Effects of Vegetation and Land Use on Channel Morphology

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Abstract.—Spatial and temporal morphologic variability in mountain streams may be attributed to local prevailing conditions. Morphologically distinct reaches of Wickiup Creek, in the Blue Mountains of central Oregon, result from differences in the composition and structure of streamside vegetation, physiography, and land use. Comparisons of grazed and ungrazed meadow reaches and a forested reach loaded with large organic debris reveal specific differences related to the local environmental setting. Overall, width, depth, and cross section area do not increase systematically downstream. The greatest widths are found in the forested reach. Stream depths are at a maximum through the ungrazed meadow reach. Spatial variability results from prevailing vegetation conditions. Temporal variability in the ungrazed exclosure results from the exclusion of livestock and subsequent revegetation of the meadow. Over a 50-year period without grazing, a 94% reduction in channel cross section area occurred.

Spatial variability in a second order, intermontane stream results from differences in the structure and composition of riparian vegetation, presence of embedded organic debris, and local physiography. Temporal variability in channel morphology is largely the result of changes in grazing management.

Several researchers have recognized the contribution of vegetation to fluvial processes and channel morphology. Nanson and Beach (1977) describe the effects of vegetation on channel morphology in northeastern British Columbia, where varying densities of floodplain vegetation are influencing overbank sedimentation rates. The character and species of vegetation also contributes to variability in channel morphology. In Vermont, small streams flowing through sod tend to be narrower and deeper than streams under forest cover (Zimmerman et al. 1967). Forested reaches of stream tend to have highly variable widths as a result of local disturbance. Smith (1976) observed the role of vegetation in reducing bank erosion and subsequent lateral migration of a glacial meltwater channel. Erosion rates drop with increases in root mass in channel bank sediments, as channel bank roots protect against fluvial erosion and anchor against collapse (Smith 1976).

Large organic debris, derived from streamside vegetation, influences channel morphology by protecting streambanks and increasing channel roughness. Further, woody debris helps control the routing of sediment and water (Swanson et al. 1982). In steep mountain streams, organic debris controls local stream morphology by trapping sediment and creating plunge pools (Keller and Swanson 1979). Log steps provide local control of base level and serve to decrease channel gradients (Heede 1985). In a coastal redwood environment, 60% of the total drop in channel elevation is associated with instream debris (Keller and Tally 1979).

Historic channel changes often obscure longer term channel evolution. Gregory (1984) and Hickin (1983) concluded that most rivers are dominated by transient behavior and never fully adjust to major climatologic events or land use change. Historic channel adjustments have been further linked to the growth and decline of bank and floodplain vegetation. Hadley (1961) and Graf (1978) describe channel narrowing and deepening in response to the progressive spread of tamarisk in the southwestern USA.

The effects of livestock grazing on stream ecosystems are receiving attention from researchers in many fields. Biologists have long been aware of grazing impacts on fisheries resources (Platts 1979). Livestock effects can be divided into impacts on streamside vegetation and impacts on the adjacent channel. Vegetation is altered by soil compaction, selective herbage removal, and physical damage by trampling and rubbing (Kauffman and Kreuger 1984). Impacts on the stream channel include increased channel bank instability, channel shape adjustments, and changes in sediment and discharge volumes (Platts 1979). Downstream from a fenced reach of stream in eastern Oregon, Winegar (1977) found reduced sediment loads. By 1978, 9 years after the establishment of the exclosure, up to 3 m of material had aggraded within the exclosed reach (Winegar 1977).

The recognition of temporal and spatial morphologic variability in mountain streams presents a challenge to the application of conventional analytic techniques. For example, the quasi equilibrium state described by downstream hydraulic geometry (Leopold and Maddock 1953) may not accommodate the range of natural variability that is found in mountain streams. Conventional analysis such as hydraulic geometry is directed towards quantifiable deterministic solutions and may ignore processes which cause deviations from predicted trends (Hickin 1984).

The identification of the causes of morphologic variability, such as vegetation, basin characteristics, and land use, will contribute towards a broader understanding of change in the natural environment as well as provide a gage for evaluation of responses to management activities. Land management goals on public lands are evolving to include multiple resource management of fisheries, wildlife, and recreation, in addition to the traditional uses of timber and range. Federal land management agencies are developing strategies for streamside management (Beschta and Platts 1986), but it may not be possible to enhance all stream resources simultaneously.

Study Area

Wickiup Creek is a second order tributary to the Silvies River in central Oregon and has a drainage area of 24 km^2 (Figure 1). The study basin lies at an average elevation of 1,650 m above mean sea level and is largely forested (95%) with mixed stands of ponderosa pine *Pinus ponderosa*, lodgepole pine *Pinus contorta*, grand fir *Abies grandis*, and Douglas fir *Pseudotsuga menziesii*. The drainage basin is

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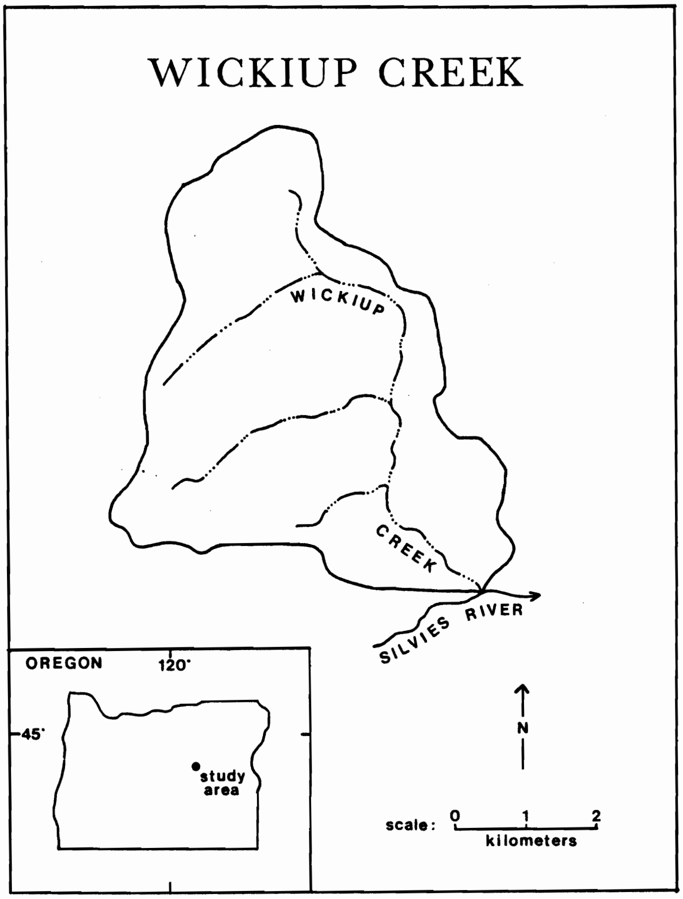
characterized by steep forested slopes and narrow alluvial valleys. At its headwaters, Wickiup Creek is ephemeral, flowing through forested reaches. Downstream, flow becomes intermittent to perennial. The valley widens into open, sagebrush *Artemisia* spp. meadows and a meandering pattern is established. Streamside vegetation consists of annual and perennial herbaceous vegetation, occasional thickets of willow *Salix* spp., and stands of mixed conifers, predominantly lodgepole pine. Seasonal livestock grazing and timber harvest constitute the principle land use activities in the study area. The basin falls within a larger cattle allotment that is divided into six pastures and is currently managed under a rest-rotation grazing system. In 1938, the county agricultural agent and U. S. Forest Service personnel cooperated in the construction of a 2.8-hectare fenced livestock exclosure on Wickiup Creek to demonstrate the effects of grazing on forage production.

Figure 1.—Location of study area.



Study Reaches

In order to establish patterns of channel morphology and evaluate sources of variability, the length (9.2 km) of Wickiup Creek was divided into five study reaches (Figure 2). A reach was identified as having similar physiography, vegetation, channel pattern, and land use treatment (Table 1).

Figure 2.—Study reaches and location of selected channel cross section survey sites.

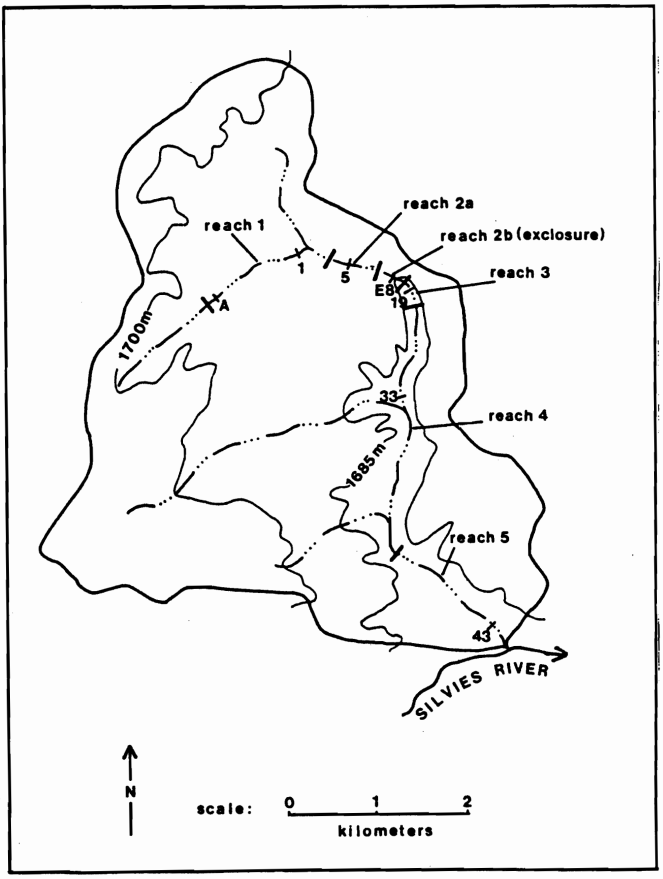


Table 1.—Summary of principle reach characteristics.

Reach	Distance downstream (meters)	Description
1	2,414-3,863	Steep, forested, headwater channel; ephemeral to intermittent flow.
2a	3,863-4,255	Moderate slope, meadow, mid-basin channel; intermittent to perennial.
2b	4,255-4,705	Exclosure channel-same as 2a.
3	4,705-5,538	Moderate slope, forested reach, embedded large organic debris; perennial flow.
4	5,538-8,153	Moderate to gentle slope, meadow-forest, valley widening; perennial.
5	8,153-9,300	Moderate to gentle slope, meadow; perennial flow.

Methods

Field sampling and historic documentary evidence were combined for the purpose of identifying stream channel interactions and response to riparian vegetation, physiography, and livestock grazing. Field data recovery was based on the establishment of representative cross section survey sites at intervals along Wickiup Creek (reaches 1, 4, and 5). Reaches 2 and 3 were intensively surveyed at 30-m intervals, and constitute the focus of this investigation. Reach 2 consists of two meadow sections, grazed (2a) and ungrazed (2b). Historic documentary evidence consists of a 50-year photographic record of channel changes within the exclosure spanning the period 1933 to 1985. Estimates of historic channel widths and depths were obtained from repeat photographs for the years 1933, 1948, 1956, and 1980.

A consistent morphologic level, the bankfull level, was identified in the field by banktop, vegetation change, and top of gravel bar. Seven variables describing channel morphology were determined from channel cross section plots and consist of: width, cross section area, mean depth, maximum depth, wetted perimeter, hydraulic radius, and width:depth ratio. Additional variables include channel slope, determined from field survey and topographic maps, channel roughness, determined by a combination of established methods (Cowan 1956; Barnes 1967), velocity, determined from the Manning equation,

$$V = (R^{0.67}\,S^{0.50})/n$$

and discharge determined from the continuity equation,

$$Q = V * A$$

where,

V = velocity (m/s)
R = hydraulic radius (m)
S = channel slope (m/m)
n = Manning's roughness coefficient
Q = discharge (m^3/s)
A = area (m^2)

Discharge estimates were verified by comparison with regionally derived flood discharge equations (Harris and Hubbard 1983).

Analysis and Results

In a conventional analysis of downstream hydraulic geometry, independent basin variables such as drainage area or distance downstream are used to evaluate systematic adjustments in channel morphology and discharge (Leopold et al. 1964). A regression analysis of the seven morphologic variables, velocity, and discharge against distance downstream reveals the absence of systematic trends ($R^2 < 0.10$), with the exception of channel area and discharge (Table 2). Very gradual increases in area and discharge with distance downstream are evident from the regression equations; however, the low level of explained variance indicates the influence of other factors. The degree to which vegetation and livestock influence channel size, shape, roughness, and velocity were examined by comparing individual reaches.

Reach Morphology

The means and standard deviations of the morphologic variables were compared by reach (Table 3). The level of between group variance is determined from an analysis of variance in which the means and standard deviations of five groups (reaches of Wickiup Creek) are compared. The null hypothesis is that there are no differences in the character of individual reaches. The analysis tests this hypothesis by comparing variation between groups to variation within groups due to random error. Significant differences ($P \leq 0.05$) are found to exist for all the morphologic variables (Table 4). The null hypothesis, therefore,

Table 2.—Regression analysis of downstream channel morphology and Discharge[1].

Variable	Regression equation	r^2	SE	F	P
Width	=.094+.000044(D)	5.2	.24	4.2	.05
Depth 1 (mean)	=.633+.000014(D)	0.0	.18	0.8	Not Sig.
Depth 2 (max.)	=.462+.000011(D)	0.0	.15	0.7	Not Sig.
Wet. per.	=.206+.000036(D)	6.8	.18	5.3	.05
Area	=-.54+.000058(D)	17.3	.18	13.2	.001
Hyd. rad.	=-.74+.000021(D)	4.4	.12	3.7	.10
Width:depth	=.705+.000030(D)	0.0	.38	0.8	Not Sig.
Velocity	=-.37+.000048(D)	7.5	.23	5.7	.05
Discharge	=-.91+.000011(D)	16.1	.34	12.1	.001

wet. per. = wetted perimeter, hyd. rad. = hydraulic radius, D = distance downstream, n = 59.

[1] Analysis of log ten values.

Table 3.—Analysis of grouped morphologic data — means (x) and standard deviations (sd).

Reach		Width	Depth (mean)	Depth (max.)	Wet. per.	Area	Hyd. rad.	W:D
1	x	2.42	0.31	0.42	2.87	0.77	0.28	8.10
	sd	0.60	0.08	0.16	1.07	0.34	0.08	2.52
2a	x	2.01	0.25	0.38	2.24	0.47	0.21	9.39
	sd	0.40	0.08	0.11	0.46	0.14	0.06	4.40
2b	x	1.21	0.41	0.50	1.71	0.43	0.26	2.62
	sd	0.79	0.13	0.16	0.64	0.16	0.05	1.39
3	x	3.34	0.22	0.35	3.42	0.67	0.21	18.14
	sd	1.75	0.08	0.13	1.69	0.26	0.07	13.64
4	x	3.28	0.26	0.40	3.40	0.81	0.25	13.49
	sd	0.88	0.07	0.10	0.88	0.18	0.06	9.13
5	x	3.02	0.45	0.59	3.46	1.44	0.38	7.32
	sd	1.27	0.18	0.27	1.25	1.23	0.15	3.23

Wet. per. = wetted perimeter, Hyd. rad. = hydraulic radius, W:D = width depth ratio.

All data in meters.

Table 4.—Analysis of variance — grouped morphologic data.

	Actual		Residual	
Variable	F	P	F	P
Width	6.96	.001	9.66	.001
Average depth	7.63	.001	6.03	.001
Maximum depth	3.22	.05	2.23	Not Sig.
Wetted perimeter	5.37	.001	5.59	.001
Cross section area	5.68	.001	3.28	.05
Hydraulic radius	5.20	.001	2.64	.05
Width:depth	5.71	.001	13.53	.001
Velocity	17.54	.001	12.03	.001
Discharge	16.60	.001	11.19	.001

can be rejected supporting the contention that differences in between-group channel morphology are representative of real differences in the morphology of Wickiup Creek. In sum, the results of the analysis of variance support the differentiation of reaches based on the following criteria: drainage basin characteristics, vegetation, and management treatment.

Results of Fisher's LSD Test

A more complete picture of the differences between individual groups emerges following application of Fisher's LSD test (Table 5). The means of each group are ranked from smallest to largest, and coded A through F. An "S" indicates that the mean is significantly different from the corresponding level. For reaches 2a, 2b, and 3, width and width:depth ratios are significantly different. For all morphologic variables except cross section area, the forested reach (3) and the grazed meadow reach (2a) are significantly different. All levels are not significantly different in all cases.

Downstream Effects

In order to account for the downstream effects of increasing drainage area, an analysis of variance was performed on standardized regression residuals. By analyzing regression residuals, the effects of increasing drainage area are removed, isolating variability due to other factors. The residuals are grouped by reaches, and the means and standard deviations compared. Again, significant differences ($P \leq 0.05$) are found, further supporting the characterization of reach morphology.

Comparing actual values and standard residuals (Table 4) reveals a decrease in the level of explained variance for depth, area, and hydraulic radius, suggesting a dependence on the downstream effects of increasing drainage area. An increase in the amount of explained variance is apparent for width, wetted perimeter, and width:depth ratio, indicating a dependence on local factors. Removing the downstream effects of increasing drainage area isolates those variables most responsive to local vegetation conditions and management treatment. Width, wetted perimeter, and channel shape, therefore, reflect local variability of streamside vegetation and intensity of livestock use.

Changes in Channel Morphology by Reach

The headwater, ephemeral channel (reach 1) of Wickiup Creek is relatively wide and enlarged, probably reflecting more infrequent flow events. Downstream, through reach 2a, the channel is intermediate in width and shallower

Table 5.—Differences between individual groups — results of Fisher's LSD Test.

Width									**Mean depth**									
Level	Reach	Mean	A	B	C	D	E	F	Level	Reach	Mean	A	B	C	D	E	F
A	2b	1.21	.	S	S	S	S	S	A	3	0.22	.	.	.	.	S	S
B	2a	2.01	S	.	.	.	S	S	B	2a	0.25	.	.	.	.	S	S
C	1	2.42	S	.	.	.	.	.	C	4	0.26	.	.	.	.	S	S
D	5	3.02	S	.	.	.	.	.	D	1	0.31	.	.	.	.	S	S
E	4	3.28	S	S	.	.	.	.	E	2b	0.41	S	S	S	S	.	.
F	3	3.34	S	S	.	.	.	.	F	5	0.45	S	S	S	S	.	.
Maximum depth									**Wetted perimeter**								
Level	Reach	Mean	A	B	C	D	E	F	Level	Reach	Mean	A	B	C	D	E	F
A	3	0.35	.	.	.	.	S	S	A	2b	1.71	.	.	S	S	S	S
B	2a	0.38	.	.	.	.	S	S	B	2a	2.23	.	.	.	S	S	S
C	4	0.40	.	.	.	.	.	S	C	1	2.87	S	.	.	.	.	.
D	1	0.42	.	.	.	.	.	.	D	4	3.4	S	S	.	.	.	.
E	2b	0.50	S	S	.	.	.	.	E	3	3.42	S	S	.	.	.	.
F	5	0.59	S	S	S	.	.	.	F	5	3.46	S	S	.	.	.	.
Area									**Hydraulic radius**								
Level	Reach	Mean	A	B	C	D	E	F	Level	Reach	Mean	A	B	C	D	E	F
A	2b	0.43	.	.	.	.	.	S	A	3	0.21	.	.	.	S	.	S
B	2a	0.47	.	.	.	.	.	S	B	2a	0.21	.	.	.	.	.	S
C	3	0.67	.	.	.	.	.	S	C	4	0.25	.	.	.	.	.	S
D	1	0.77	.	.	.	.	.	S	D	2b	0.26	S	.	.	.	.	S
E	4	0.81	.	.	.	.	.	S	E	1	0.28	.	.	.	.	.	S
F	5	1.44	S	S	S	S	S	.	F	5	0.38	S	S	S	S	S	.
Width:depth ratio									**Velocity**								
Level	Reach	Mean	A	B	C	D	E	F	Level	Reach	Mean	A	B	C	D	E	F
A	2b	2.62	.	.	.	S	S	S	A	2b	0.52	.	.	S	S	S	S
B	5	7.32	.	.	.	.	.	S	B	3	0.66	.	.	.	S	S	S
C	1	8.10	.	.	.	.	.	S	C	2a	0.75	S	.	.	S	S	S
D	2a	9.39	S	.	.	.	.	S	D	5	1.06	S	S	S	.	.	.
E	4	13.49	S	.	.	.	.	.	E	4	1.31	S	S	S	.	.	.
F	3	18.14	S	S	S	S	S	.	F	1	1.62	S	S	S	S	.	.

than adjacent reaches. By comparison, the exclosure channel (reach 2b) consists of a narrow and deep channel. Through the forested reach (reach 3) the channel is wider and shallower than adjacent reaches, and, in the downstream reaches of Wickiup Creek (reaches 4 and 5), a narrower deeper channel with gradually increasing cross section area is evident.

Differences in mean reach velocities are also evident, comparing the exclosure against adjacent reaches. Mean velocities are lowest in the exclosure (0.5 m/s) compared to upstream (0.8 m/s) and downstream (0.7 m/s). Through the exclosure reach, velocities are reduced by thick channel bank vegetation which offers greater resistance to flow.

Selected cross section plots illustrate changes in channel morphology through reaches 2a, 2b, and 3 (Figures 3-5). Reaches 2a and 3 exhibit inset bankfull channel cross sections within enlarged cross section areas. No inset channel is evident through reach 2b, suggesting aggradation of bed and banks. Valley and channel bed profiles show a bulge in the bed profile corresponding to the exclosure (Figure 6). Approximately 1 m of sediment has accumulated within the exclosure, the result of filtering by channel bank vegetation and reduced velocities.

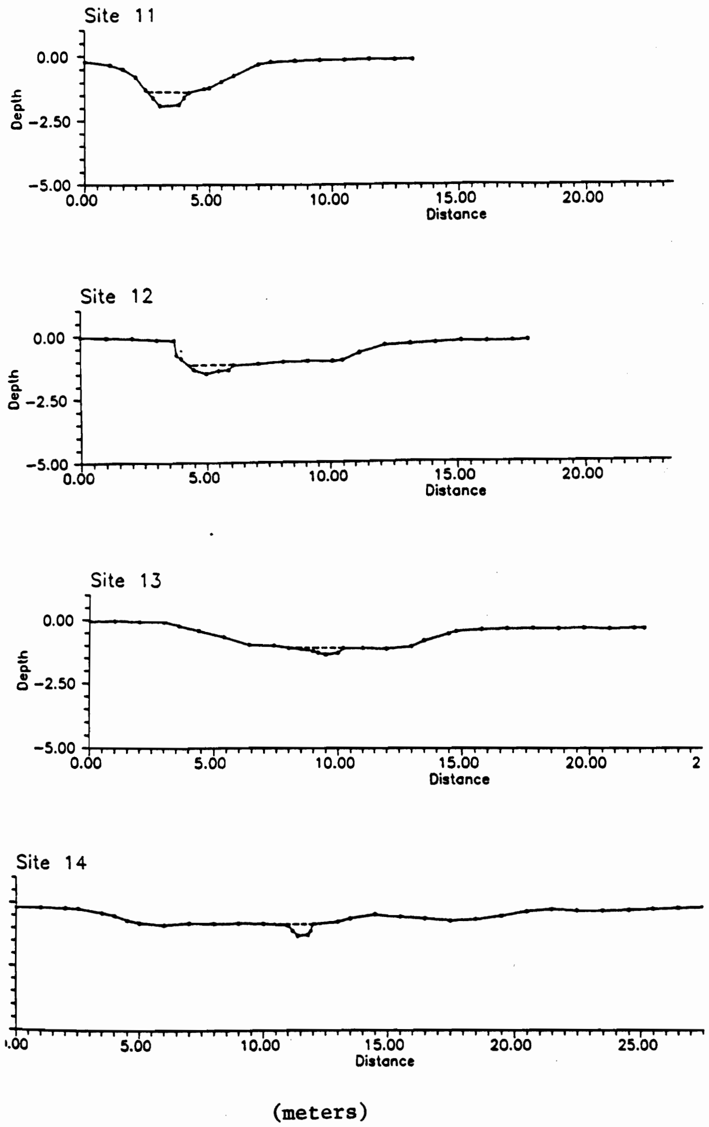


Figure 3.—Selected channel cross section plots: Reach 2a.

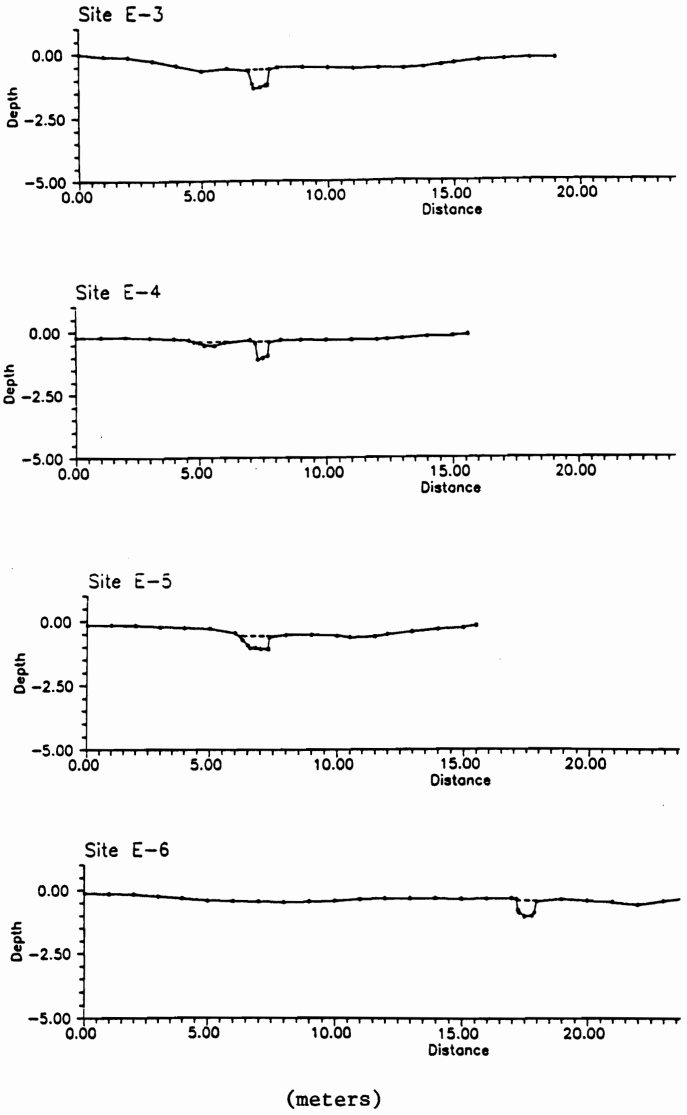


Figure 4.—Selected channel cross section plots: Reach 2b (exclosure).

Figure 5.—Selected channel cross section plots: Reach 3.

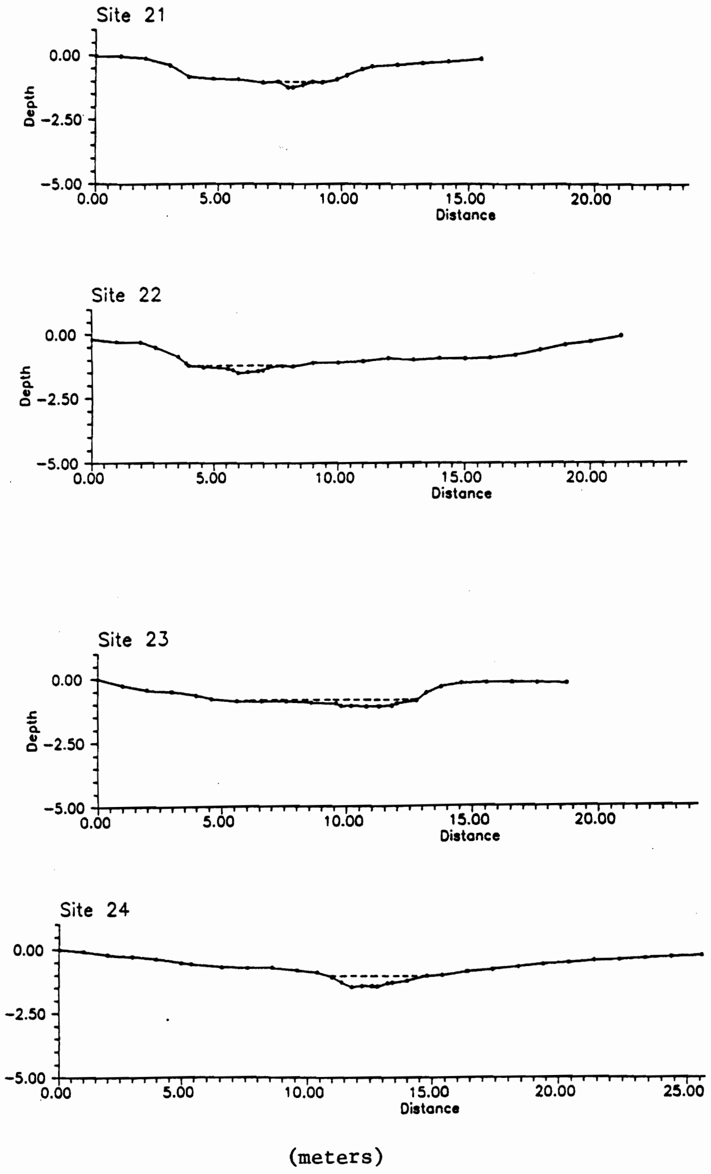
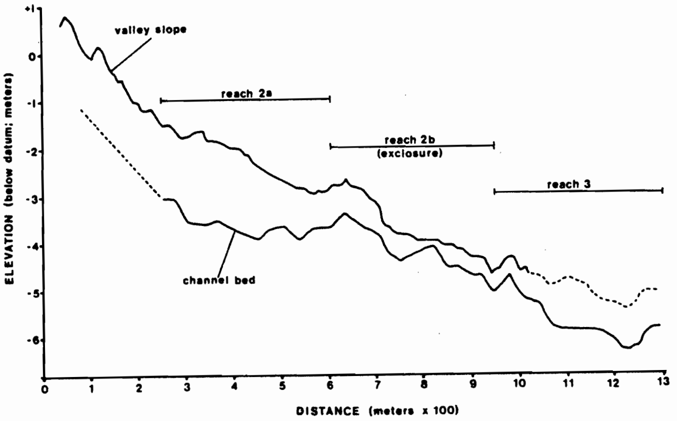


Figure 6.—Surveyed valley profile and depth of channel bed below valley floor.



Historic Channel Change

Historic photo documentation in the exclosure (reach 2b) provides information on vegetation trends and morphologic adjustments. Prior to the establishment of the exclosure, the meadow appears barren of vegetation and mineral soil is exposed (Figure 7a). The stream channel has banks approximately 1.3-m high. No channel bank vegetation is evident, and the channel has a trapezoidal shape with outsloped banks (Figure 7b). By 1948, 10 years after the establishment of the exclosure, the meadow had revegetated, the channel bed had aggraded approximately 0.60 m, and vegetation had become reestablished on the channel banks (Figures 8a and 8b). Continued revegetation occurred in the exclosure after 1948 so that, by 1956, the channel banks were partially obscured by thick bank vegetation and the channel was still narrower (Figure 9a). Willow, completely absent in 1933, gradually recovered. By 1980 the channel is almost completely obscured by grasses and sedges, and willow thickets are evident in the foreground (Figure 9b).

Estimates of channel dimensions from the 1933 and 1948 photographs provide evidence of stream channel adjustments within the exclosure (Table 6). Between 1933 and 1948 there was a 64% reduction in channel cross section area. Between 1948 and 1986, a cross sectional area reduction of 82% occurred. Overall, in 50 years without grazing, a 94% decrease in channel area occurred. Although the figures are estimates only, the total reduction represents an order of magnitude change in channel area. Channel adjustments in the exclosure are predominantly the result of the absence of livestock and channel bank revegetation.

Figure 7.—Historic photos of exclosure: overview and channel prior to fencing, 1933. (Malheur National Forest Files).

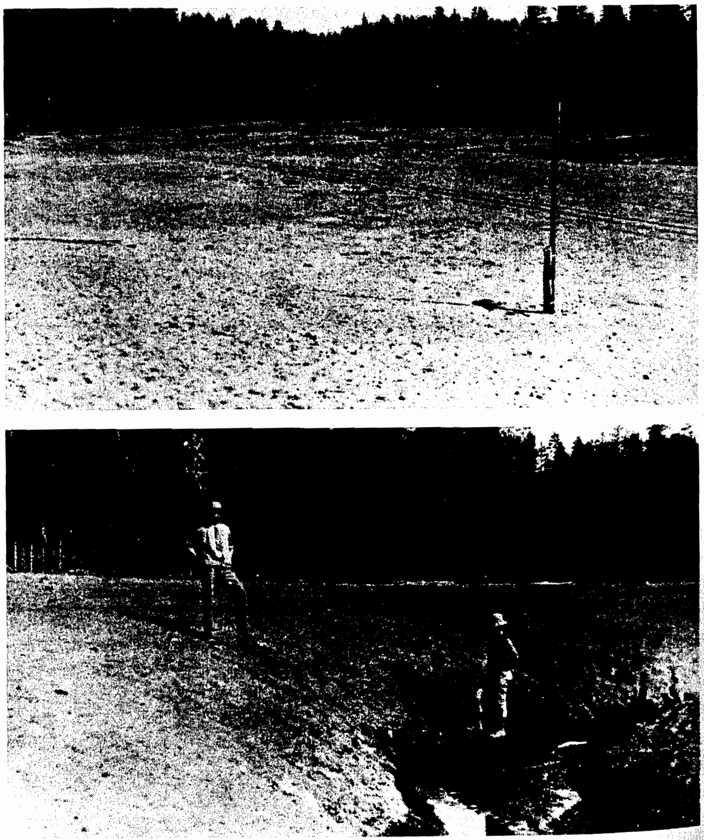
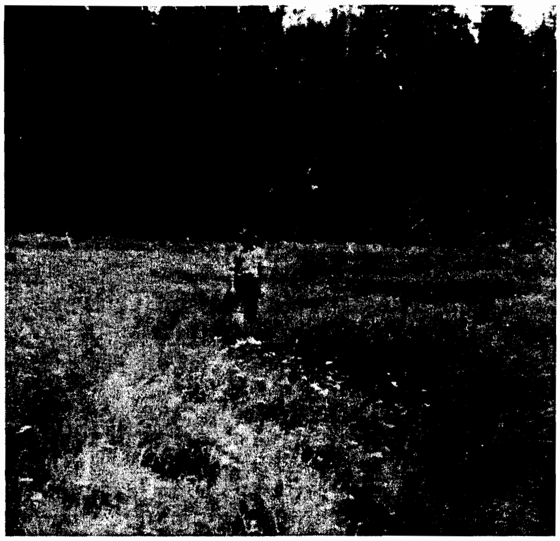


Figure 8.—Historic photos of exclosure: overview and channel following fencing, 1948. (Malheur National Forest files).

Figure 9.—Historic photos of channel in exclosure: 1956 and 1980. (Malheur National Forest files).



Discussion and Conclusions

Morphologic variability in mountain streams limits conventional analysis of downstream channel geometry based on regular, continuous adjustments of width, depth, and capacity. Scatter in downstream plots is often attributed to multivariate control of channel morphology (Richards 1982). Vegetation and land use activities contribute to deviations from predicted trends (Mosley 1981).

Spatial and temporal adjustments in the morphology of Wickiup Creek are largely the result of vegetation structure and composition, local physiography, and livestock use. Dense bank vegetation, in the ungrazed reach, has produced a narrow and deep channel. Channel bank vegetation traps suspended sediment and increases bank strength, producing aggradation of the bed and banks. Abundant grasses and sedges growing in the channel offer greater resistance to flow further reducing fluvial erosion by decreasing velocities. Zimmerman et al. (1967) reported similar findings on the differential influence of forest and meadow vegetation on the morphology of small headwater streams in northern Vermont. Overall, width and depth did not increase systematically downstream (Zimmerman et al. 1967).

Table 6.—Historic channel adjustments — reach 2b.

Year	Width	Depth	Area
1932	5.25	1.30	6.83
1948	3.50	0.70	2.45
1986[1]	3.50	0.12	0.43

[1] field survey

Through the forested reach, channel shape is highly variable. An abundant supply of organic debris effects channel form and fluvial processes by providing sites for deposition, locally reducing or enhancing bank erosion, and dissipating stream energy (Keller and Swanson 1979). Typically, channel widths increase upstream from blockages, and depths are locally enhanced in plunge pools downstream. Elevation changes associated with embedded organic debris dissipate erosional energy.

Historic adjustments in the morphology of Wickiup Creek were observed in the exclosure. Historic photos show a dramatic change in vegetative cover from 1933 to 1980. In 1933 the entire reach and adjacent meadow were barren of vegetation. Cattle were excluded in 1938, and by 1948 the site had revegetated and the channel had narrowed and deepened. By 1986 the channel had undergone an order of magnitude reduction in bankfull channel cross section area. Today, thickly vegetated overhanging banks obscure a narrow and deep channel.

On Camp Creek in central Oregon, Winegar (1977) described the recovery of a reach excluded from grazing in the 1960s. Winegar emphasized the function of riparian vegetation in channel stabilization and sediment deposition. Sediment load sampling along Camp Creek indicated significant reductions in suspended load occurring through 5.6 km of protected stream. The exclosure on Wickiup Creek is also functioning as a sediment trap, as indicated by changes in channel morphology. The principle non-fluvial effects of streamside vegetation are anchoring of channel banks and trapping sediment. Vegetation influences hydraulic interactions by contributing roughness elements and shear strength to the channel boundary. Increased roughness increases resistance to flow and promotes sediment deposition through reduced competency.

In conclusion, the channel morphology of Wickiup Creek shows a high degree of variability when examined by reaches of relatively uniform characteristics. Conventional plots of morphologic variables such as width and depth against distance downstream do not exhibit strong systematic trends because of the small size of the drainage basin (24 km^2) and because of the overwhelming influence of local vegetation and land use. Specifically, width, wetted perimeter, and channel shape are most responsive to local variability of streamside vegetation and intensity of livestock use. Where Wickiup Creek flows through the ungrazed exclosure the channel is narrow and deep, the result of thick bank vegetation promoted by the absence of livestock. In the forested reach the effects of downed timber are reflected in the channel morphology; the stream is wider and shallower and exhibits a variable channel shape. Large organic debris deflects channel flow and controls the routing of sediment down-channel.

Traditionally, mountain regions in the West have been exploited for their forage, timber, and mineral resources, often at the expense of the stream and riparian environment. Alternative values such as wildlife and recreation are gaining attention. In addition, there is growing concern over quantity and quality of water supply for downstream users. Studies of small mountain stream systems provide insight into sources of variability in channel morphology and fulfill a more immediate need for an understanding of the functioning of mountain streams for improved management.

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