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Effects of Earthflows on Valley Floor and Channel Morphology

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ABSTRACT

Lateral encroachment of large, slow moving landslides, termed earthflows, into high gradient mountain streams can cause geomorphic changes in the channel and associated valley floor. Contiguous upstream earthflow, and downstream reaches were studied at five earthflows with estimated downslope velocities of 0.01 to 2 m/yr at the toe. Three of the earthflows studied followed the expected pattern of steeper gradients and a relatively high frequency of cascade channel units in the earthflow-constricted reaches. These sites had upstream reaches with relatively wide valley floors and low gradient channels with riffle-rapid dominated channel unit structures. Aggradation and consequent steepenings of gradient in earthflow reaches results from accumulation of large (> 1.5 m intermediate diameter) boulders from the earthflows. This deposition and increase in local base level leads to aggradation and decreased slope in the upper reach. This pattern was not evident in the other two sites, apparently because the lack of large boulders entering the channel from the earthflow, the steep overall gradient of the channel, and narrow valley floor limit change in the valley floor and channel form.

Key words - Landslide, Fluvial geomorphology

EFFECTS OF EARTHFLOW CONSTRICTION ON STREAM CHANNEL AND VALLEY FLOOR STRUCTURE, WESTERN CASCADE RANGE, OREGON

O'Connor et al. (1986), Baker and Pickup (1987), Kelsey (1988), Ashley et al. (1988), and others have recently focused attention on the effects of bedrock and other constraints on channel form and hydraulics. Constraints also affect valley floor geomorphic features with important implications for geomorphic processes and for riparian and stream ecosystems. Large landslides are a major form of constraint with variable impact, depending on the amount and rate of material supplied to a valley floor and the ability of the fluvial system to remove that material (Swanson et al. 1985; Costa and Schuster 1988).

In this study, we examine the effects of large, slow-moving (0.01 to 2 m/yr) landslides, locally termed earthflows, on the morphology of channels and valley floors in the Cascade Range, Oregon. We consider the case of earthflows impinging laterally onto valley floors more or less perpendicular to the channel axis. This constitutes one class of landslide effects on fluvial systems (Swanson et al., 1985; Costa and Schuster 1988). This mode of impingement is quite common in the central part of the western Cascade Range (Swanson and James, 1975; Hicks, 1982). Observations of Kelsey (1977), Bovis (1985), and Swanson et al. (1985) indicate that earthflows encroaching on valley floors alter the earthflow-adjacent valley floor and channel, as well as up- and downstream areas (Table 1; Figure 1).

Earthflows of the type found in the Cascade Range characteristically involve deep-seated, translational sliding and rotational slumping along 5 to 20 m deep failure surfaces that intersect the stream channel (Swanson and Swanston, 1977; Varnes, 1978; Bovis, 1985; Iverson and Major, 1988). Movement rates within a single earthflow complex may vary greatly both spatially and temporally (Swanson and Swanston, 1977; Varnes, 1978; Bovis, 1985; Iverson and Major, 1988). Annual movement of monitored earthflows in the western Cascades ranges from 0.01 to 15 m with distinct seasonal and, in some cases, storm event-related peaks of movement (Hicks, 1982; Swanson et. al., 1985). Earthflow landforms appear to have persisted for centuries to thousands of years (Swanson and James, 1975; Swanson and Swanston, 1977; Bovis, 1986), but data on on the actual age of such features are sparse.

We studied five earthflows that impinge on third- to sixth-order streams. The study streams are characteristic of those draining the western Cascade Range in having straight, high gradient (slopes ranging from 0.02 to 0.10) channels. Mean unvegetated channel width, referred to as the active channel width, ranges from 8 to 20 meters. Active channel width is similar to bankfull channel width in lowland systems; however, due to bedrock outcrops and the large size of bed and bank particles, distinctive banks and floodplains are not well developed. The mean width of the valley floor from hillslope to hillslope generally ranges from 1 to 5 active channel widths, but may be wider. The valley floor is comprised of floodplain, terrace, and secondary channel features.

We analyzed the effects of earthflows on stream channels at three scales of channel and valley floor features: stream bed particle, channel unit, and stream reach (Swanson et al., in press). Individual reaches extend over 10^2 to 10^3 meters of stream length and are distinguished by type and degree of hillslope constraint on valley floor and channel morphology. Constrained reaches have narrow valley floors, usually less than two active channel widths wide, resulting from passive constraints such as bedrock and active constricting agents such as alluvial fans and earthflows. Unconstrained reaches have wider valley floors, typically more than three active channel widths wide. In this study, only the earthflow reach was defined by type of hillslope constraint. The upstream and downstream reaches sampled at each site were defined by fixed numbers of channel units.

The stream channel can be divided into channel units which are finer scale features than reaches. Four types of channel units are recognized in this study: pools, riffles, rapids, and cascades (Table 2). These units are defined during low flow by their gradient and a visual estimate of the area in supercritical flow (Grant, 1986; Grant et al., in press). Units are usually at least one channel width in length; however cascades include some shorter units such as bedrock steps, bedrock falls, and log falls (Grant 1986; Grant et al., in press) (Table 2). Channel units and other aspects of channel geometry are directly influenced by exogenous materials such as large woody debris, bedrock, and large boulders (Grant, 1986; Lisle, 1987). Since reaches may differ in the density of each of these types of unit-forming materials, the distribution of channel units may vary systematically by reach type.

HYPOTHETICAL EFFECTS OF EARTHFLOWS ON CHANNEL AND VALLEY FLOOR FORM

We analyzed effects of earthflows on channel and valley floor landforms by comparing three contiguous reaches--upstream, within, and downstream of earthflow-constricted reaches (Fig. 1). Based on published work and observations in this study, we hypothesize certain contrasts in the form of these reaches and the mechanisms responsible.

The earthflow-constricted reach is expected to have a narrow valley floor as a result of earthflow encroachment across the valley floor. Degree of valley floor constriction would be a function of initial width, rate and duration of earthflow movement, time since cessation of movement in the case of dormant earthflows, and the rate of fluvial removal of earthflow deposits. The active channel may also be narrowed if the rate of earthflow encroachment exceeds the rate of removal of fluvial process or if changes in channel gradient and bed roughness result in altered channel hydraulics and form. Accumulation of very large bed material eroded from the earthflow toe leads to increased bed elevation and slope (Kelsey 1977, Swanson et al., 1985). These very large particles and bedrock exposed as a result of channel erosion of the valley wall opposite the earthflow should contribute to development of pool-boulder cascade sequences of channel units--extremely large boulders and bedrock outcrops aid pool formation while abundant intermediate sized boulders accumulate in cascades (Grant, 1986; Lisle, 1987; Grant et al. in press).

In the stream reach upstream of an earthflow constriction, we expect to observe lower channel gradient, wider valley floor, and possibly channel, and less channel area in pools than in either the earthflow-constricted or the subsequent downstream reaches. We expected these conditions to develop primarily as a result of aggradation in the earthflow reach which would raise streambed elevation at the downstream end of the reach upstream of the earthflow (Fig. 1). The upstream reach would then aggrade with sediment and debris flow deposits from tributary streams and the mainstem draining the upper part of the basin. The upstream reach would have gentler slope because particle size is smaller than in the earthflow reach which contains massive earthflow-delivered particles. Both finer particles, gentler gradient, and lack of constriction by earthflow movement lead to development of a wider channel, and more numerous secondary channels in the upstream reach. Rapid and riffle channel units are more extensive in the upstream reach because of the relative lack of very large boulders and bedrock outcrops limits development of cascades and pools. In the upstream reach, aggradation without earthflow constriction should also result in a wider valley floor.

STUDY SITES

The five sampled earthflows lie within the Willamette River drainage in the central part of the western Cascade Range (Table 3, Fig. 2). All of the earthflows selected enter stream channels at angles of approximately 90^o. Lengths of toes of sampled earthflows range from 310 m to 1130 m and the drainage area of streams flowing past the earthflow varies from 10 to 184 Km^2 (Table 3). Downslope velocities of these earthflows were evaluated using direct and indirect methods (Vest, 1988), and vary from 0.01 m/yr to 1.7 m/yr for the past 1 - 150 years (Table 3).

Two of the five earthflow are located along Lookout Creek in the H. J. Andrews Experimental Forest (Fig. 2). The Lookout Creek earthflow was chosen because of its 13 year record of movement, documenting a velocity of approximately 0.1 m/yr near the toe (G. Lienkaemper, pers. comm.). Swanson and Swanston (1977) estimate the Lookout earthflow has been active for at least 300 yrs, based on the present valley floor geometry and assuming a constant movement rate. Mazama volcanic ash found in depressions on the surface of the presently inactive Lower Lookout earthflow, indicate that earthflow topography had developed before approximately 7000 yrs before present (Swanson and James, 1975).

French Pete Creek, Landes, and Middle Santiam Research Natural Area (RNA) earthflows (Fig. 2) have no records of measured movement; however, velocities have been estimated using dendrochronologic techniques (Vest, 1988). French Pete and Middle Santiam earthflows enter streams of the same names; Landes enters Hills Creek. French Pete and RNA earthflows are located within Wilderness Areas and have not been affected by logging. Parts of the surface of the Landes and both Lookout earthflows have been logged as have portions of their upstream drainage basins. While logging may have affected the amount of woody debris contributed to channels, it has probably not appreciably increased the movement rate (Pyles et al., 1987).

Earthflows at all study sites are developed within Tertiary volcaniclastic rocks of the Little Butte and Sardine Formations (Peck et al., 1964). Extensive hydrothermal alteration and weathering have led to widespread development of unstable soil and rock materials in these formations (Swanson and James, 1975; Hicks, 1982).

The climate of the western Cascades is dominated by wet winters and warm, dry summers. Annual precipitation ranges from 1700 to 2600 mm/yr with most of the precipitation falling during long duration, low intensity events between October and March (Grant, 1986). The study sites are located in the transient snow zone found between 400 and 1200 m. elevation (Harr, 1981) where snow accumulates and melts several times each year.

The five study sites are located within the conifer-dominated Tsuga heterophylla zone of the Douglas Fir (Pseudotsuga menziesii) Region (Franklin, 1979). The near-stream environment is dominated by deciduous species, such as red alder (Alnus rubra) and big-leaf maple (Acer macrophyllum), which typically invade sites disturbed by landslides, debris flows, and fluvial processes. Except for clearcuts, areas of salvage logging, and roads resulting from management activities over the past 40 years, the forest cover on the study sites is natural, post-wildfire stands ranging from about 100 to 500 years in age.

METHODS:

Channel units and valley floor surfaces were mapped using a tape, a hand-held clinometer, stadia rod, and compass. Low flow and active channel widths were measured at the ends of every channel unit (error $\pm$ 0.5 m). The length of each channel unit was measured along its center line, which was not necessarily the thalweg (estimated error $\pm$ 2.0 m). The low flow water surface slope of each unit was measured using a clinometer (estimated error $\pm$ 0.01). Other information collected during the mapping of each channel units included unit type, the number of boulders greater than 1.5 m in diameter (intermediate axis), and the percentage of each channel bank and the channel bed in exposed bedrock.

Reach boundaries are defined by several criteria. The earthflow reach is denoted by the extent of the earthflow toe adjacent to the stream channel. The up- and downstream reaches extended for approximately 30 channel units in each direction from the earthflow reach.

The valley floor was sampled with transects perpendicular to the axis of the valley. Generally, 10 to 12 transects were sampled within each reach at an interval of 50 to 100 m of channel length, the interval between transects varied so that the transects fit within each reach to be sampled. A uniform transect spacing was maintained within a site. All surfaces less than six meters above the low flow water surface were measured; inventoried valley floor surfaces were almost entirely of fluvial origin, but may also include some low slump benches along earthflow toes and debris flow runout deposits. Alluvial fans were mapped but are not included as valley floor surfaces.

RESULTS:

Earthflow movement appears to have laterally deflected the locations of the channels and valley floors at three of the five study sites (Lower Lookout, Landes, and RNA; Fig. 3). The most pronounced deflection occurs at Landes, amounting to approximately 200 m. At the other two sites, the present axes of the channels and valley floors follow a line projected between the upstream and downstream reaches, indicating no lateral deflection.

Other geomorphic characteristics of the study sites follow many of the hypothesized effects of earthflows on stream channels and valley floors (Table 1), but also differ in some substantial ways. The most consistent geomorphic patterns among sites is variation in valley floor width. At all sites the earthflow reach is the narrowest, the upstream reach is widest, and the downstream reach is intermediate in both absolute terms and in terms of a valley floor width index, the ratio of mean valley floor width to mean active channel width for each reach (Table 4). At all sites, mean valley floor width is greatest in the upstream reach and least in the earthflow reach (Table 4). Valley floors in the upstream reaches are also consistently wider than in the downstream reaches by factors of 0.3 to 4.1 times. The valley floor width index exhibits similar patterns, although several of the sites have wider channels in the upstream reaches which reduces the apparent contrast between reaches expressed in terms of the index. Valley floor width index is most useful in reducing effects of differences in drainage area while making site to site comparisons. At all five sites, the earthflow constricted reach has the lowest valley floor width index, with values ranging from 1.3 to 2.3. The upstream reaches at all sites have width index values ranging from 4.0 to 9.0, which are substantially greater than the values for the downstream reach which range from 2.6 to 4.1. The relatively unconstrained upstream reaches have greatest variation in width index and the constrained earthflow reaches have least variation.

At four of the five sites a valley flat (a relatively wide, low gradient area hundreds of meters in length) is formed in the upstream reach. Development of multiple channels is common in valley flat areas. In some cases, these channels are stable features bordered by 100+ yr old confer forest. In other cases, the secondary channels are transient, shifting every few years and separated from the main channel by sparsely vegetated gravel bars. The Lookout earthflow is the only site without an extensive flat, and, although there is a split channel in the upstream reach, the bars between the two channels are vegetated with old-growth (approximately 500 yrs old) Douglas-fir, and there is little evidence of recent large scale deposition in this reach, as there is in the flats of the other reaches.

At three of the five sites (Landes, Lower Lookout, and RNA) the active channel in the upstream reach is significantly ($p>0.1$) wider than in the earthflow reach (Table 4). At all sites there is very little difference in active channel width between the downstream and earthflow reaches. At French Pete and Lookout, there is very little variation in active channel width among the three reaches.

The earthflow reach is the steepest at Lower Lookout, Landes, and RNA (Table 5; Fig. 4). However, the hypothesized lower gradient in the upper reach is found only at Landes. The upstream and downstream reaches of Lower Lookout and RNA have similar reach gradients, but are less than that of the earthflow reach. For Lookout, the steepest reach is the upstream reach. The steepest reach at French Pete is the downstream reach (Table 5; Fig. 4).

Greater density of large boulders in earthflow reaches tends to produce abrupt slope breaks in the channel, resulting in development of extensive cascade-pool channel unit sequences (Tables 6, 7). At all sites except French Pete, the portion of channel units in pools and cascades (by either reach length or unit number) is greatest in earthflow reaches; pools and cascades account 68, 71, 61, and 61% of total units in Lookout, Lower Lookout, Landes, and RNA, respectively (Table 6). Earthflow reaches of Lower Lookout, Landes, and RNA also have the highest densities of large boulders for each site (Table 7). Upstream and downstream reaches, in contrast, exhibit the highest densities of riffle and rapid channel units, indicating that the bed profile is smoother with fewer sharp slope breaks. Upstream reaches of Lower Lookout, Landes, RNA, and French Pete contain the lowest densities of large boulders, highest percentage of riffles, and lowest percentage of cascades for the sites. Lookout is the exception; the downstream reach, which is the least steep, has the highest boulder density while the earthflow reach has the lowest boulder density for that site.

Variation in the density of large boulders among reaches and sites is controlled in part by differences in origin of the boulders. Many of the large boulders in the lower reach of French Pete may be derived from debris flow deposits originating from a tributary whose confluence with French Pete is located downstream from the earthflow. Many of the large boulders at Lower Lookout, Landes, and RNA appear to be from earthflow colluvium and from bedrock outcrops on the valley walls opposite the earthflows. Large boulders are also delivered to the valley floors of third-order and larger channels by debris flows down tributary streams, as occurred in the upstream reach of French Pete in 1964. The lower density of large boulders in the earthflow reach of Lookout Creek than in up- and downstream reaches may reflect a general pattern of high density of boulders derived from glacial deposits in the stream channel which are partially obscured in the earthflow reach by deposition of finer, earthflow-derived sediment.

We have argued that much of the earthflow effect on channels results from aggradation. The magnitude of aggradation in earthflow reaches (h) can be estimated roughly using the slopes of the earthflow (Se) and downstream (Sd) reaches and the length of the earthflow toe (L), which is the distance over which directly earthflow-induced aggradation has occurred (Fig. 1):

$$h = (Se - Sd)\ L$$

This approach yields estimates of aggradation of 10.9 m at Lower Lookout, 7.3 m at Landes, and 7.9 m at RNA, the three sites where relative channel gradient among the three reaches and other landform feature indicate that significant aggradation has occurred.

DISCUSSION:

Relative channel and valley floor characteristics among earthflow and up- and downstream reaches follow predicted patterns only for valley floor width at all five study sites. The other predicted characteristics are met in most cases by three of the five sites--Lower Lookout, Landes, and RNA. These conditions can be interpreted in relation to a general model of earthflow effect on channels and valley floors.

Where an earthflow encroaches on a channel, aggradation will occur if the rate of sediment supply from the earthflow toe exceeds the rate of sediment removal by fluvial processes. A crucial factor in this balance is the size distribution of earthflow-derived material. The three study sites that fit the predicted geomorphic contrasts among reaches have highest densities of large boulders in their earthflow reaches. These predominantly earthflow-derived boulders cause aggradation and channel steepening in the earthflow reach. These processes raise local baselevel of the upstream reach, leading to aggradation with sediment derived from upstream sources, reduction of channel gradient in this reach, and widening of the valley floor. We believe that in these study sites greater valley floor width in the upper reach is a response to constriction and aggradation in the earthflow reach, not from along-stream variation in erodibility of rocks or geologic structure, which are important in other areas (Baker and Pickup, 1987; Kelsey, 1987, 1988; McHugh, 1987; Ashley et al. 1988). The reach downstream of the earthflow may be little affected or may receive large boulders and finer sediments derived in part from the earthflow reach.

This general model appears to account for conditions in Lower Lookout, Landes, and RNA sites. Why do reach characteristics at Lookout and French Pete differ in most respects? Lookout and French Pete do fit the expected pattern of valley floor width variation which is a relatively conservative landform modification created by earthflow movement across a valley floor. Constriction of valley floor width by earthflow deposits, for example, can persist for long periods of time even after earthflow movement has ceased. Adjustment of channel form and gradient, on the other hand, is likely to be more rapid, since fluvial energy is more effectively focused on the channel bed and banks.

The failure of the Lookout and French Pete sites to match predicted channel characteristics can be interpreted in terms of the balance between sediment supply and removal at the toes of these two earthflows. The absence of the expected response of channel gradient and density of large boulders suggests that these earthflows have not supplied material of sufficient volume and particle size to have left a long-term imprint on these two channels. Channel response may also be muted by site conditions independent of earthflow effects. The Lookout site has the smallest drainage area above the earthflow constriction, steepest channel gradient, and highest density of large boulders in the vicinity of the earthflow. French Pete is similar, though less distinctive in these respects relative to the other three sites studied. We expect the high gradient of these sites to limit development of extensive upstream depositional areas because there is substantial stream power for removal of earthflow-derived sediment. Furthermore, from a strictly geometric viewpoint, a given unit of vertical aggradation at the head of the earthflow reach will produce less extensive areas of upstream deposition in steeper channels. The Lookout site is characterized by an overall high density of boulders derived from glacial deposits. The low density of large boulders in the earthflow reach of Lookout relative to adjacent reaches may result from deposition of finer material or large organic material from the earthflow toe which would obscure the large boulders of earthflow origin. Channel pattern in map view at Lookout and French Pete sites also suggests that the earthflows at these sites have not been active for long periods. These channels are not conspicuously deflected into the opposite valley wall in the earthflow reach (Fig. 3).

CONCLUSIONS

We hypothesize that the movement of large earthflows into stream channels results in altered valley floor width and channel width, slope, and unit structure in the earthflow-adjacent and upstream reaches. These geomorphic predictions are based on a model of earthflow encroachment delivering sediment, including large boulders, to the channel, leading to aggradation and steepening of the channel. Pool and cascade units are developed in response to increased gradients, abundant boulders and bedrock outcrops where earthflow movement leads to erosion of the opposite valley wall. Aggradation in the earthflow reach would lead to reduced gradient and widening of the upstream channel and valley floor. Upstream reaches are dominated by rapid and riffle channel units in part because of the abundance of alluvium and absence of large boulders.

The expected patterns of valley floor form are observed at all five study sites suggesting that constriction of valley floor width is a common and persistent feature in earthflow-affected areas. Expected patterns of channel slope, boulder density, and channel unit structure in earthflow and upstream reaches occur at only three of the five study sites. Failure of toe sites to display these geomorphic features appears to be a result of lack of sufficiently recent, voluminous, or boulder-rich sediment from the earthflow toes to produce aggradation in the earthflow reaches. Width of active channel is not significantly constricted in earthflow reaches, apparently because this is the least conservative of earthflow effects examined. Fluvial processes can more quickly reestablish channel width than valley floor width or channel gradient after alteration by earthflow encroachment.

Channel form and fluvial resetting of surfaces varies among reaches. In upstream reaches, especially where valley flats are present, relatively low channel gradient and mobile bank material favor development of a relatively wide active channel and a greater probability of fluvial resetting of vegetation. Channel avulsions and presence of secondary channels are common. Downstream reaches are straight and have densities of large boulder (relative to the upstream reaches). Earthflow and downstream reaches are relatively resistant to resetting of streamside floodplain forest by fluvial processes because of bedrock outcrops and large boulders in the stream bed and banks.

Development of valley flats in the upstream reaches can occur in response to a variety of processes operating on different time scales, but we have little evidence to evaluate details of history of these events. The degree of disturbance of trees growing on earthflows, for example, indicates the movement history over the past 200+ years, a fraction of the probable lifetime of the earthflows. Valley flats might form rapidly as a result of deposition upstream of a dam produced by rapid landslide movement. However landslide dammed lakes are extremely rare in the Western Cascade Range, because catastrophic, large-scale landsliding is rare (Swanson and Lienkaemper, 1985). Debris flows from tributary streams entering upstream reaches may leave deposits in these relatively low gradient areas. Probability of debris flow deposition at the heads of earthflow reaches is enhanced as the log-laden snout of debris flows encounters the narrowed valley floor and channel at the head of the earthflow reach. This phenomena has been observed at several of the studied earthflows in the past three decades. Overall, however, we feel that valley flats develop predominantly as a result of prolonged periods of gradual earthflow encroachment onto valley floors and associated deposition of alluvium in upstream areas.

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Table 4 Mean valley floor width, active channel width, and valley floor width index for each reach.

Table 5 Bed gradient of each reach by site.

Table 6 Percentage of each unit type in each reach by number and length of units.

Table 7 Density of large boulders in each reach.

Table 1. Hypothesized relative differences in channel and valley floor characteristics in upstream, earthflow adjacent, and downstream reaches due to earthflow constriction.

	Reach		
	Upstream	Earthflow	Downstream
Density of Large Boulders	Lowest	Hightest	Intermediate
Relative Reach Gradient	Lowest	Highest	Lowest to Intermediate
Relative Active Channel Width	Widest	Narrowest	Intermediate
Relative Valley Floor Width	Widest	Narrowest	Intermediate
Extent of Cascade Channel Units	Lowest	Highest	Intermediate
Extent of Riffles Rapid Channel Units	Highest	Lowest	Intermediate

Table 2. Channel unit types and their characteristics at low flow.

Unit Type	Gradient	Percent Area in Supercritical Flow
Pools	0 - 0.01	< 15%
Riffles	0.01 - 0.025	0 - 30%
Rapids	0.025 - 0.04	30 - 50%
Cascades[1]	> 0.04	> 50%

[1]Includes bedrock falls, log falls, and boulder steps which are usually less than one channel width in length.

Table 3. Earthflow and channel characteristics of the five study sites.

	Earthflow				
Site	Area (ha)	Toe Length (meters)	Toe Velocity (m/yr)	Drainage Area Above Earthflow (km^2)	Stream Order
Lookout	17	315	0.1[1]	10	3
French Pete	29	410	0.1[2]	79	5
Lower Lookout	100	1090	0.01[3]	52	4
Landes	205	660	1.7[2]	98	5
RNA	91	1130	0.6[2]	184	6

[1]Measured 1974-1985 (Swanson et al., 1985).

[2]Estimated using dendrogeomorphic techniques (Vest, 1988).

[3]Maximum estimated rate based on lack of micro landforms (e.g., tension cracks and scarps) indicative of current movement.

Table 4. Mean valley floor width, active channel width, and valley floor width index for each reach.

Site	Mean Valley Floor Width (meters)	Standard Error	Mean Active Channel Width by Reach (meters)	Standard Error	Mean Valley Floor width Index	Standard Error
Lookout						
Upstream	48[2]	5.1	7.5	0.5	6.4[2]	0.68
Earthflow	19[2]	3.0	8.4	0.4	2.2[2]	0.24
Downstream	38[2]	1.5	9.4	0.3	4.1[2]	0.16
French Pete						
Upstream	107[3]	14.7	18.8	1.2	5.7[3]	0.78
Earthflow	26	5.5	20.2	1.5	1.3	0.28
Downstream	53	6.4	20.3	1.0	3.2	0.33
Lower Lookout						
Upstream	252[3]	43.3	27.9[1]	1.5	9.0[3]	0.96
Earthflow	30	6.1	19.5	1.0	1.6	0.31
Downstream	49	7.8	18.0	0.9	2.7	0.43
Landes						
Upstream	203[3]	24.8	22.6[1]	1.0	9.0[3]	1.09
Earthflow	30	3.6	16.7	1.0	1.8	0.22
Downstream	70	9.8	17.9	0.6	3.9	0.55

RNA						
Upstream	141[2]	16.5	35.1[1]	1.9	4.0	0.47
Earthflow	43[2]	4.5	28.5	1.4	1.5[4]	0.16
Downstream	88[2]	16.6	27.9	1.3	3.2	0.59

[1]Significantly greater (p>0.1) than other reaches using Tukey's Test.

[2]Significantly greater (p>0.05) than other reaches using Tukey's Test.

[3]Significantly greater (0>0.05) than downstream and earthflow reaches using Tukey's Test.

[4]Significantly less (p>0.05) than downstream and upstream reaches using Tukey's Test.

Table 5. Bed gradient of each reach by site.

	Reach Slope (m/m)		
Site	Upstream	Earthflow	Downstream
Lookout	0.071	0.060	0.056
French Pete	0.037	0.033	0.041
Lower Lookout	0.021	0.030	0.020
Landes	0.023	0.052	0.041
RNA	0.016	0.024	0.017

Table 6. Percentage of each unit type in each reach by number and length of units.

Site-Reach	Percent of Total Units by Number: Pools	Riffles	Rapids	Cascades	Percent of Total Reach Length: Pools	Riffles	Rapids	Cascades	Total Number of Units	Total Reach Length (meters)
Lookout										
Upstream	33.3	11.1	25.0	31.6	17.9	11.5	34.8	35.8	36	460
Earthflow	40.0	8.0	24.0	28.0	27.8	12.7	31.9	32.7	25	315
Downstream	28.3	19.6	17.4	34.8	14.2	23.4	22.2	40.2	46	760
French Pete										
Upstream	22.6	16.1	22.6	38.7	12.8	10.8	29.5	46.9	31	950
Earthflow	28.6	7.1	28.6	35.7	16.3	2.6	56.9	24.1	14	410
Downstream	32.3	3.2	16.1	48.4	10.7	1.2	47.1	40.9	31	1385
Lower Lookout										
Upstream	28.1	21.9	31.3	18.8	28.8	25.5	30.4	15.3	32	645
Earthflow	31.3	14.6	14.6	39.6	27.3	21.6	18.3	32.8	48	1090
Downstream	35.0	7.5	22.5	35.0	25.8	4.9	42.9	26.5	40	1180

Landes										
Upstream	26.7	36.7	23.3	13.3	25.6	39.1	27.8	7.5	30	1025
Earthflow	26.1	13.0	26.1	34.8	20.2	12.1	39.7	28.1	23	660
Downstream	31.0	10.3	37.9	20.7	16.1	6.0	62.6	15.4	29	1100
RNA										
Upstream	20.0	36.7	33.3	10.0	26.8	35.7	34.8	2.7	30	1780
Earthflow	35.7	17.9	21.4	25.0	46.5	14.2	28.7	10.6	28	1130
Downstream	22.6	25.8	32.3	19.4	27.3	31.6	32.5	8.5	31	1140

Table 7. Density of large boulders in each reach.

	Boulders / 100 m^2 Channel Area		
Site	Upstream	Earthflow	Downstream
Lookout	3.40	1.86	5.35
French Pete	0.59	0.96	1.33
Lower Lookout	0.08	0.68	0.27
Landes	0.03	4.39	3.99
RNA	0.11	0.99	0.70

FIG 1

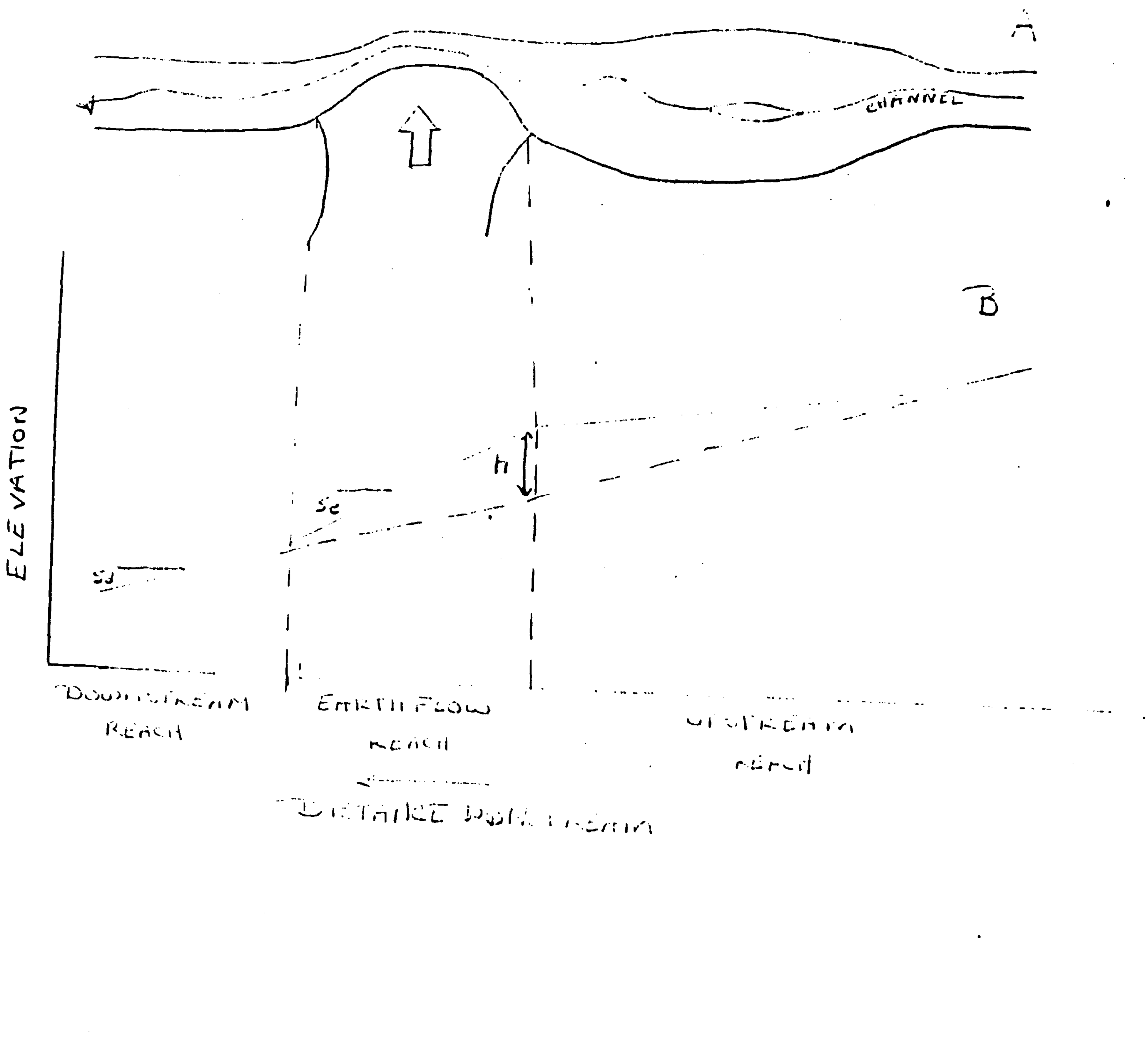
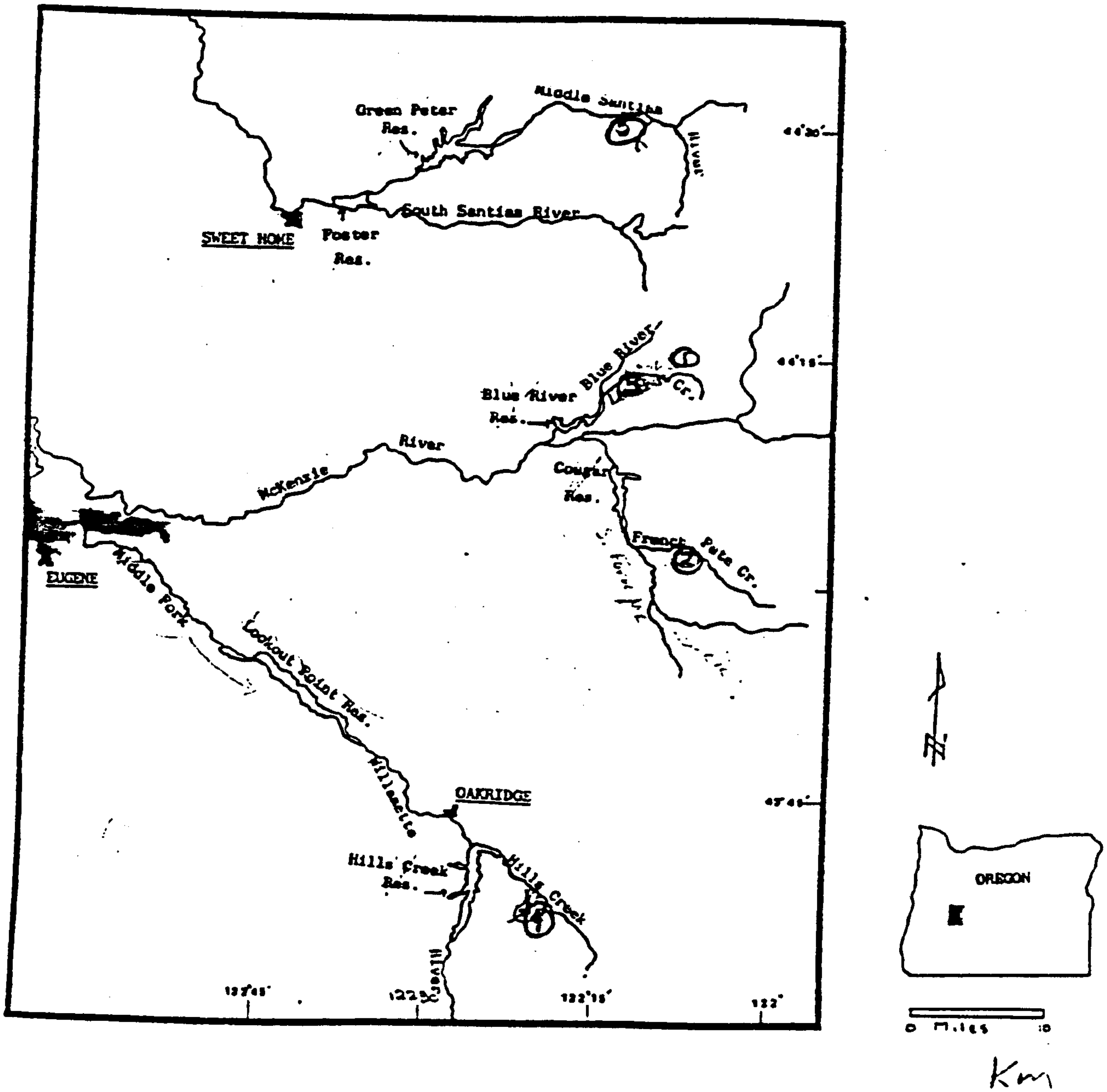


Fig 2



Green Peter
Res.
Middle Santiam
South Santiam River
SWEET HOME
Foster
Res.
Blue River
Blue River
Res.
River
McKenzie
Cougar
Res.
French Pete Cr.
EUGENE
Middle Fork
Lookout Point Res.
Willamette
OAKRIDGE
Hills Creek
Res.
Hills Creek
44°30'
44°15'
43°45'
122°45'
122°30'
122°15'
122°
OREGON
0 Miles 10
Km

FIG. 3

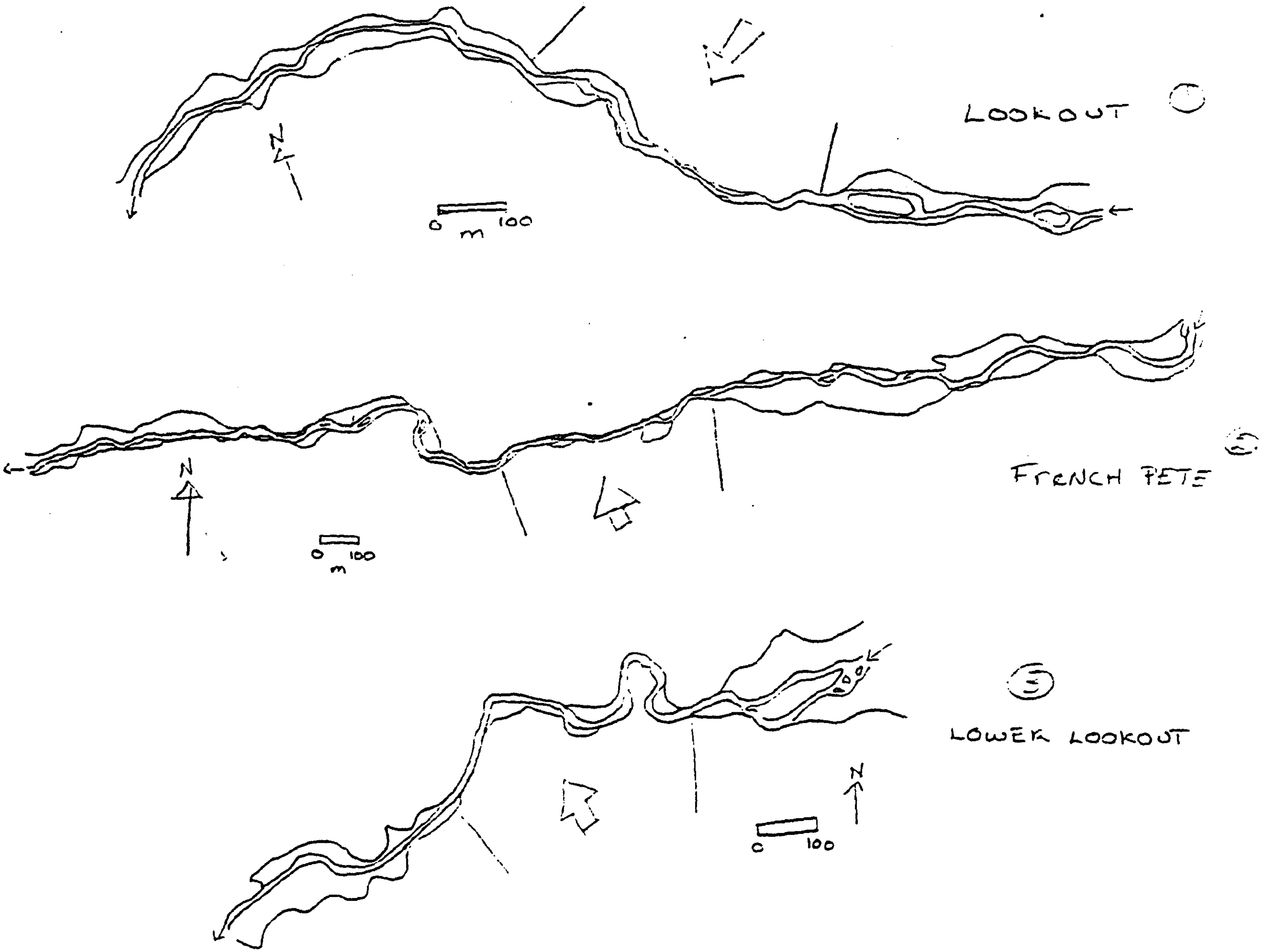


FIG. 3 (cont)

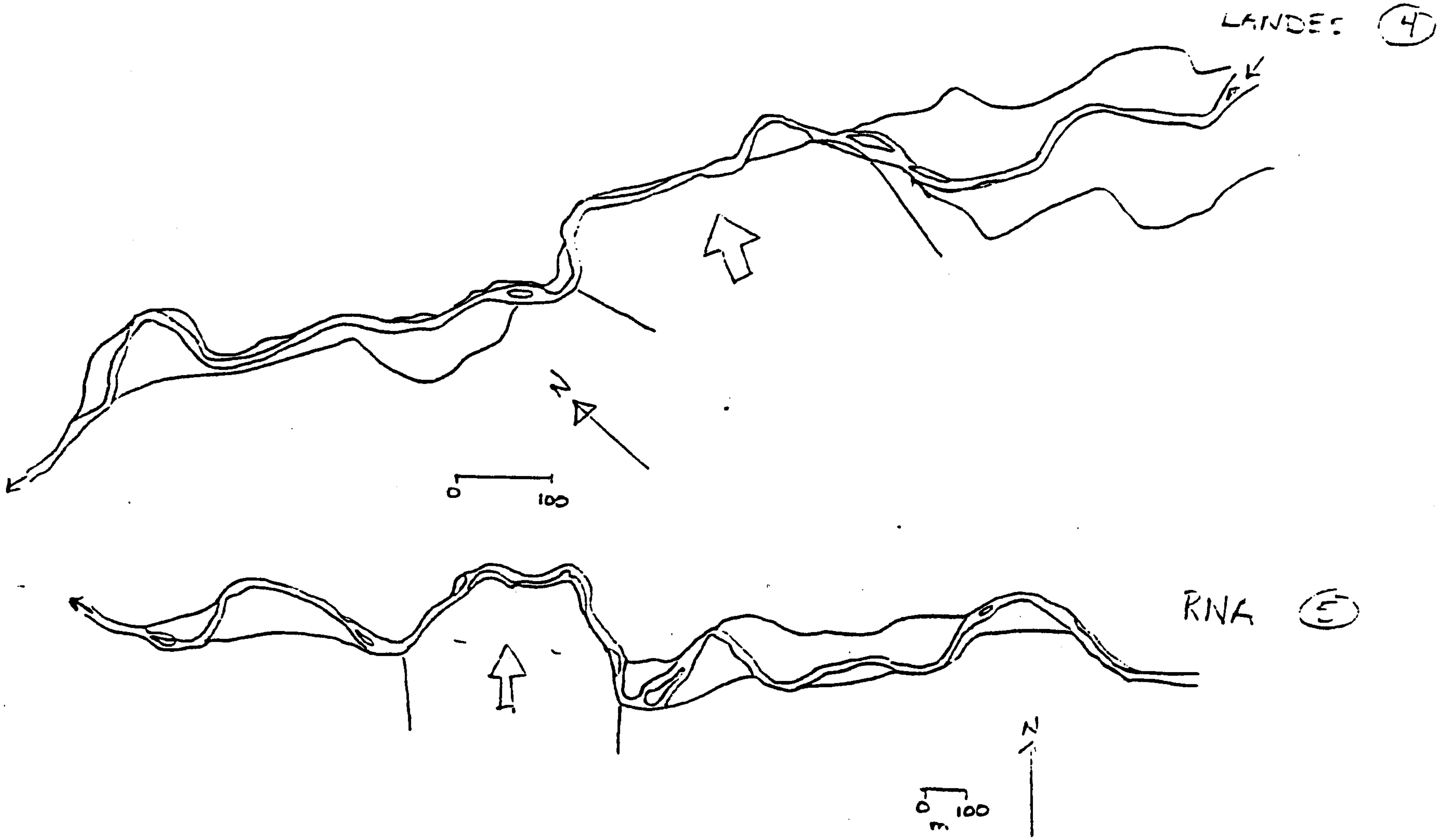
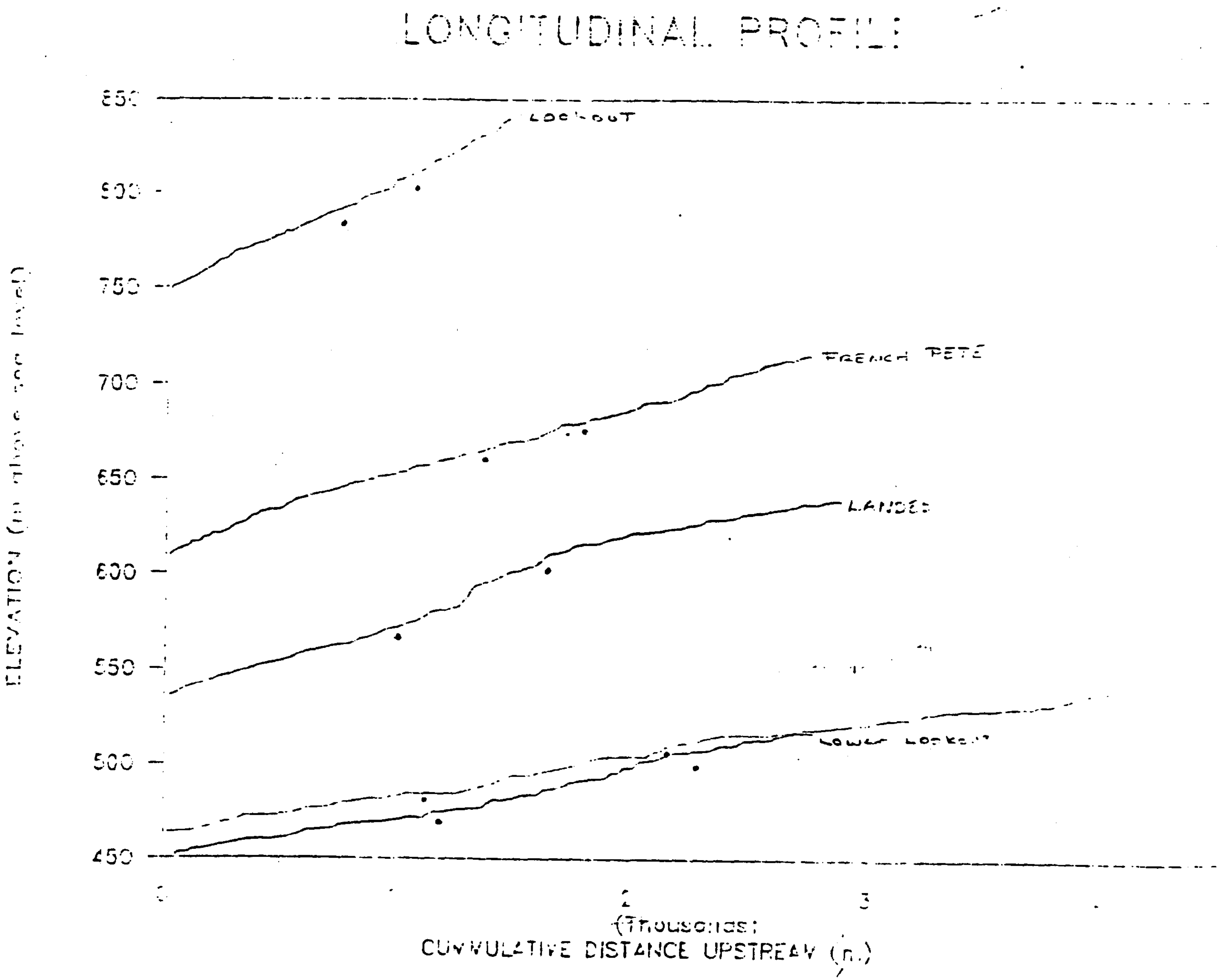


Fig. 4


LONGITUDINAL PROFILE
850
800
750
700
650
600
550
500
450
ELEVATION (m above sea level)
LOOKOUT
FRENCH PETE
LANDES
LOWER LOOKOUT
0
2
3
(Thousands)
CUMMULATIVE DISTANCE UPSTREAM (m)