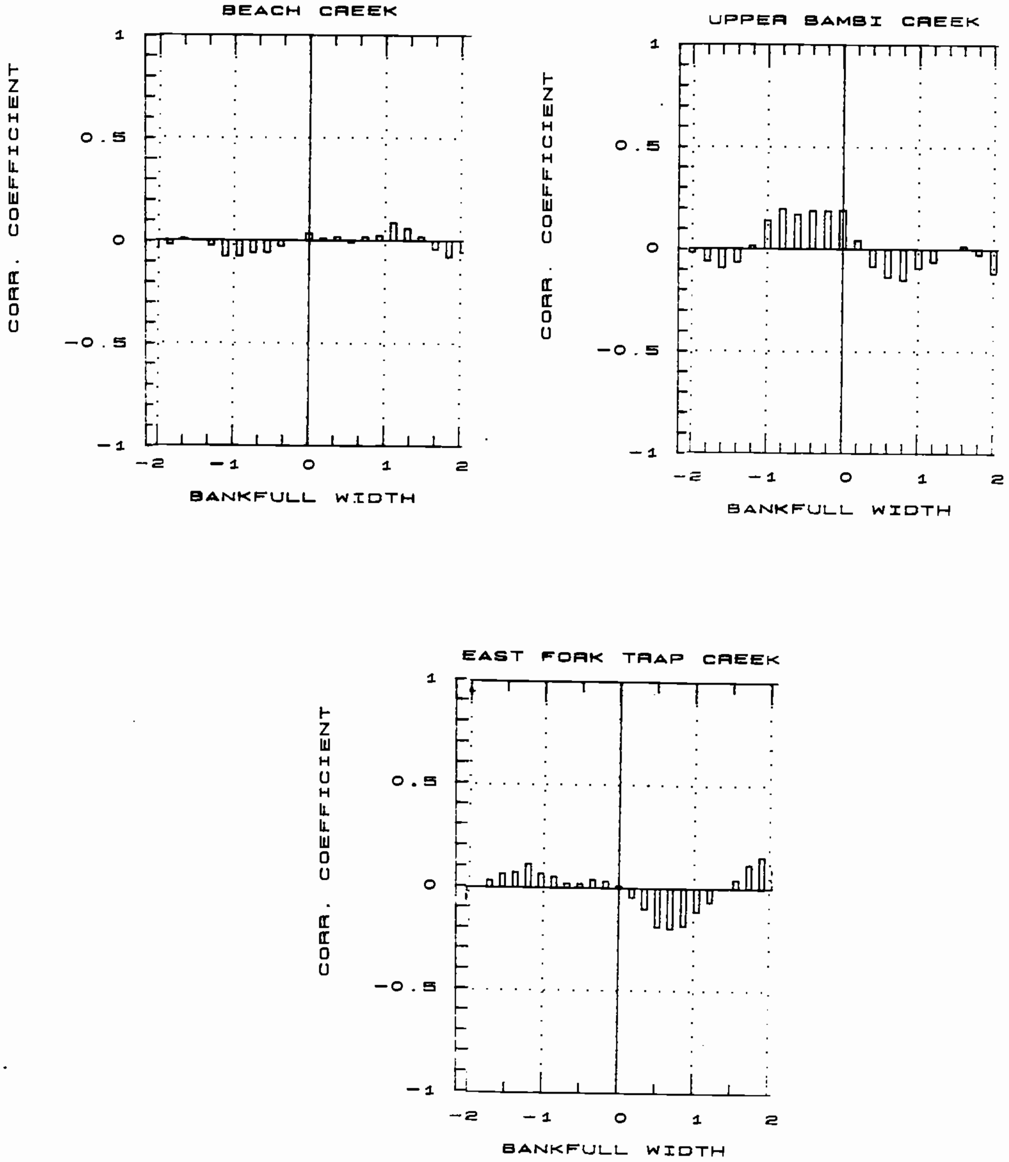
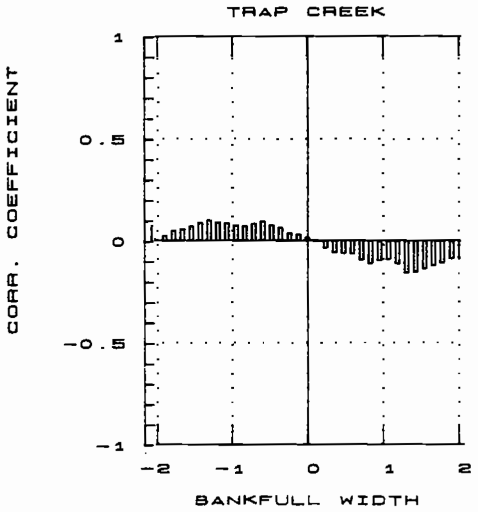


Figure 24. Cross-correlations in width verses depth in relation to longitudinal distance for the five study streams.



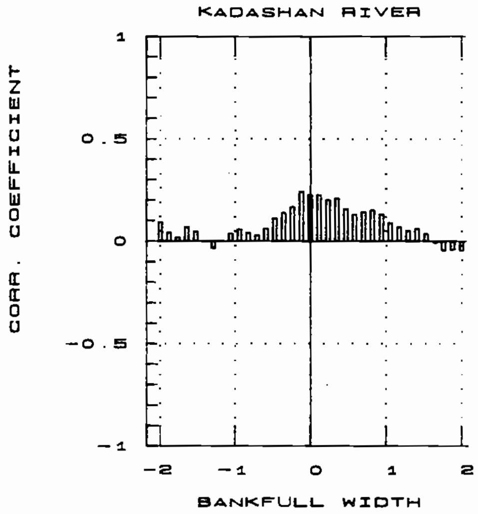


Figure 24. Continued.

at the next measurement point if the stream exhibits memory. If the correlation coefficients of a correlogram descend gradually from the left-hand side, the stream feature in question has relatively high "memory." If the coefficients drop rapidly to zero there is little or no "memory." "Repeatability" (periodicity) is the capability of a measurement value to repeat itself on a consistent basis at some given distance upstream or downstream. If the correlation coefficients of a correlogram rise or descend beyond the significance line of the correlogram the stream feature in question has relatively high "repeatability."

For depth measurements (Figure 20) there is little or no memory as the correlation coefficients approach and or cross the significance line between lags of 1/2 and 1 bankfull widths. Repeatability is not almost non-existent and at most accounts for five percent of the variability.

For bankfull width measurements (Figure 21), memory was greatest in Upper Bambi Creek (crossing significance line after one bankfull width), but was generally low in all streams. The repeatability in bankfull width was almost nonexistent for all streams (Figure 21). The Kadashan River had a negative repetition at about four bankfull widths and a positive one at about eight bankfull widths, but this explained only about 8% of the variability in the data (Figure 21). Beach Creek was not presented because visual inspection of the spatial series of bankfull width indicated that there were three distinct "jumps" in the spatial distribution.

Memory associated with cross-sectional area was almost nonexistent, with the correlation coefficient crossing the significance line before 1/2 bankfull width in Upper Bambi Creek and East Fork Trap Creek and in less than one bankfull width for the other three streams (Figure 22). Repeatability was nonexistent with no correlation coefficients crossing the significance line.

In width-depth ratios there was almost no memory or repeatability (Figure 23). One exception was in East Fork Trap Creek had a negative repetition at 4 and a positive one at 8 bankfull widths lag that explained approximately 8% of the data's variability.

These results indicate that the five study streams are influenced by a wide variety of interacting and independent factors and processes which result in channel dimensions of characteristic high variability, with an absence of "memory" and "repeatable" components. Unlike the conclusions of Keller and Melhorn (1978), pools in these undisturbed streams do not occur systematically at 5 to 7 channel widths. Instead the morphological types are "choppy" and measurements at one location have relatively little or no bearing on nearby measurements.

The cross-correlations (Figure 24) show the relationship between low-flow wetted width verses low-flow depth with width being the independent variable. On Beach Creek there is no correlation between width and depth (Figure 24). On Upper Bambi Creek there is a weak positive correlation that indicates that a location of increased thalweg depth will generally have a corresponding increased wetted width at the given point extending 3/4 of a bankfull width (12 feet) downstream (Figure 24). This correlation explains only approximately 4-5 percent of the variation. On East Fork Trap there is also a weak negative correlation (explaining approximately 4% of the data) that indicates that deeper areas will be preceded by narrow areas upstream. There is also a similar, but less obvious, pattern on Bambi and Trap Creek (Figure 24). The Kadashan River (Figure 24) has a weak positive correlation between depth and width immediately downstream and upstream of a given point. This pattern indicates that deep areas will be preceded, associated, and followed by wider areas along the longitudinal profile of the stream.

Figure 24 shows that depth is weakly correlated with width in these study streams. In laboratory studies, streams normally have areas of constriction in width preceding areas of increased depth (Keller and Melhorn 1978). These study streams show only a slight tendency towards this pattern and in one case (Upper Bambi Creek) an opposite relationship was found. These findings seem to confirm that pool formation, in these low-gradient undisturbed streams of southeast Alaska, is not controlled by endogenous processes but instead from exogenous factors that appear to be largely random.

INTERACTIONS

During data collection and analysis there were observations and results that indicated some sort of interaction, or lack of, between LWD and stream morphology. These results are presented here in the following order: Beach Creek spatial distributions; side channels and LWD volume; contrast between Upper and Lower Bambi Creek; and regression analysis of LWD volume verses morphological measurements.

Beach Creek

Figure 25 shows the spatial distributions of bankfull width and Zone 1+2 LWD volume. Bankfull width, as mentioned earlier, has three distinct sections. From 0-300 feet the spatial distribution of width changes relatively systematically with distance along the channel. From 300 to 810 feet there is an area of decreased average

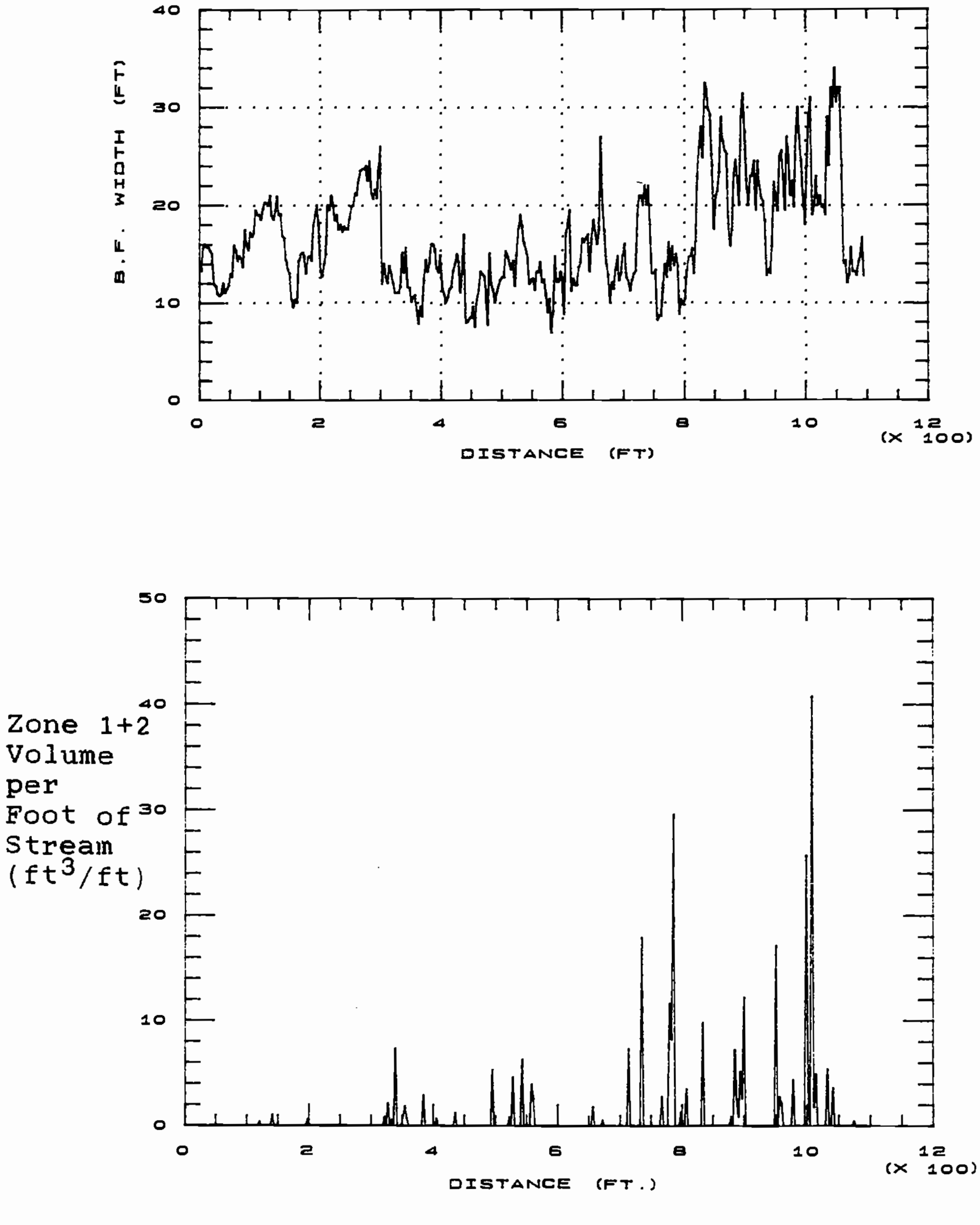


Figure 25. Longitudinal distributions of bankfull width and total Zone 1+2 large woody debris volume for Beach Creek.

bankfull width and increased flucuations in bankfull width measurements with distance. From 810 feet to the upstream end of the study reach, there is an area of increased average bankfull width and increased flucuations. The Zone 1+2 LWD volume distribution indicates almost no volume from 0 to 300 feet, increased volume from 300 to 810 feet, and even greater volume from 810 feet to the top of the study site (Figure 25). These results indicate that width fluctuations are not as large or as frequent in the low volume section Beach Creek, increased fluctuations and decreased width with moderate volume, and increased flucuations and average width with increased volume. These results also indicate that Beach Creek can be broken into three stream types based on the patterns of the bankfull width spatial distribution.

Similar width responses were not found for Bambi Creek. On the larger streams there were no extended areas with low LWD volume to replicate the results found for Beach Creek. It is important to note that there was a tidal effect that could have impacted the downstream portions of Bambi and possibly Beach Creek. Also, there was also no apparent relationship with Zone 1+2 loadings and thalweg depth, except there was a jump in both average depth and variability at 300 feet distance in Beach Creek. For low flow wetted width, cross-sectional area, and width depth ratio there was no relationship found in their spatial distributions at Beach Creek.

Side Channels

From field observations it was expected that the LWD volume immediately downstream from sidechannel inlets (upstream end of a side channel) would have increased LWD volume in relation to the rest of the stream. This is because an increased accumulation of LWD volume increases flow resistance, and thus creates a backwater effect, increasing a stream's potential energy to divert and carve alternate channel routes.

The results of comparing volume below side channels with the average volume for the whole stream for three of the streams often showed the opposite effect (Figure 26). These results seem to indicate that the effects of LWD accumulations on causing side channel, while occurring in some places, is limited and other mechanisms of side channel formation (i.e., deflection of flow by upstream obstructions, meander cutoffs, etc....) are more common. There were some individual side channels displaying this

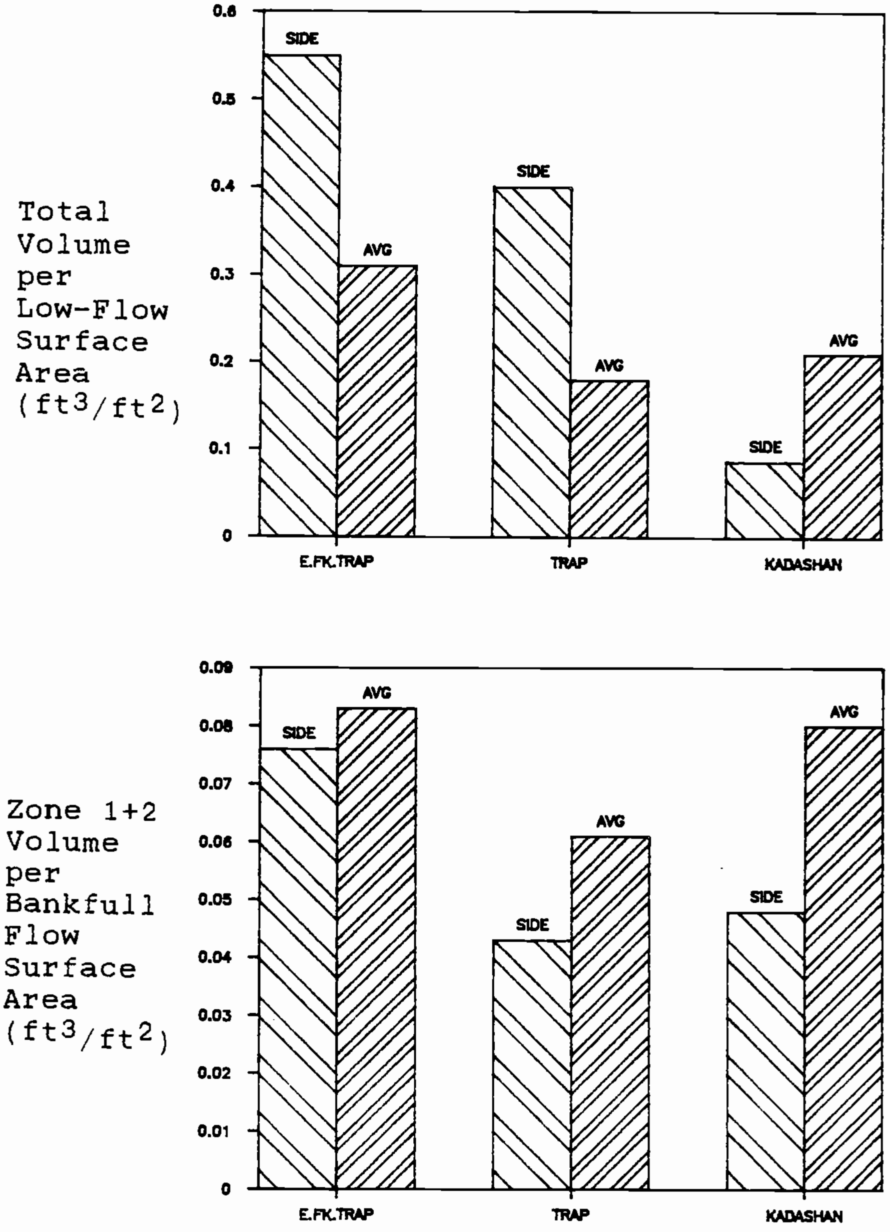


Figure 26. Total and Zone 1+2 large woody debris volumes per unit surface area for 30 feet downstream of side channel inlets compared with average volume values for three study streams.

effect (Appendix E) but on the average volumes downstream of side channel inlets were lower.

Upper and Lower Bambi

Upper Bambi Creek has large quantities of LWD present ($0.053\ ft^3/ft^2$ Zone 1+2 volume per bankfull flow surface area) and Lower Bambi has no LWD present. This situation provided an opportunity to compare morphological results and make inferences about the presence or absence of LWD. It is important to note that Lower Bambi Creek has tidal influence backing up water into it during extreme high tides. It is also important to note that Lower Bambi Creek flows through a grassy area with less bank resistance (stability) than the forested Upper Bambi Creek. The bank material on the lower reach is a less stable cohesiveless beach dune material that is more easily eroded than the bank material along the upper reach. It could be that the differences in the following comparisons are due to one of these factors and not due to the presence or absence of LWD.

Lower Bambi Creek has less morphological types (Figure 27), but has an overall greater percentage of pools (44 to 33%) (Table 10). Lower Bambi has only one

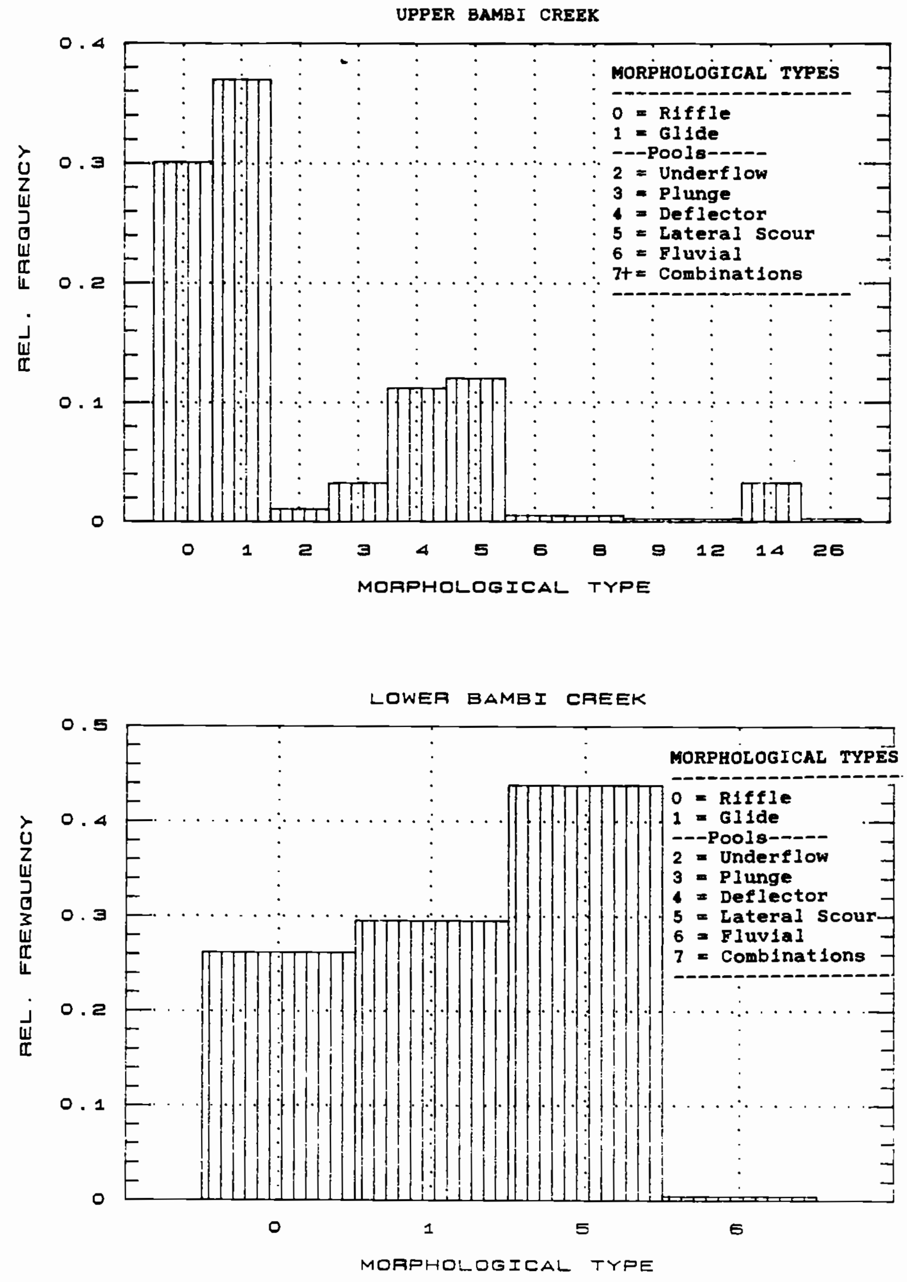


Figure 27. Relative frequency histograms of morphological types for Upper and Lower Bambi Creek.

pool forming element while Upper Bambi has several types (Figure 28).

Autocorrelations show that Lower Bambi has greater memory in depth and bankfull width measurements (Figures 29 and 30). This is shown by the coefficients declining more rapidly from the right on Upper Bambi Creek (Figures 29 and 30). This indicates that the longitudinal profile on Upper Bambi Creek is more "choppy" since a measurement at one spot has less bearing on what adjacent measurements will be.

Regression Analysis

Each study stream was subdivided into channel reaches equaling five bankfull widths in length. The standard deviation of depth and bankfull width (as a measure of variability) for each reach was regressed with total and Zone 1+2 LWD volume. Total volume had weaker relationships with the morphological variables than Zone 1+2 volume and was discarded.

Figure 31 shows a highly significant direct relationship between standard deviation of depth and Zone 1+2 LWD volume for all streams combined that explained 46% of the variation in the data. However, when stream size is accounted for by scaling using an indicator of stream size (i.e., bankfull width, Figure 32), or by dividing the data into individual streams the apparent relationship

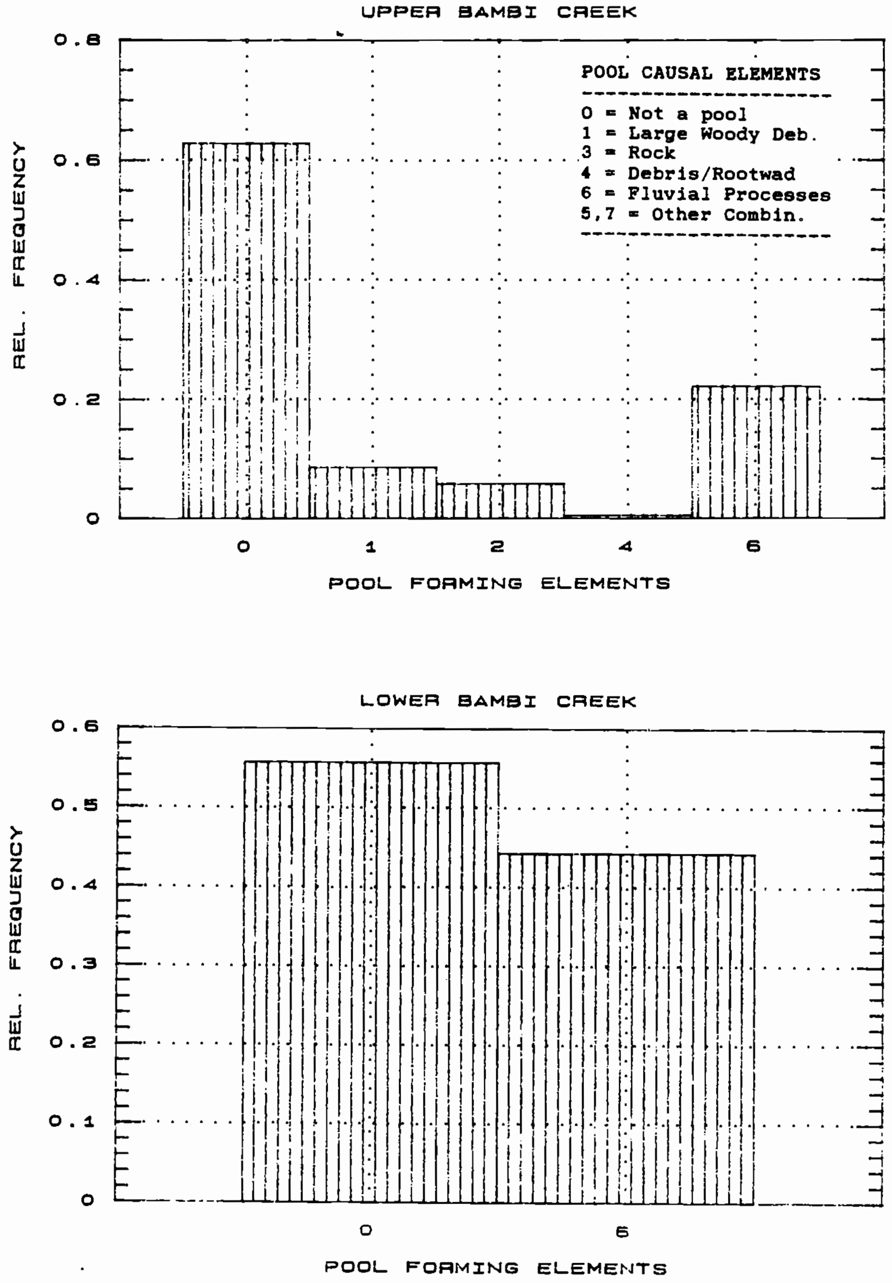


Figure 28. Relative frequency histograms of pool causal elements for Upper and Lower Bambi Creek.

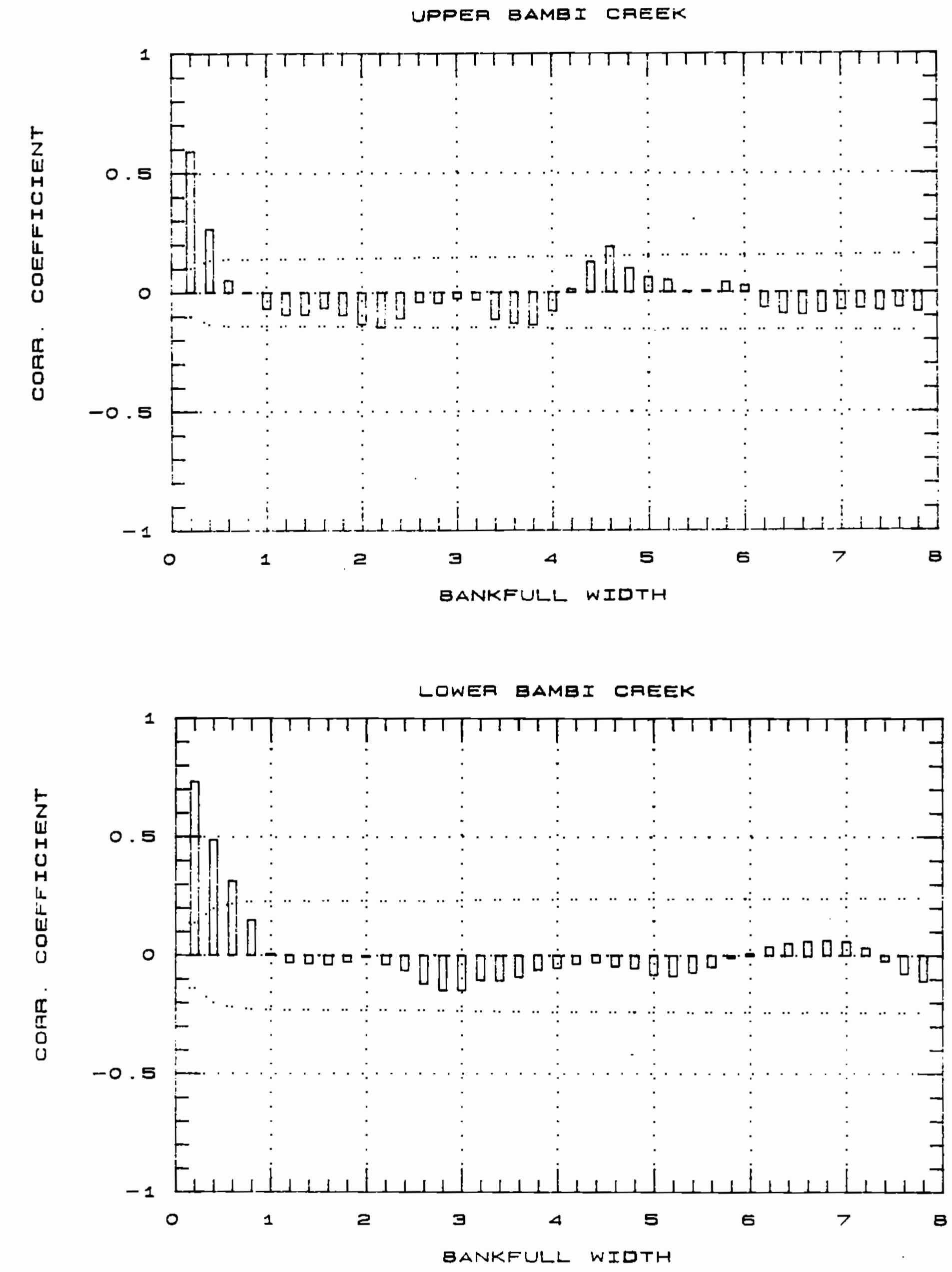
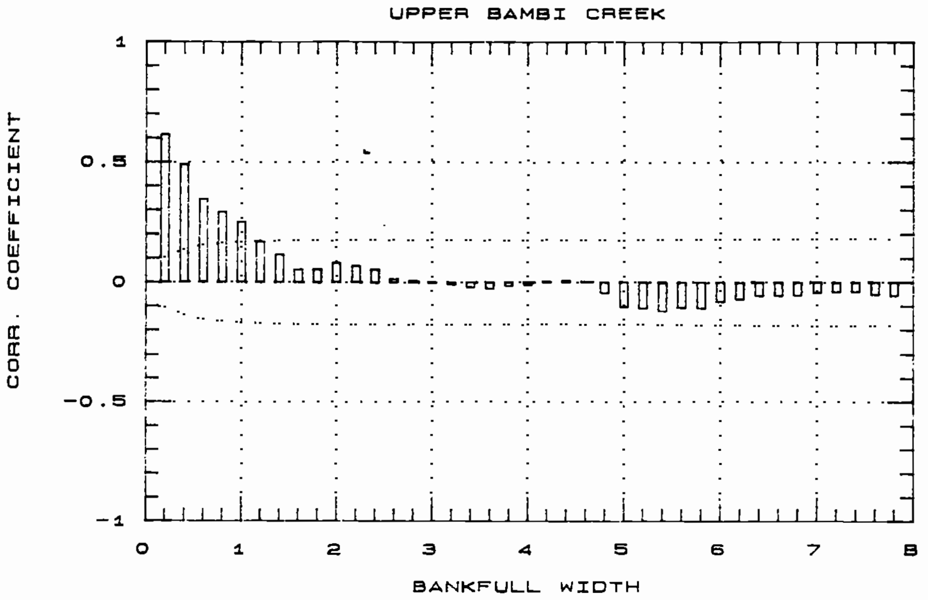


Figure 29. Autocorrelations in depth with longitudinal distance for Upper and Lower Bambi Creek.



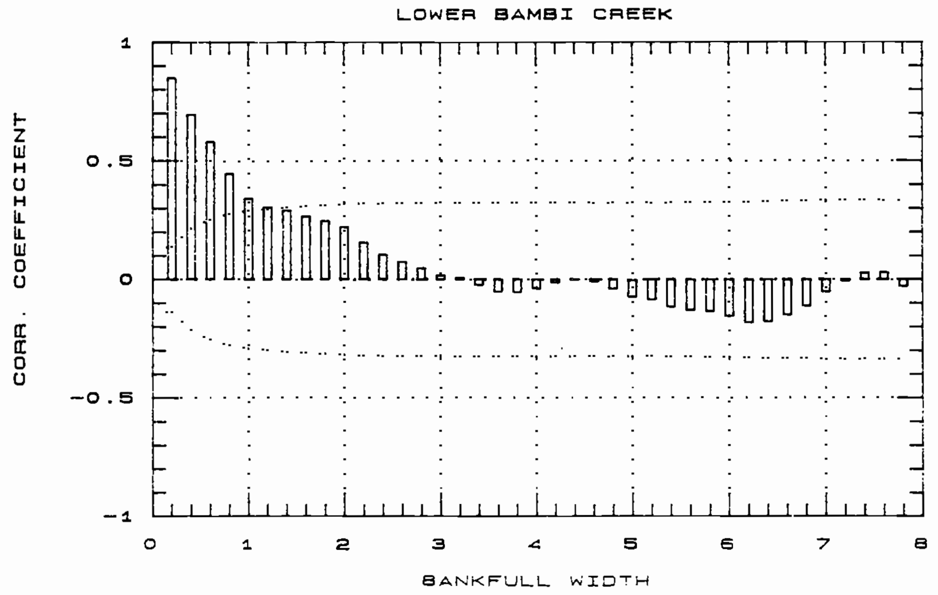


Figure 30. Autocorrelations in bankfull width with longitudinal distance for Upper and Lower Bambi Creek.

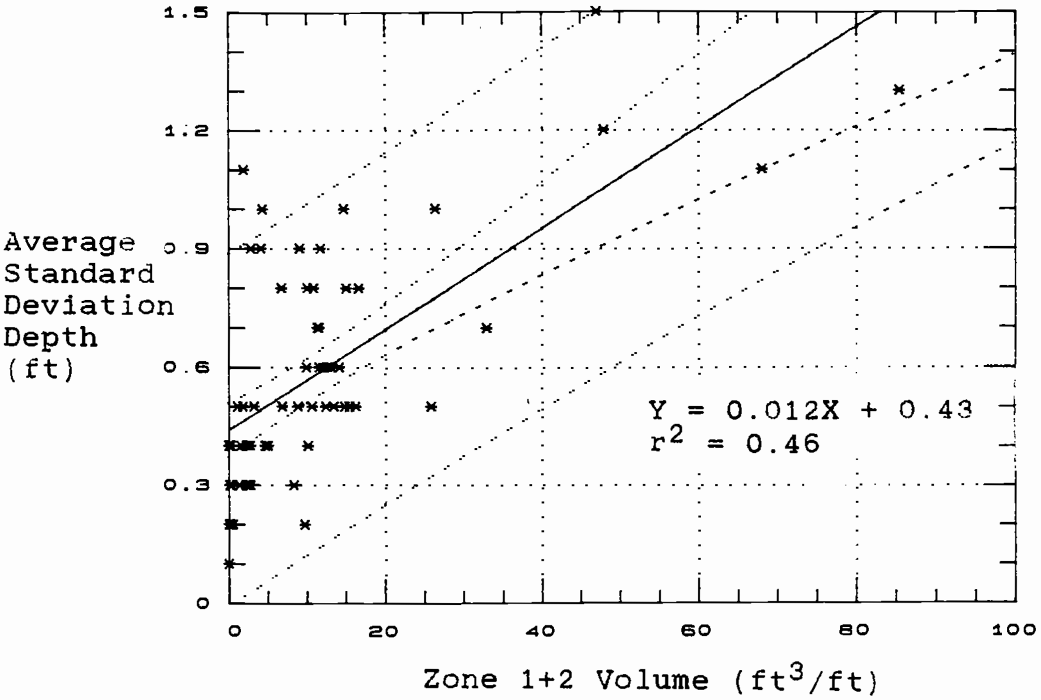


Figure 31. Scatterplot with fitted regression line for average standard deviation in thalweg depth verses average Zone 1+2 large woody debris volumes, at five bankfull widths longitudinal distance, for all study streams.

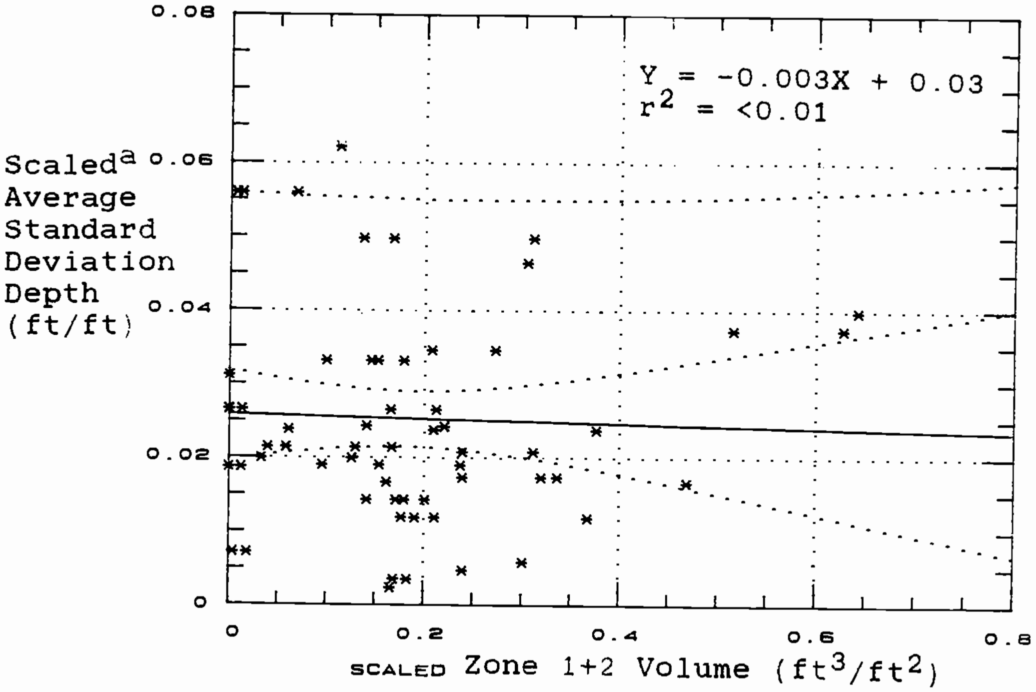


Figure 32. Scatterplot with fitted regression line for scaleda average standard deviation in thalweg depth verses scaled average Zone 1+2 large woody debris volumes, at five bankfull widths longitudinal distance, for all study streams.

a - Scaled by dividing each variable by the average bankfull width of each study stream.

vanishes (Table 11). This occurs because the magnitude of standard deviation of depth and Zone 1+2 LWD volume generally increases with stream size and this occurs because bigger streams are generally deeper and have more surface area to contain LWD.

Figure 33 shows a highly significant direct relationship (explaining 63% of the data's variability) between the standard deviation bankfull width and Zone 1+2 LWD volume. This relationship is also affected by stream size but not to as great an extent as found with depth. Figure 34 and Table 12 indicate that even when the variables are scaled to stream size there is still a relationship though a weaker one.

These results show that LWD affects the variability in bankfull width more than thalweg depth. The spatial distributions of channel dimensions for Beach Creek indicate a similar conclusion. Bankfull width was the only morphological variable that was correlated with a measure of LWD.

LOCALIZED EFFECTS

To evaluate the local effects of LWD on channel morphology, 14 pools associated with LWD were deliberately chosen and cross-sectional depth measurements were obtained at 2 foot intervals longitudinal distance. The

Table 11. Regression results for standard deviation of depth verses Zone 1+2 large woody debris volume, at five bankfull widths longitudinal distance, for each study stream and all streams combined.

Stream	Regression Results				
	N	Regress. Slope (ft/ft^3)	Regress. Intercept (ft.)	r^2	Probability Level
All Streams Combined	62	0.012	0.43	0.46	<0.01[b]
Beach Creek	13	0.005	0.34	0.02	0.64
Upper Bambi Creek	13	-0.009	0.41	0.01	0.76
E. Fk. Trap Creek	10	0.005	0.55	0.01	0.77
Trap Creek	22	0.003	0.67	0.01	0.65
Kadashan River	4	-0.003	0.40	0.09	0.70
All Streams Combined Scaled[a]	62	-0.003	0.03	<0.01	0.82

a - Scaled by dividing each value by the average bankfull width of each study stream.

b - Highly Significant Relationship

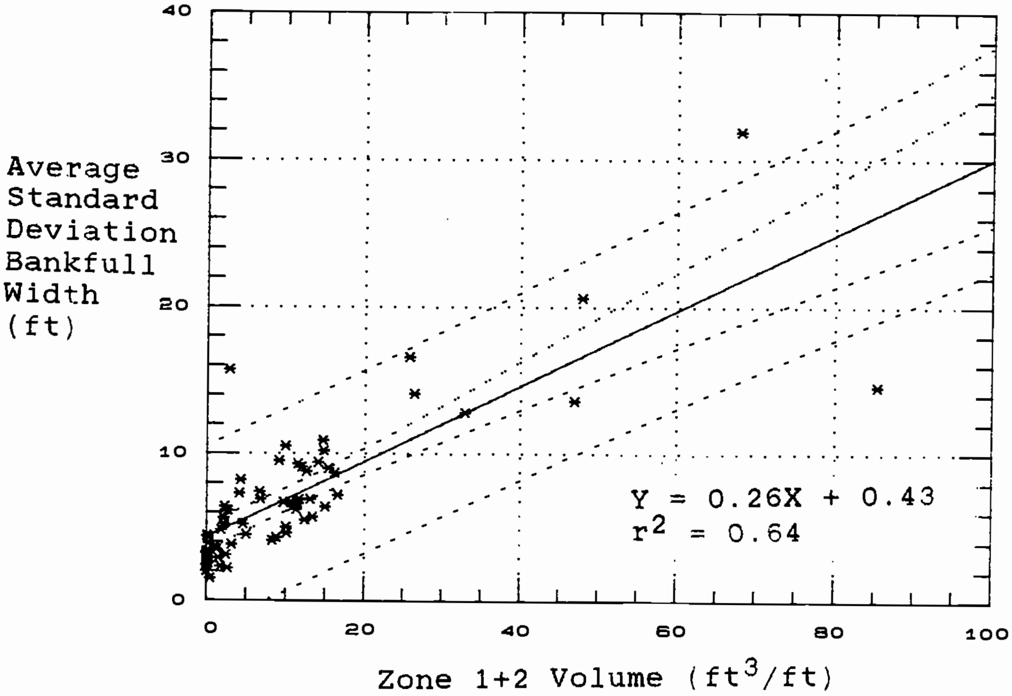


Figure 33. Scatterplot with fitted regression line for average standard deviation in bankfull width verses average Zone 1+2 large woody debris volume, at five bankfull widths longitudinal distance, for all study streams.

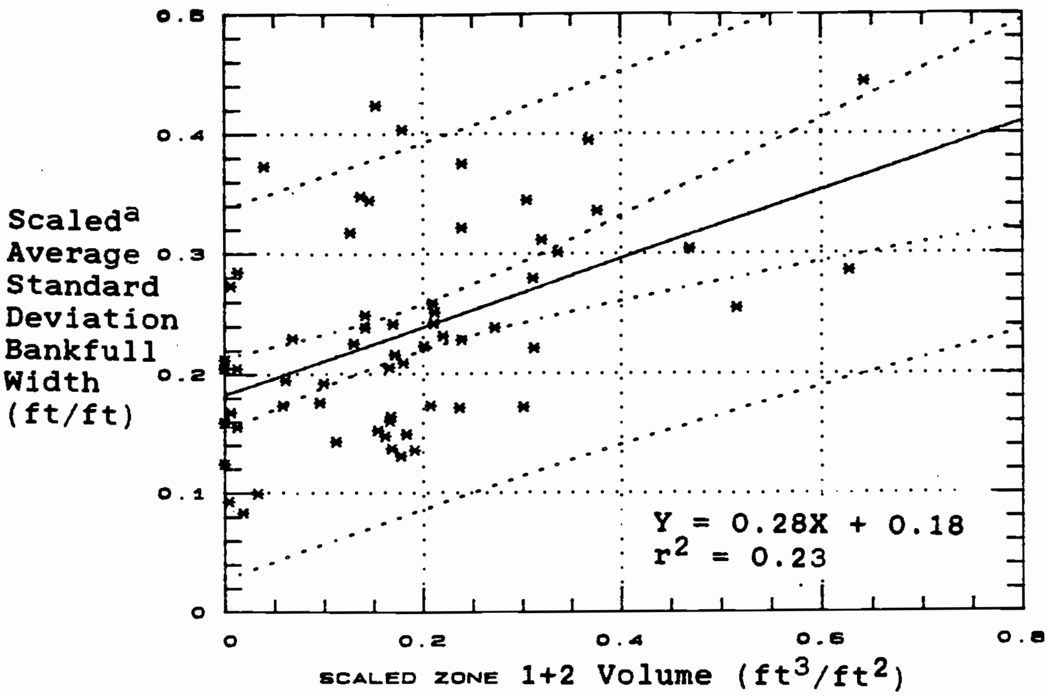


Figure 34. Scatterplot with fitted regression line for scaled average standard deviation in bankfull width verses scaled[a] average Zone 1+2 large woody debris volume, at five bankfull widths longitudinal distance, for all study streams.

a - Scaled by dividing each variable by the average bankfull width of each study stream.

Table 12. Regression results for standard deviation bankfull width verses Zone 1+2 large woody debris volume, at five bankfull widths longitudinal distance, for each study stream and all study streams combined.

Stream	Regression Results				
	N	Regress. Slope (ft/ft^3)	Regress. Intercept (ft.)	r^2	Probability Level
All Streams Combined	62	0.26	4.3	0.64	$<0.01^b$
Beach Creek	13	0.15	3.1	0.21	0.11
Upper Bambi Creek	13	0.41	3.3	0.42	0.02^c
E.Fk. Trap Creek	10	0.30	3.4	0.30	0.10
Trap Creek	22	0.24	5.9	0.32	0.01^b
Kadashan River	4	0.03	18.1	0.01	0.92
All Combined Scaled[a]	62	0.28	0.2	0.23	$<0.01^b$

a - Scaled by dividing each value by the average bankfull width of each study stream.
b - Highly Significant Relationship
c - Significant Relationship

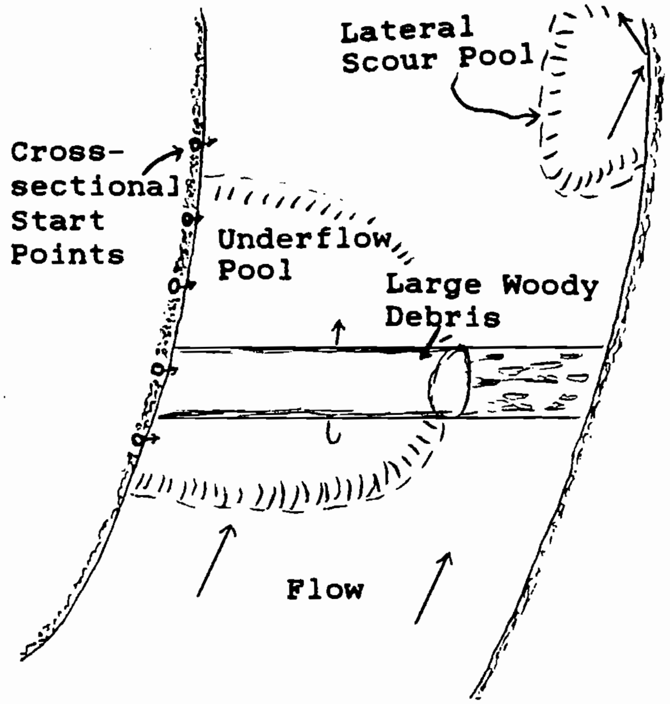
position and size of the LWD present was also determined and related to the cross-sectional measurements.

One objective was to find relatively "simple" locations where a single piece of LWD was associated with a single pool. This was not an easy task because in over 2.5 miles of study reaches there were few if any places where this type of simple cause and effect relationship existed. For instance, what may be noted as a deflector pool related with LWD in the morphology section can in fact have several pieces of LWD deflecting flow causing a single major pool and several other shallow pools along with it. Also in a given sample cross-section the LWD may cause in addition to a deflector pool at thalweg, several pocket pools along the cross-section that may include underflow, plunge, or other deflector pools.

The local effects of LWD are demonstrated by Figures 35-37. Figure 36 shows a series of cross-sections measured on East Fork Trap Creek. This sample represents one of the simplest series of cross-sections, but even here it shows how the underflow pool is complicated by a lateral scour pool downstream (Figure 35). It also shows how quickly the thalweg can change from one side of the cross-section to the other due to the presence of LWD.

Figure 37 shows a series of partial cross-sections from a braided section of Trap Creek. Evaluating only a partial cross-section simplifies this sample but even here

A) East Fork Trap Creek Sample #4



B) Trap Creek Sample #6

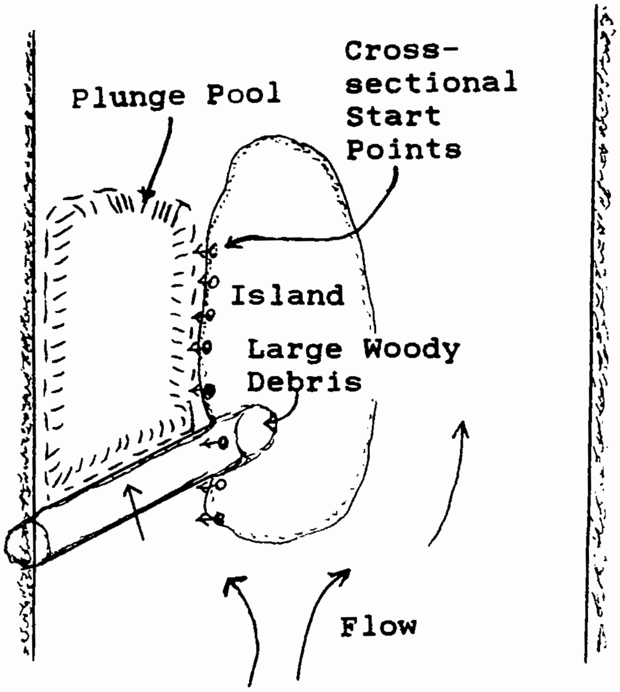


Figure 35. Plan view sketches of two detailed study sites (Note: sketches not to scale).

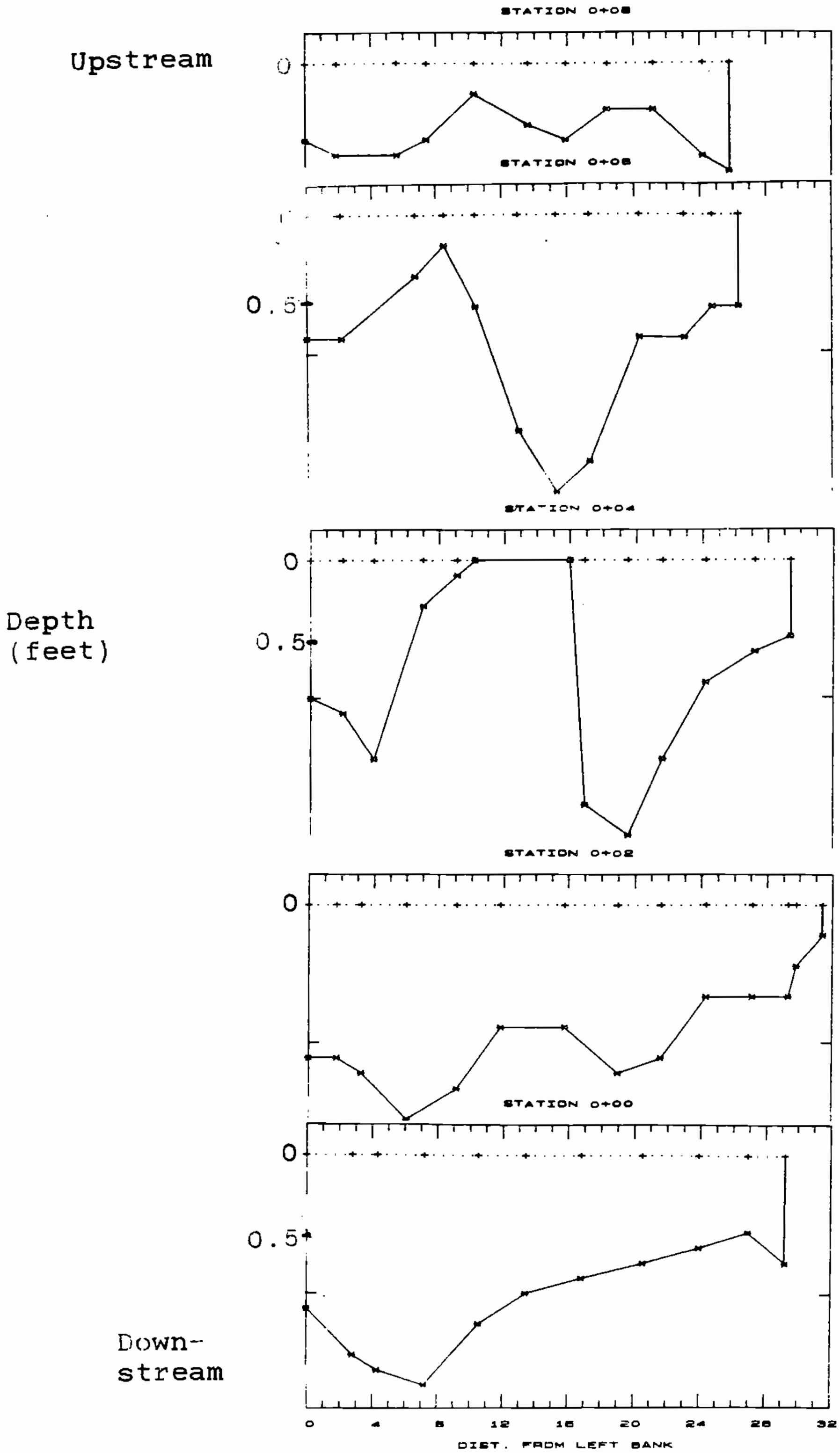


Figure 36. Detailed cross-sectional measurements of depth for an underflow pool study site (Sample #4, Figure 35) on East Fork Trap Creek.

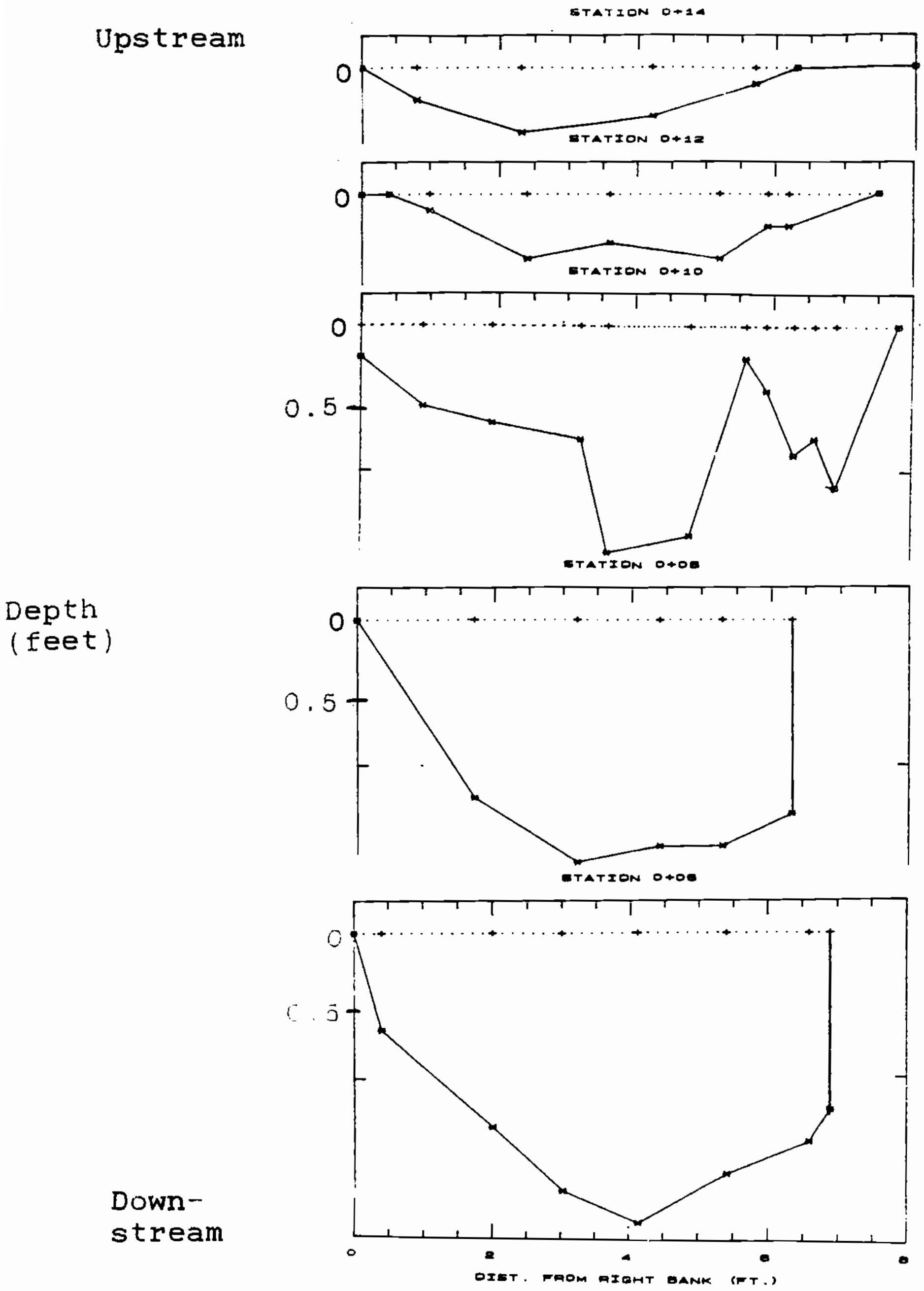


Figure 37. Detailed cross-sectional measurements of depth for a combination plunge/defector pool study site (Sample #6, Figure 35) on Trap Creek.

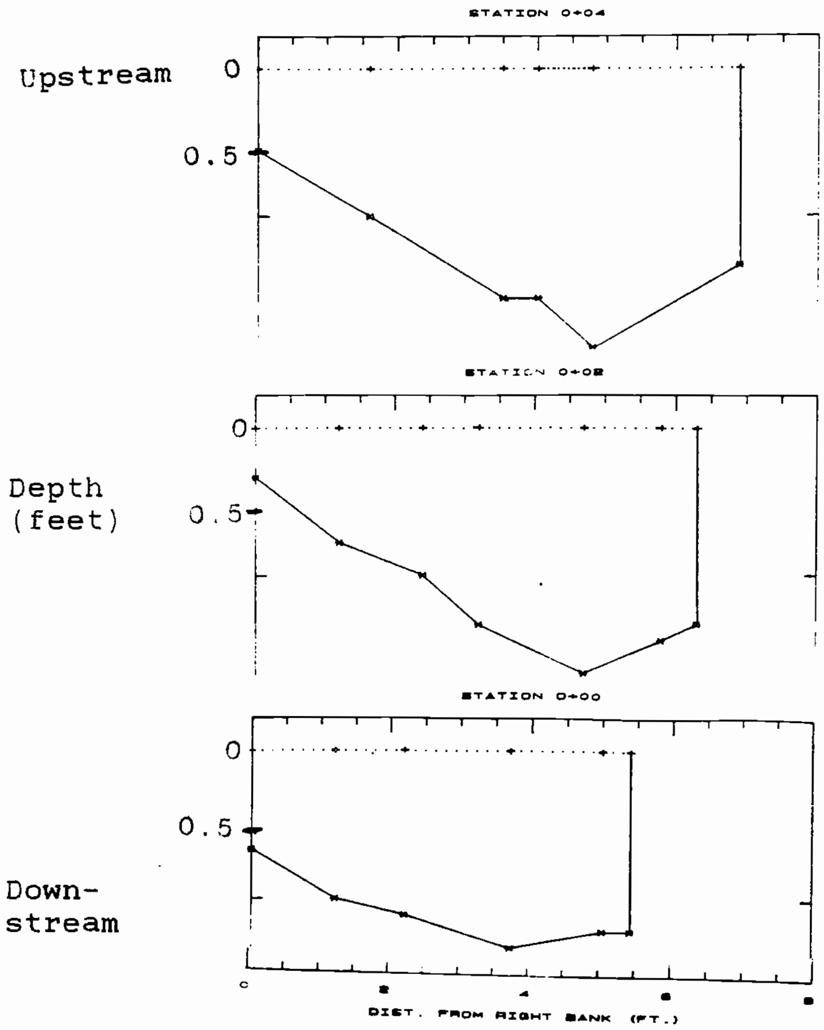


Figure 37. Continued.

the single LWD is at an orientation greater than 90^o to the flow and the flow lines themselves are defected from the presence of an island. This causes the plunge pool to have its greatest depth 4 ft. downstream from the wood obstruction and to have a different shape than the pool shown in Figure 1.

The preceding figures show that even in the simplest cases, pool formation is a complex process. Thus, when examining pools on a local level, many of the generalities regarding pool causing elements and processes can't be simply invoked.

SUMMARY

The results of this study indicate that, the riparian stand, LWD in and near the stream, and stream morphology are all interrelated variables, but the variability encountered makes it difficult to delineate simple-cause-and-effect relationships.

Along the fourth-order stream riparian stand composition was affected by lateral channel movement. A "one sided" alternating alder corridor exists along this stream based on evaluation of air photos and the relatively high proportion of alder measured in the field (Figure 9, Table 4). However, regression analysis was not effective at identifying a relationship between alder present and the bank angle of the channel.

Total LWD volume generally increased with stream size; however, the unit volume of LWD increased or decreased as a function of increasing stream size depending on the method used to express it. If total LWD volume per bankfull-flow surface area is used, there is a general decrease with increased stream size (Table 5). If Zone 1+2 LWD volume (Figure 6) per bankfull-flow surface area is used then there is no trend. This effect may be due to the placement of LWD within a channel cross section changing as stream size increased (Table 6). In the smaller streams there was relatively greater proportional amounts of LWD on the sides of streams rather than in the streams themselves. There was also an increase in rootwads in the channel (Figure 11) with increasing stream size. The larger streams had a greater ability to move laterally and the increased presence of rootwads in the channel appears to indicate that channel cutting is a more prevalent form of LWD recruitment.

There was a tendency for a relatively high proportion of LWD to be oriented at 90^{o} to general stream flow. Horizontal orientation was not correlated with LWD piece length for ungrouped pieces (Table 9). Such a relationship may be confounded by other factors, including LWD's degree of burial and its relative position with respect to the channel. LWD volumes along the channel were highly variable for all five study streams (Figures 14 and 15). While the distributions of LWD volumes tend to be different, field observations indicate that the processes influencing these distributions also vary with stream size. In the small first and second order streams LWD accumulations are caused by episodic blow-down and are loosely arranged. As stream size increases some LWD begins to be grouped by alluvial processes, in which LWD is arranged tightly, and the proportion of accumulations caused by episodic blowdown decreases, but blowdown is still the major component in all streams.

The relative proportions of side channels and braiding increased with stream size (Figure 16). Similarly, the relative proportions of morphological types and pool forming elements also changed in relation to stream size (Figures 17 and 18). In all streams, except Bambi Creek, LWD was the leading element associated with pool formation. In two streams LWD alone or in combination with other elements were associated with almost 50% of all the morphological types along the thalweg.

Autocorrelations of depth, bankfull width, cross-sectional area and width/depth ratio measurements indicated that these variables are the result of apparently random processes. "Memory" was low inferring that long riffles, glides, and pools are almost nonexistent and short "choppy" features are predominate on these streams (Figures 20-23). Autocorrelations also indicated that the channel dimensions do not repeat at a fixed interval as might be expected from streams dominated by endogenous processes. These results seem to indicate exogenous large roughness elements (i.e., LWD) are strongly influencing fluvial processes in these undisturbed stream systems.

Cross-correlations of low-flow width verses depth indicated little correlation between the two variables (Figure 24). Results from the different streams were not consistent and in all instances the coefficients of determination (i.e.,r2) remained less than 0.10. Again, these results differ from those of streams dominated by endogenous processes where depth and width are more closely correlated.

Changes in LWD volume did affect the variability of bankfull width measurements, but did not affect the other morphological variables. In Beach Creek, increasing Zone 1+2 LWD volume was associated with changes in the average and the variability of bankfull width values (Figure 25). A similar relationship was not found in Bambi Creek, and sufficiently long stretches with little or no LWD did not occur along the other three streams. LWD volumes were also associated with decreases in the "memory" of channel dimensions, and increases in diversity of morphological types and pool forming elements present for Upper and Lower Bambi Creek.

Regression analysis indicated that increases in Zone 1+2 LWD volume for five bankfull width long reaches is directly related to the standard deviation in bankfull width (Figure 34). A highly significant relationship existed between the standard deviation of thalweg depth and LWD volume (Figure 31), but the relationship was dependent on a hidden variable (stream size). When both variables were adjusted to account for stream size, no significant relationship was found (Figure 33, Table 11). Significant relationships between Zone 1+2 LWD volume and other morphological variables were not found.

Detailed measurements of selected cross-sections (Figures 35-37), indicates that the presence of LWD can, in some cases, cause the thalweg to shift from one side of a channel to the other within a few feet of longitudinal distance. Furthermore, a single thalweg depth measurement at any given cross section only indexes overall channel dimensions because there are often other pools present within the same cross section.

CONCLUSIONS AND RECOMMENDATIONS

This study has attempted to identify the quantitative spatial "signature" of riparian stand, LWD, and channel morphology characteristics along several undisturbed streams. If pristine conditions are assumed to be the most favorable for salmonids (Sullivan et.al. 1987), then these results provide a quantitative and sometimes qualitative "picture" of what undisturbed coastal streams are like. Furthermore these results may provide a quantitative benchmark for comparison with other small-to-medium sized low-gradient streams in southeast Alaska.

Autocorrelations from managed streams could be compared with these results to determine if and to what extent differences may exist. Channels with "fisheries enhancement structures" could also be compared with these findings to evaluate differences. In the same way morphological type and pool causal element histograms can be compared and contrasted between streams. Spatial distributions of the channel dimensions could also be compared. The standard deviations and average values of stream morphological variables (along sections five bankfull widths in length) could be evaluated to see if

LWD volume increases variability in stream morphological variables.

The assumption that channel variability is directly correlated with increased fish populations needs to be tested. Indices of memory or repeatability in channel dimensions could be correlated with fish population data to evaluate whether apparently random distributions in morphology increase fish populations. Also channel morphology characteristics, such as shown the for Beach Creek bankfull width (Figure 25), could be used to divide a study reach into separate units for biological research.

Other data and analysis techniques may also be desirable in future studies. For instance, variation in the spatial distributions in morphology and LWD can be indexed and evaluated for different streams by determining the sinuosity of a given variable's spatial distribution with distance. Variation could also be estimated or indexed by the number of times a given spatial distribution crosses the mean or some other specified value (i.e., cross-level analysis). In addition to longitudinal variation in channel features, latitudinal (cross-channel) variation of detailed cross-sectional measurements could be evaluated.

The preceding methodologies and research ideas have had an underlying purpose: to find a quantitative way of evaluating stream morphological and LWD variables so they can be related to fish populations or other measures of biological productivity. In the past fishery biologists and other resource managers have made important economic and ecological decisions based on qualitative impressions from interpretations of LWD maps, air photos, and on site inspection. This method of decision making is valid and necessary where definitive scientific evidence is lacking. However, the collection of objective and numerical data that can be replicated by other scientists to support or reject such decisions is a continuing need. It is hoped that this study has provided a framework from which these goals can be effectively pursued.

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APPENDICES

Appendix A. Descriptive locations of the study sites.

Beach Creek :	A first order tributary of Trap Creek that enters Trap Creek approximately 60 feet upstream from Trap Creek's confluence into Trap Bay. The downstream end of the study site is approximately 400 feet upstream from the mouth of Beach Creek.
Upper and Lower Bambi Creek :	A second order stream that enters Trap Creek approximately 600 feet upstream of the mouth of Trap Creek. The downstream end of the study site is located at the mouth of Bambi Creek. Bambi Creek is divided into Upper and Lower reaches where the continuous forest begins approximately where an intake for an automatic sediment sampler is located.
E. Fk. Trap Creek :	A second order stream that enters Trap Creek approximately 1.5 miles upstream from the confluence of Trap Creek with Trap Bay. The downstream end of the study site is approximately 30 feet upstream of the mouth of East Fork Trap Creek.
Trap Creek :	A third order stream that flows into the Tenakee Inlet at Trap Bay (Figure 3). The downstream end of the study site is located approximately 500 feet downstream from a stream gauge located on the west-side bank of the stream.
Kadashan River :	A fourth order stream that flows into the Tenakee Inlet almost due south of Tenakee Springs (Figure 3). The downstream end of the study site is located approximately 500 feet upstream of the confluence of the West Fork with Main Branch Kadashan River. Upper Kadashan represents the upstream 1800 feet of the reach where continuous LWD measurements were taken.

Appendix B. Distribution fitting using the Kolomogorov-Smirinov statistic (KS) for relevant large woody debris and channel morphology measurements.

Variable Stream	N	Dist-ribution[a]	KS Signif. Level	Signif. Fit[b]
Depth				
Beach Cr.	366	Nor.	3.3×10^{-5}	N
		Ln.	4.4×10^{-3}	N
Up. Bambi Cr.	371	Nor.	9.9×10^{-5}	N
		Ln.	1.0×10^{-4}	N
Low. Bam. Cr.	210	Nor.	1.5×10^{-5}	N
		Ln.	1.0×10^{-2}	Y
E. Fk. Trap	300	Nor.	5.2×10^{-3}	N
		Ln.	2.3×10^{-1}	Y
Trap Cr.	1004	Nor.	1.9×10^{-4}	N
		Ln.	---	-
Kad. River	301	Nor.	3.0×10^{-5}	N
		Ln.	2.4×10^{-3}	N
Low-Flow Width				
Beach Cr.	366	Nor.	1.4×10^{-2}	Y
		Ln.	1.2×10^{-1}	Y
Up. Bambi Cr.	371	Nor.	3.9×10^{-3}	N
		Ln.	5.2×10^{-1}	Y
Low. Bam. Cr.	210	Nor.	1.8×10^{-4}	N
		Ln.	2.5×10^{-1}	Y
E. Fk. Trap	300	Nor.	1.3×10^{-2}	Y
		Ln.	1.0	Y
Trap Cr.	1004	Nor.	1.3×10^{-1}	Y
		Ln.	2.3×10^{-3}	N
Kad. River	301	Nor.	4.3×10^{-3}	N
		Ln.	2.6×10^{-1}	Y

a - Nor. = Normal Distribution
Ln. = Lognormal Distribution
b - Significant at KS > 0.01, Y = Signif. Fit

Appendix B. Continued.

Variable Stream	N	Dist- ribution[a]	KS Signif. Level	Signif. Fit[b]
Bankfull Flow Width				
Beach Cr.	366	Nor.	3.2×10^{-4}	N
		Ln.	1.1×10^{-1}	Y
Up. Bambi Cr.	371	Nor.	$2.5. \times 10^{-3}$	N
		Ln.	3.7×10^{-2}	Y
Low. Bam. Cr.	210	Nor.	7.9×10^{-7}	N
		Ln.	4.2×10^{-3}	N
E. Fk. Trap	300	Nor.	1.7×10^{-1}	Y
		Ln.	1.0	Y
Trap Cr.	1004	Nor.	8.5×10^{-6}	N
		Ln.	5.4×10^{-3}	N
Kad. River	301	Nor.	1.3×10^{-4}	N
		Ln.	8.8×10^{-2}	Y
Cross-Sectional Area				
Beach Cr.	366	Nor.	4.0×10^{-5}	N
		Ln.	1.0	Y
Up. Bambi Cr.	371	Nor.	0	N
		Ln.	2.3×10^{-1}	Y
Low. Bam. Cr.	210	Nor.	1.0×10^{-7}	N
		Ln.	4.6×10^{-1}	Y
E. Fk. Trap	300	Nor.	1.5×10^{-4}	N
		Ln.	4.7×10^{-1}	Y
Trap Cr.	1004	Nor.	0	N
		Ln.	1.0	Y
Kad. River	301	Nor.	0	N
		Ln.	1.0×10^{-1}	Y

a - Nor. = Normal Distribution
Ln. = Lognormal Distribution
b - Significant at KS > 0.01, Y = Signif. Fit

Appendix B. Continued.

Variable Stream	N	Dist- ribution[a]	KS Signif. Level	Signif. Fit[b]
Width/Depth Ratio				
Beach Cr.	366	Nor.	2.2×10^{-6}	N
		Ln.	3.3×10^{-1}	Y
Up. Bambi Cr.	371	Nor.	0	N
		Ln.	1.0	Y
Low. Bam. Cr.	210	Nor.	6.7×10^{-6}	N
		Ln.	1.0	Y
E. Fk. Trap	300	Nor.	2.2×10^{-3}	N
		Ln.	1.0	Y
Trap Cr.	1004	Nor.	7.0×10^{-5}	N
		Ln.	5.0×10^{-2}	Y
Kad. River	301	Nor.	1.3×10^{-2}	Y
		Ln.	2.7×10^{-1}	Y
LWD Total Volume (Spatial)				
Beach Cr.	366	Ln.	0	N
Up. Bambi Cr.	371	Ln.	0	N
E. Fk. Trap	300	Ln.	0	N
Trap Cr.	1004	Ln.	0	N
Up.Kad. Riv.	301	Ln.	0	N
LWD Zone 1+2 Volume (Spatial)				
Beach Cr.	366	Ln.	0	N
Up. Bambi Cr.	371	Ln.	0	N
E. Fk. Trap	300	Ln.	0	N
Trap Cr.	1004	Ln.	0	N
Up.Kad. Riv.	301	Ln.	0	N

a - Nor. = Normal Distribution
    Ln. = Lognormal Distribution
b - Significant at KS > 0.01, Y = Signif. Fit

Appendix B. Continued.

Variable Stream	N	Dist-ribution[a]	KS Signif. Level	Signif. Fit[b]
LWD Length (Ungrouped) Piece)				
Beach Cr.	35	Nor.	2.8×10^{-1}	Y
Up. Bambi Cr.	28	Nor.	4.7×10^{-2}	Y
E. Fk. Trap	91	Nor.	2.0×10^{-3}	N
Trap Cr.	163	Nor.	2.4×10^{-4}	N
Up.Kad. Riv.	89	Nor.	2.7×10^{-2}	N
LWD Orientation (Ungrouped) Piece)				
Beach Cr.	35	Nor.	8.2×10^{-2}	Y
Up. Bambi Cr.	28	Nor.	2.9×10^{-1}	Y
E. Fk. Trap	91	Nor.	1.6×10^{-1}	Y
Trap Cr.	163	Nor.	2.1×10^{-2}	Y
Up.Kad. Riv.	89	Nor.	3.0×10^{-1}	Y
Basal Area/ Acre				
Beach Cr.	23	Nor.	1.0	Y
Up. Bambi Cr.	22	Nor.	1.0	Y
E. Fk. Trap	31	Nor.	4.2×10^{-1}	Y
Trap Cr.	101	Nor.	1.0	Y
Up.Kad. Riv.	61	Nor.	2.0×10^{-1}	Y

a - Nor. = Normal Distribution
    Ln. = Lognormal Distribution
b - Significant at KS > 0.01, Y = Signif. Fit

Appendix B. Continued.

Variable Stream	N	Distribution[a]	KS Signif. Level	Signif. Fit[b]
Stems/Acre				
Beach Cr.	23	Nor.	1.0	Y
Up. Bambi Cr.	22	Nor.	1.0	Y
E. Fk. Trap	31	Nor.	2.6×10^{-1}	Y
Trap Cr.	101	Nor.	3.2×10^{-2}	Y
Up.Kad. Riv.	61	Nor.	9.3×10^{-3}	N
Bank Angle (for Timber Cruise)				
Beach Cr.	23	Nor.	2.5×10^{-1}	Y
Up. Bambi Cr.	22	Nor.	5.0×10^{-2}	Y
E. Fk. Trap	31	Nor.	1.0×10^{-1}	Y
Trap Cr.	101	Nor.	6.7×10^{-4}	N
Up.Kad. Riv.	61	Nor.	2.9×10^{-2}	Y
Cross-Sectional Area (3-Point Method)				
Beach Cr.	36	Nor.	1.5×10^{-1}	Y
		Ln.	1.0	Y
Bambi Cr.	58	Nor.	9.1×10^{-4}	N
		Ln.	5.0×10^{-1}	Y
E. Fk. Trap	30	Nor.	4.3×10^{-1}	Y
		Ln.	1.0	Y
Trap Cr.	100	Nor.	4.7×10^{-2}	Y
		Ln.	1.0	Y
Kad. River	30	Nor.	9.0×10^{-2}	Y
		Ln.	1.0	Y
All Streams (Combined)	260	Nor.	0	N
		Ln.	5.3×10^{-1}	Y

a - Nor. = Normal Distribution
    Ln. = Lognormal Distribution
b - Significant at KS > 0.01, Y = Signif. Fit

Appendix B. Continued.

Variable Stream	N	Dist-ribution[a]	KS Signif. Level	Signif. Fit[b]
Cross-Sectional Area (Detailed Method)				
Beach Cr.	36	Nor.	9.0×10^{-2}	Y
		Ln.	1.0	Y
Bambi Cr.	58	Nor.	8.2×10^{-4}	N
		Ln.	5.1×10^{-1}	Y
E. Fk. Trap	30	Nor.	3.6×10^{-2}	Y
		Ln.	3.7×10^{-1}	Y
Trap Cr.	100	Nor.	4.6×10^{-2}	Y
		Ln.	1.0	Y
Kad. River	30	Nor.	1.1×10^{-1}	Y
		Ln.	1.0	Y
All Streams (Combined)	260	Nor.	0	N
		Ln.	4.2×10^{-1}	Y
Standard Deviation Depth at 5 Bankfull Widths				
Beach Cr.	13	Nor.	2.8×10^{-1}	Y
Bambi Cr.	13	Nor.	1.1×10^{-1}	Y
E. Fk. Trap	10	Nor.	3.7×10^{-1}	Y
Trap Cr.	22	Nor.	1.0	Y
Kad. River	4	Nor.	1.0	Y
All Streams (Combined)	62	Nor.	2.1×10^{-2}	Y
All Streams (Combined & Scaled)	62	Nor.	8.5×10^{-2}	Y

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a - Nor. = Normal Distribution
Ln. = Lognormal Distribution

b - Significant at KS > 0.01, Y = Signif. Fit

Appendix B. Continued.

Variable Stream	N	Distribution[a]	KS Signif. Level	Signif. Fit[b]
Standard Deviation Bankfull Width at 5 Bankfull Widths				
Beach Cr.	13	Nor.	1.0	Y
Bambi Cr.	13	Nor.	1.0	Y
E. Fk. Trap	10	Nor.	1.0	Y
Trap Cr.	22	Nor.	1.0	Y
Kad. River	4	Nor.	1.0	Y
All Streams (Combined)	62	Nor.	3.8×10^{-2}	Y
All Streams (Combined & Scaled)	62	Nor.	1.0	Y
1+2 LWD Vol. at 5 Bankfull Widths				
Beach Cr.	13	Nor.	4.4×10^{-1}	Y
Bambi Cr.	13	Nor.	5.2×10^{-1}	Y
E. Fk. Trap	10	Nor.	1.0	Y
Trap Cr.	22	Nor.	4.0×10^{-1}	Y
Kad. River	4	Nor.	1.0	Y
All Streams (Combined)	62	Nor.	6.6×10^{-4}	N
All Streams (Combined & Scaled)	62	Nor.	2.3×10^{-1}	Y

a - Nor. = Normal Distribution
Ln. = Lognormal Distribution
b - Significant at KS > 0.01, Y = Signif. Fit

Appendix C. Numerical coding of the different morphological types and pool causal elements.

Morphological Type	Number Coding
Single Type	
Riffle (R)	0
Glide (G)	1
Underflow Pool (UF)	2
Plunge Pool (PP)	3
Deflector Pool (DP)	4
Lateral Scour Pool (LS)	5
Fluvial Pool (FP)	6
Dam Pool (DM)	26
Combinations	
UF/PP	7
UF/DP	8
UF/LS	9
UF/LP	10
PP/DP	11
PP/LS	12
PP/FP	13
DP/LS	14
DP/FP	15
LS/FP	16
UF/PP/DP	17
UF/PP/LS	18
UF/PP/FP	19
UF/DP/LS	20
UF/DP/FP	21
UF/LS/FP	22
PP/DP/LS	23
PP/LS/FP	24
DP/LS/FP	25
LS/DM	27
DP/DM	28
PP/DM	29

Appendix C. Continued

Pool Causal Elements	Number Coding
Not a Pool	0
Debris (D)	1
Rootwad (RW)	2
Rock (RO)	3
D/RW	4
D/RO	5
Fluvial Processes (None of the above)	6
D/RW/RO	7

Appendix D. Regression results of the three point method verses the standard detailed method for determining cross-sectional area for the five study streams and all streams combined.

Stream	Regression Results					
	N	Regression Type[a]	Regres. Intercept (ft^2)	Regres. Slope	r^2	Probability Level
Beach Cr.	36	Nor.	0.11	0.95	0.78	*
		LN	-4.8	0.97	0.83	*
Bambi Cr.	57	Nor.	0.13	0.87	0.91	*
		LN	-.04	1.00	0.93	*
E.Fk.Trap Cr.	30	Nor.	3.5	0.77	0.80	*
		LN	0.33	0.87	0.69	*
Trap Cr.	100	Nor.	2.4	0.98	0.84	*
		LN	0.25	0.94	0.82	*
Kadashan River	30	Nor.	-6.4	1.13	0.88	*
		LN	0.18	0.96	0.87	*
All Str. Combined	260	Nor.	-0.54	1.06	0.93	*
		LN	-0.03	1.01	0.98	*

a - Nor. = Normal distributions simple regression
LN = Natural Logarithm Transformation linear regression

* - Denotes the regression equation is highly significant at alpha <0.01.

Appendix E. Total and Zone 1+2 large woody debris volume per unit of surface area for 30 feet below the upstream end of a side channel and for the average values for the entire stream on East Fork Trap Creek, Trap Creek, and the Kadashan River.

Side Channel		Volume			
		Total Volume per low flow surface area (ft^3/ft^2)		Zone 1+2 Volume per bankfull flow surface area (ft^3/ft^2)	
		30 feet below Side Ch.	Average for Stream	30 feet below Side Ch.	Average for Stream
E.Fk.	#1	0.39	0.31	0.029	0.083
Trap Creek	#2	0.14	0.31	0.053	0.083
	#3	1.14	0.31	0.150	0.083
Trap	#1	0.20	0.18	0.044	0.061
Creek	#2	1.10	0.18	0.035	0.061
	#3	0.08	0.18	0.011	0.061
	#4	0.28	0.18	0.089	0.061
	#5	0.30	0.18	0.013	0.061
	#6	0.79	0.18	0.026	0.061
	#7	0.50	0.18	0.041	0.061
	#8	0.30	0.18	0.017	0.061
	#9	0.01	0.18	0.001	0.061
Kadashan	#1	0.07	0.21	0.048	0.080
River	#2	0.06	0.21	0.013	0.080
	#3	0.08	0.21	0.031	0.080
	#4	0.12	0.21	0.084	0.080
	#5	0.11	0.21	0.065	0.080