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AN APPROACH TO EVALUATING OFF-SITE EFFECTS OF TIMBER HARVEST ACTIVITIES ON CHANNEL MORPHOLOGY[1]

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The downstream effect of forest practices has proved difficult to evaluate for a number of reasons. Differences in rock type, hydrology, topography, soils and disturbance history may all produce highly variable responses among drainage basins. In particular, the management history of a basin is often complex, with logging and road construction taking place over prolonged periods in different parts of the basin, which makes comparisons between basins with different histories uncertain. In addition, similar processes can give rise to different end results, depending on the type of terrain. Conversely, a particular form of channel response can often be attributed to multiple causative factors. All of these circumstances make it difficult to evaluate the causes and importance of downstream effects.

A study was undertaken to determine whether off-site effects of timber harvest activities were an important factor in producing channel changes among fourth- and fifth-order streams in the western Cascade Range of Oregon. In this paper, we suggest a theoretical framework for predicting how different off-site effect mechanisms might influence stream channel morphology. We also present an air photo interpretation technique for measuring stream channel response to disturbance, and report preliminary results from the analysis of a large storm event.

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Abstract: We present a methodology and develop a new quantitative, aerial photograph interpretation technique for assessing channel response to various off-site effects associated with timber harvest activities. The degree of channel enlargement, associated with a 100-year storm event in the Oregon western Cascades, is strongly related to upstream logging activities. The nature of the response relates to the mechanism by which sediment and water are introduced to the stream. Of the five types of initiation site (axial landslide, riparian landslide, forest growth, clearcut, and road) for channel enlargement, axial landslides were overwhelmingly important in their occurrence and influence.

THEORETICAL FRAMEWORK

In what context do 'off-site effects' occur? Off-site effects are one stage in a cascading series of causes and effects that constitute the 'management-induced disturbance system' (Figure 1). Each stage in this system is both an effect of preceding stages and a cause of subsequent ones. The system is initiated by the activities associated with cutting and removing trees from the forest and reforestation practices: construction of logging roads and landings, falling and yarding timber, and planting site preparation (often by burning). These activities produce changes in local site conditions, such as compacted soils and altered ground cover (Dyrness 1965, 1967), reduced root strength (O'Loughlin 1974, Ziemer and Swanston 1977), and opened canopies. On-site impacts can, in turn, alter site processes, resulting in 'on-site effects'. In the Pacific Northwest, these effects have been observed to include reduced infiltration and subsurface flow (Megahan 1972a), altered patterns of snow accumulation and melt (Harr 1981, Harr and Berris 1983), expanded drainage networks (Janda 1978, Harr 1979), and accelerated erosion from both surface and mass movement processes (Mersereau and Dyrness 1972, Swanston and Swanson 1976).

On-site effects can produce changes in patterns of water and sediment movement through the basin as a whole. This translation of on-site effects downstream occurs through changes in specific supply mechanisms that route water and sediment; these changes are referred to as off-site or downstream effects which may combine to produce what are sometimes referred to as 'cumulative effects'. Although on-site effects are clearly linked in space and time with their management cause, off-site effects can produce delayed changes throughout the basin. Reported off-site effects include increased peak flows (Ziemer 1981, Christner

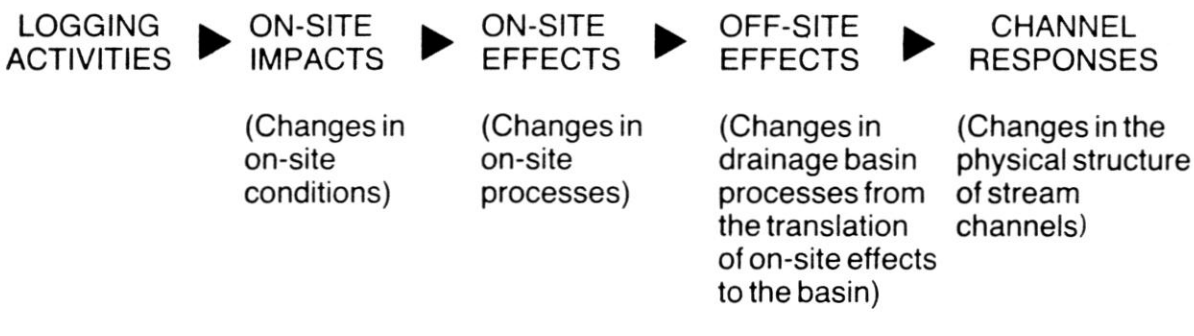

Figure 1. General management-induced disturbance system

and Harr 1982), increased landsliding (Swanson and Dyrness 1975, Earth Sciences Assoc. 1980), increased frequency of debris torrents (Swanson et al. 1981), and increased chronic sedimentation from roads and clearcut surfaces (Megahan 1972b, Rice et al. 1972).

Considerable evidence, therefore, suggests that timber harvest activities can affect the volumes, rates and timing of water and sediment movement through a drainage basin. Less clearly understood is how stream channels respond to such changes in regime - the terminal link in Figure 1. Reported channel responses include aggradation (O'Loughlin 1969, Kelsey 1980), widening and braiding (Bennett and Selby 1977, Nolan and Janda 1979, Lyons and Beschta 1983), and increased deposition of fines (Adams and Beschta 1980). In most of these studies, however, the links between upbasin activities and downstream channel changes are assumed, and the relative importance of various specific supply mechanisms are not described. From a management point of view, distinguishing between different supply mechanisms can be important in designing improved strategies to combat erosion problems.

In order to explore some of these linkages we have hypothesized that: (1) different modes of water and sediment delivery to channels produce different types of channel response;
(2) channel response is distinctive enough to be used as an indicator of the delivery processes involved, and hence provides a way to determine whether specific off-site effects are active in a given basin. This approach requires the classification of off-site effects by delivery mode and supply mechanism.

In Table 1 a general framework for analyzing channel and basin behavior resulting from management-induced disturbances is presented. Column 1 describes on-site effects responsible for generating off-site effects (detailed in adjacent columns). The delivery mode classification (column 2) is based on whether the primary causative agent is water or sediment. Column 3 describes the specific mechanism by which this agent is supplied. In the case where increased sediment delivery is the primary mechanism, a further distinction is made between 'chronic' inputs (due to surface erosion and creep from bare soil surfaces distributed over the basin) and 'pulse' inputs (from mass movements which impinge on channels). In the first case, sediment delivery is likely to be relatively slow, involving small amounts of fine material supplied intermittently over long periods of time in a way that produces little stress and adjustment within the channel. Pulse sedimentation, by contrast, involves rapid transfer of large amounts of predominantly coarse sediment and organic debris directly into the stream network. In this case, high sediment loads, coarse debris, abrupt delivery, and the shear force generated by mass movement within the channel all may play a role in determining channel response. We distinguish between slope mass movements travelling into the channel, where channel adjustment is due to the high quantities of sediment and debris supplied from the hillslope, and mass movements taking place within the channel, including debris flows and torrents, where the impact force of the mass movement travelling downstream strongly affects channel response.

Physical changes in channel morphology that are produced by these supply mechanisms are given in column 4. Note that while some parameters are unique to specific supply mechanisms, there is considerable overlap in the ways that channels adjust. In particular, some kind of channel widening or enlargement is predicted for all supply mechanisms. This is an example of the principle of geomorphic convergence mentioned earlier, whereby different processes give rise to the same result.

Table 1. Predicted channel and basin behavior resulting from changes in water and sedimentdelivery caused by on-site effects.

ON-SITE EFFECTS	PRIMARY DELIVERY MODE	SUPPLY MECHANISM	CHANNEL RESPONSE	REPONSE OF BASIN Qw AND Qs
Change in quantity and timing of hillslope runoff • Greater efficiency of drainage network • Greater snow accumulation and melt rates • Reduced Evapotranspiration	Water	High peak flows	• Increased channel capacity, widening • Debris dam instability	Peak discharges for logged basins greater than for unlogged basins. Qw varies as a function of the increase in drainage network due to compaction and road drainage, and the area of management activity in transient snow zone
Increased surface erosion	Sediment	"Chronic" sediment input	• Channel widening and braiding • Accumulation of fines	Qs varies gradually as a function of % of basin area in bare soil which is connected with drainage network
Greater incidence of shallow landslides	Sediment	"Pulse" sediment input to channel		Qs varies episodically with mass movement events
• Reduced root strength • Change in slope mass and water balances		Into channel	• Channel widening and braiding below sediment source • Fluvial texture and structure of deposits • Buried trees	
		Within channel	• Channel scouring and removal of riparian vegetation • Boulder levees, scarred vegetation • Mass movement texture and structure of deposits	

Predicted changes in basin water and sediment yields associated with specific supply mechanisms are given in column 5 and can be used as corroborating evidence for determining which mechanisms are active.

Because our hypothesis states that channel response is indicative of the kind of supply mode, a detailed set of diagnostic parameters is needed which is sufficiently sensitive to register the variety of induced channel conditions. We have defined critical parameters as being (1) the site conditions where the channel first shows some response, (2) the degree of physical linkage between this initiating site and downstream responding reaches, (3) the change in channel response with distance downstream, and (4) the extent to which channel response varies as a function of the kind and intensity of management operations. These diagnostic criteria are shown in the last column of Table 2 for different classes of supply mechanism.

The relationship between channel response and supply mechanism was tested by looking at channel changes which occurred during a large, 100-year runoff event in December 1964.[3] The analysis involved fourth- and fifth-order basins tributary to the Middle Fork of the Willamette River (MFW), Oregon. The geology, vegetation, soils, and logging history of this area have been described by Lyons and Beschta (1983). They report significant channel changes on both the main stem and its tributaries in conjunction with this event and conclude that these changes result mainly from clearcutting and road construction within the basin. The premise underlying our approach is that this large event acted as a trigger for the management-induced disturbance system; channel response to the 1964 event should therefore reflect the relative importance of different supply mechanisms. The assumption was made that effects from the storm and snow conditions were more or less uniform over the basins in question; an examination of the storm record (Wanaanen et al. 1971) indicates that this is valid.

METHOD AND TECHNIQUES

Thirty-seven fourth- and fifth-order streams that are tributaries of the MFW were identified through a Horton-Strahler analysis performed on 1:62,500-scale topographic maps that were enlarged to a scale of 1:24,000. The selection of fourth- and fifth-order streams was based on the assumption that streams of this size would be sensitive to both fluvial and hillslope influences. Sequential aerial photos taken in 1959 and 1967 at scales of 1:12,000 and 1:15,840, respectively, were used to identify channel reaches among this population which showed changes as the result of the 1964 event. All observed changes were attributed to this event because the next largest flood during the interval 1959-67 had a recurrence interval of only two to three years. Preliminary analysis indicated that the dominant channel response visible on the photographs was 'channel opening' or enlargement of the channel corridor by removal of riparian vegetation (Figure 2). Streams were classed by whether their drainage basins had experienced any logging activity at the time of this storm, as determined from aerial photos and USDA Forest Service records.

[3] The December 1964 event which combined heavy rainfall with an extensive snow cover and extreme melting conditions was immediately followed by a slightly smaller event in January 1965. Because of this rapid succession of events, the separate effects are difficult to distinguish and are referred to collectively as the 1964 event.

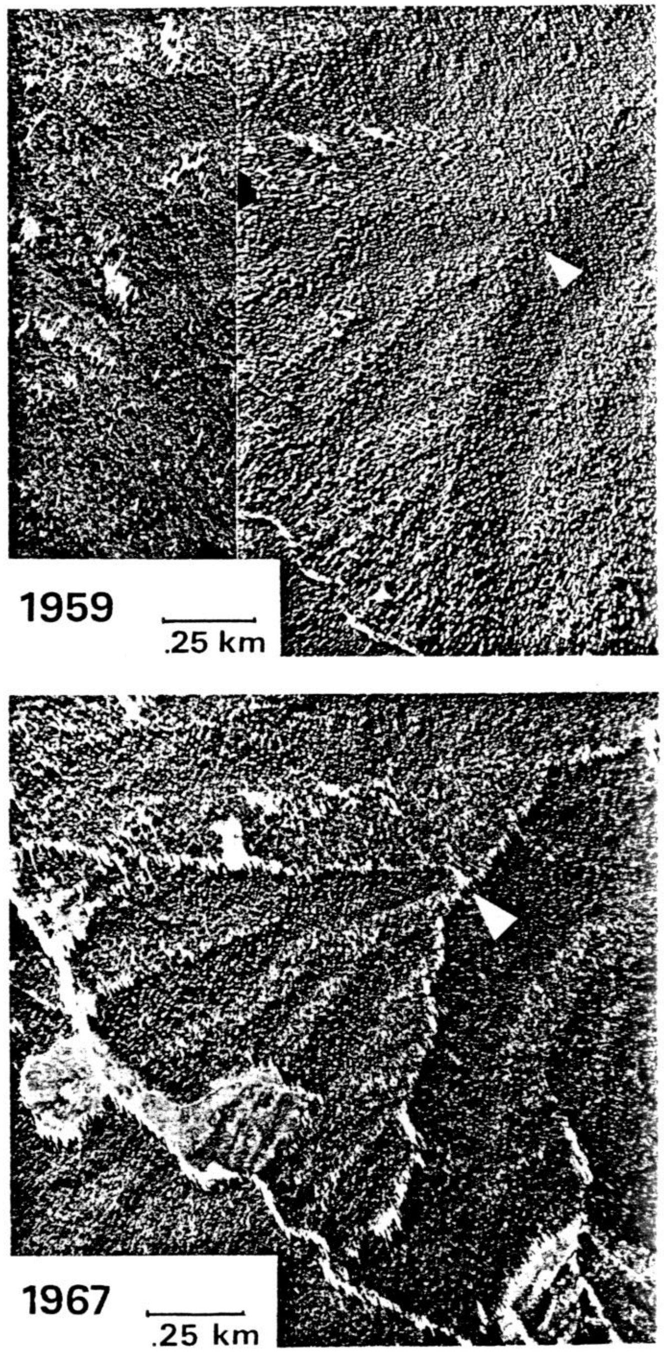

Figure 2. Channel conditions on upper Bohemia Creek for 1959 and 1967 showing marked enlargement of the riparian corridor following the 1964 storm.

Based on this preliminary survey, we selected six basins for detailed analysis, all of which showed some channel response and had different degrees of logging activity.

Basins were selected from the lower part of the MFW drainage, for similar area, elevation, orientation, and slope angle, in an attempt to ensure that storm conditions were uniform amongst the sample. All basins had been

Table 2. Dominant supply modes corresponding with initiation sites and predicted channel condition.

Initiation Site	Supply Mode	Predicted Channel Condition Index[1]
1) Axial landslide	pulse sediment & channel mass transport	Cg - long; Cn - continuous; W - decrease
2) Riparian landslide	pulse sediment with possibility of channel mass transport	Cg - moderate; Cn - continuous; W - decrease
3) Forest	low increase in runoff, low increase in chronic sediment	Cg - short; Cn - patchy; W - decrease
4) Clearcut	high increase in runoff, high increase in chronic sediment	Cg - variable; Cn - continuous to patchy; W - decrease
5) Road	increase in localized runoff, high increase in chronic sediment	Cg - short; Cn - patchy; W - decrease
6) Multiple	two or more different sites contribute	Depends on dominant supply mode

[1]CG is length of contiguous reach, Cn is continuity of responding channel, and W is change in width downstream.

partially logged by 1964; the intensity of timber harvest activities ranged from a few roads and scattered clearcuts to extensive clearcut and road networks. Channel response or opening within the basins ranged from a few open patches to long continuous open reaches.

All open channel reaches in these six basins identified on the 1967 photos were traced onto maps and assigned an initiation site. The furthest upstream point where some channel response could be observed was designated as the initiation site. Initiation sites were classed by whether the changed channel reach began at an axial or riparian landslide, in forest growth, clearcut, or at a road without a visible landslide. These initiation sites correspond with supply mechanisms as shown in Table 2. Landslides were defined as axial if the slide occurred essentially parallel to, or within, the axis of the creek or drainage depression; riparian landslides were defined as those slides more or less perpendicular to the axis of the creek. For landslide initiation sites, the management condition of the site (forest growth, clearcut, or road) was also noted.

The next step in characterizing the condition of the channels involved the degree of linkage between the initiation site and the affected channel. If a section of channel immediately downstream from an initiation site showed a continuous response along its course, without incorporating any sections of unaffected channel, it was termed a contiguous reach. The section of channel from the first visible break (unaffected channel) onward was termed a discontiguous reach. Channel openings which occurred along a discontiguous reach were termed discontiguous openings (DO). The lengths of the contiguous or discontiguous reach (LCR and LDR respectively) and the lengths of discontiguous openings (LDO) were measured using an electronic digitizer.

Finally, measurements were made on the air photos to estimate width of features. Widths of open channel within both contiguous and discontiguous reaches were measured at 100 m intervals. The site condition (forest, clearcut, or road) was recorded at each measurement site. All measurements were made in the center of the photos to minimize edge distortion. Sequential photos taken along the same flight path were examined to reduce the effects of shading and camera angle. All measurements were repeated until at least two measurements agreed. Based on measurements of known distances, accuracy is estimated to be ± 15% percent.

In basins having multiple open reaches, the longest contiguous channel reach was defined as the main stem, and other responding reaches as tributaries. The location where other responding reaches, either contiguous or discontiguous, joined the main stem was noted, as was the location of riparian landslides adjacent to the channel. Where two responding reaches with different classes of initiation sites joined, the channel below the junction was classified as having 'multiple' initiation sites. Where two tributaries each having the same class of initiation site joined, the downstream channel was considered as being a continuation of the tributary having the longer contiguous reach.

Separate tabulations of lengths and average widths were made for contiguous and discontiguous reaches in each site class shown in Table 2. Although individual tallies were kept according to management condition for landslide sites, all landslides of a particular type (axial, riparian) were considered together in this initial analysis. Subsequent analyses could separate landslides from different management categories.

In order to test the relationship between the character of downstream channel response and the nature of the initiation site we developed several indices of channel disturbance (Table 3) from the measurements outlined above. Depending on how the data are arrayed,indices can be generated which define: (1) individual responding channel reaches, (2) all reaches within a basin having a particular initiation site, (3) all reaches of a particular site class among all basins, and (4) all site classes within a particular basin. These different ways of computing indices allow for comparison among individual reaches, different classes of initiation sites, and different drainage basins.

RESULTS

Examination of aerial photographs taken in 1959 and 1967 indicated that dramatic changes in channel conditions occurred among many of the fourth- and fifth-order streams during this period. Most of the observed changes consist of an opening or widening of the riparian corridor as a result of stripping of streamside vegetation. Many channels that were obscured under a closed canopy in the 1959 photos are clearly visible in the 1967 photo (Figure 2). Although some channels have open reaches that extend continuously downstream for distances of 2-3 km, others show discontinuous patches of open channel separated by closed canopy reaches. Open reaches within clearcuts were identified by their light-colored 'streaked' appearance and visible trimlines, as can be seen in the lower clearcut unit in the 1967 photo (Figure 2).

The general relationship among streams showing open channels and their management history for 1959 and 1967 is shown in Table 4. Of the 37 streams inventoried, 7 showed open reaches in the 1959 series (Table 4A). Most of the openings observed in these streams were patchy and discontinuous when compared with openings observed in the 1967 photos. All 7 streams had experienced logging and road construction in their upbasin area and none of the unlogged streams had open reaches. A chi-square test indicated that the null hypothesis that channel conditions are independent of management can be rejected at a 99.995 percent level of confidence.

Table 4B shows the distribution of channel conditions for logged and unlogged basins in the 1967 photos. A check of USDA Forest Service records indicated that all basins in the 'logged' category had been entered before the 1964 event. In the 1967 photos, over three times as many streams had open reaches; of these, only one open reach was observed in an unlogged basin. A chi-square test again confirmed the strong relationship between management condition and streams with open reaches.

Figure 3 shows how the technique outlined here can be applied to evaluate the specific linkage between management activities and channel response. It indicates how the initiation sites and channel reaches in this section were classified. Note that since axial landslides and riparian landslides are treated as separate initiating factors, the uppermost channel is considered to have multiple influences below the junction of the landslide. Measurements made on this section and derived indices are shown in Table 5.

Some preliminary results are reported here to indicate the relative importance of different supply mechanisms in producing particular patterns of channel change among the six basins studied. Figure 4 shows the frequency distribution of initiation sites by site class. Axial landslides represent 75 percent of all initiation sites; over 70 percent of these landslides occurred in clearcuts. Non-landslide sites make up only 21 percent of the initiation sites, and most of these also occurred in clearcuts.

Table 3. Channel and basin response indices. (Definitions of formula abbreviations are given in Figure 3.)

INDEX	DESCRIPTION	FORMULA
Length of Responding Channel (LRC)	The total length of responding channel measured downstream from an initiation site to basin mouth or junction with main stream (m).	$LCR + LDR$
Responding Channel Opening (RCO)	A measure of opening for channels showing some response expressed as a percentage of channel responding.	$\frac{LCR + \sum_{o}^{n} LDOj \times 100\%}{LRC}$ where $n = NDO$
Contiguity Index (CI)	The degree to which response can be directly related in space to a particular initiation site.	$\frac{LCR}{LRC}$
Absolute Channel Opening (ACO)	An approximation of total area of open channel (m^2)	$(LCR \times \overline{WCR}) + (\sum LDO \times \overline{WDR})$
Relative Basin Channel Opening (RBCO)	An approximation of the proportion of a basin in open condition, treated as a percentage.	$\frac{ACO}{\text{Total basin area}} \times 100\%$
Discontinuity Index (DI)	The degree of discontinuity in a discontiguous reach. High values indicate relatively low degree of opening within the reach while low values indicate a high degree of opening.	$\frac{LDR \times NDO}{\sum LDO}$
Patchiness Index (PI)	The frequency of opening per linear kilometer of of discontiguous channel.	$\frac{NDO}{LDR} \times 1000$

Table 4. Distribution of streams with and without open reaches in relation to basin management history for 1959 and 1967

A. 1959	Open	No open	Total
Logged	7	10	17
Unlogged	0	20	20
Totals	7	30	37

B. 1967	Open	No open	Total
Logged	21	7	28
Unlogged	1	8	9
Totals	22	15	37

Figure 5 illustrates the effectiveness of different classes of initiation site in producing channel response. It is apparent that axial landslides are the most common cause of channel opening and are also the most effective agent in producing direct or contiguous response. The effect of this mechanism is probably even greater than that pictured

Table 5. Tabulation of measurements and computed indices for a sample area shown schematically in Figure 3. Formulas for indices are given in Table 3 and abbreviations explained in Figure 3. Drainage area = 4.50 km^2 and computed RBCO = 2.8 percent.

Measurements by initiation site						
(m) WDO	(m) LCR	(m) WCR	(m) LDR	(m) WDO	NDO	(m) LDO
AL_R	1934	32	166	0	0	0
AL_F	890	32	0	0	0	0
F	127	20	485	25	3	201
M	852	33	0	0	0	0
Totals	3803	32	651	25	3	201

Computed channel response indices						
	(m) LRC	(pct) RCO	(m/m) CI	(m^2) ACO	(m/m) DI	(openings/km) PI
AL_R	2100	92	.92	61,888	--	0
AL_F	890	100	1.00	28,480	--	0
F	612	54	.21	7,565	7.24	6.18
M	852	100	1.00	28,116	--	0
Totals	4454	90	.85	126,049	9.72	4.61

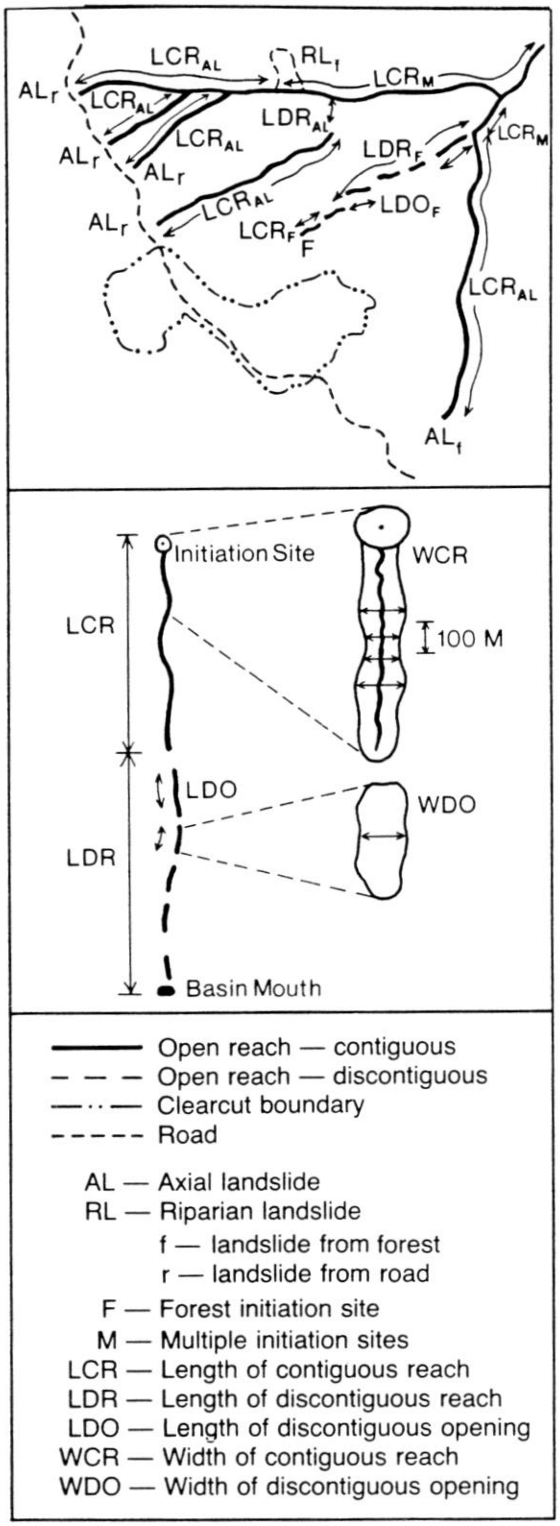

Figure 3. An example of the classification and measurement technique. (a) Map shows how initiation sites and stream reaches were classified. (b) Visual display of length and width measurements made on contiguous and discontiguous reaches.

here as over 90 percent of the reaches in the 'multiple' category had streams with axial landslide initiation sites as one of their contributing influences. Riparian landslides and sites without mass movements do not appear to be particularly effective in producing channel response.

DISCUSSION

Although the results presented here are preliminary, several important points can still be made. First, in this area there is a clear relationship between timber harvest activities within a basin and the occurrence of downsteam channel opening. This relationship appears to exist with or without the impact of a large storm event but it is decidedly more pronounced following such an event. This relationship is apparently not simply a function of harvest intensity, because a number of the basins studied in the initial inventory had considerable logging activity in their headwater areas without showing any channel response. Clearly, other factors, such as the location of clearcuts and roads in relation to the stream network, hillslope stability, and the channel's intrinsic sensitivity to disturbance all are able to influence the nature of channel response.

Second, the kind of channel response observed (opening or enlargement of the riparian corridor) is in accordance with the adjustment to logging activities predicted by the theoretical model. Channel 'opening' is not synonymous with 'channel widening', because the actual change in channel width cannot be measured from one photo series to the next owing to the closed canopy obscuring undisturbed reaches. However, some kind of channel enlargement is predicted by all classes of supply mechanism (Table 2). Channel enlargement can occur as the result of high streamflow alone, i.e., without management-induced disturbance (Costa 1974, Gupta and Fox 1974, Lisle 1981). However, the association between this characteristic and basin logging history (Table 4) along with the direct linkage between upslope activities and downstream response (Figure 5), argue against channel enlargement being brought about solely by the storm.

Third, the method we have described here for linking channel response to specific supply mechanisms via the initiation site, contiguity and continuity of response, and other critical parameters offers a way of evaluating the relative importance of different classes of off-site effects. In the MFW basin, most channel opening is associated with pulse sediment events. Sites of timber harvest activity which have not been subject to

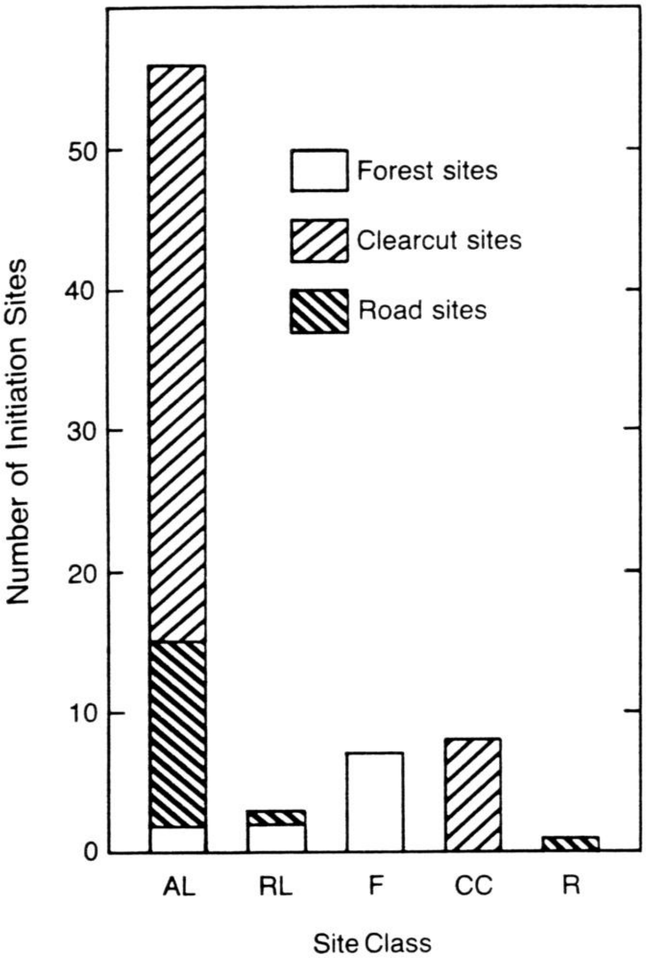

Figure 4. Distribution of initiation sites by site class.

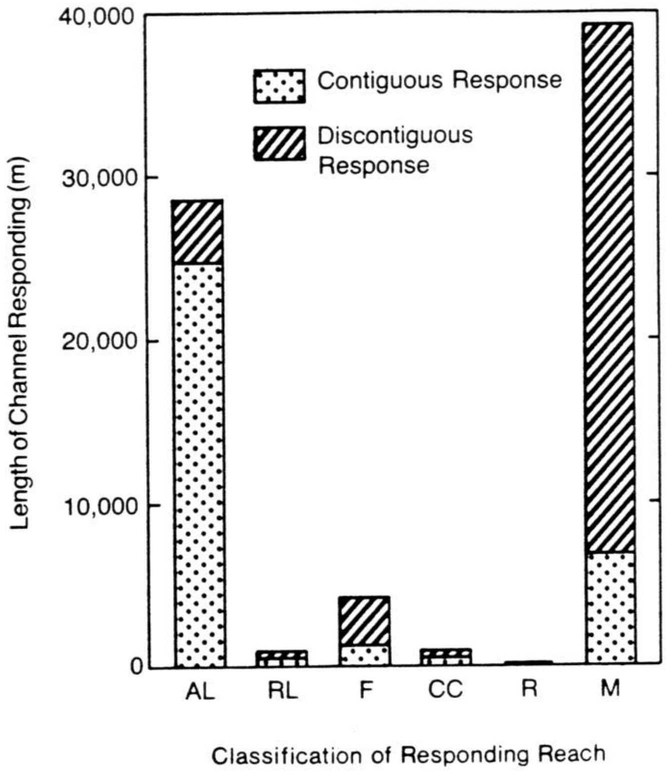

Figure 5. Effectiveness of different initiation sites for producing channel response. Key: AL - axial landslide; RL - riparian landslide; F - forest growth; CC - clearcut; R - road; M - multiple sites.

landsliding, even after a major climatic event, play only a minor role in affecting the morphology of downstream channels.

Fourth, the indices developed as part of this approach (Table 3) provide quantitative measures of the degree and form of one type of channel disturbance. These offer a way to analyze both the degree of channel response associated with particular supply modes and the overall basin response to a storm event. The response of basins with different management histories can therefore be contrasted. Moreover, these indices allow certain channel conditions to be monitored over time, so that channel recovery from disturbance (largely vegetation regrowth) and/or the effects of subsequent storms can be assessed.

Finally, this approach uses parameters that can be rapidly and inexpensively measured on aerial photographs as opposed to requiring detailed field observations. It lends itself well to situations where other data are not available or where time and budgetary constraints make a more detailed field survey impractical. Perhaps most importantly, it allows resource scientists and managers to address the issue of off-site effects on the same spatial scale at which these effects are presumed to operate.

Adams, L. N.; Beschta, R. L. Gravel bed composition in Oregon coastal streams. Can. J. Fish. & Aquat. Sci. 37(10):1514-1521; 1980.

Bennett, J. R.; Selby, M. J. Induced channel instability and hydraulic geometry of the Mangawhara Stream, New Zealand. J. Hydrol. (N.Z.) 16(2):134-147; 1977.

Christner, J.; Harr, R. D. Peak streamflows from the transient snow zone, western Cascades, Oregon. Proceedings, Western Snow Conference; 1982 April 19-23; Reno, NV. Colorado State Univ., Fort Collins, CO; p. 27-38.

Costa, J. E. Response and recovery of a Piedmont watershed from Tropical Storm Agness, June, 1972. Water Resour. Res. 10(1):106-112; 1974.

Costa, J. E.; Jarrett, R. D. Debris flows in small mountain stream channels of Colorado and their hydrologic implications. Bull. Assoc. Eng. Geologists 18(3):309-322; 1981.

Dyrness, C. T. Soil surface disturbance following tractor and high lead logging in the Oregon Cascades. J. For. 63:272-275. 1965.

Dyrness, C. T. Soil surface conditions following skyline logging. Res. Note PNW-55. Portland, OR: Pac. Northwest For. and Range Exp. Stn., For. Serv., U.S. Dept. of Agric.; 1967. 8 p.

Earth Sciences Associates, Lower Klamath River Investigations, Report No. 2037, prepared for U.S. Department of the Interior, Bureau of Indian Affairs, Palo Alto, CA; 1980, Vol. 1.

Gupta, A.; Fox, H. Effects of high magnitude floods on channel form: a case study in Maryland piedmont. Water Resour. Res. 10(3):499-503; 1974.

Harr, R. D. Effects of timber harvest on streamflow in the rain-dominated portion of the Pacific Northwest. Proceeding, Workshop on scheduling timber harvest for hydrologic concerns; 1979 Portland, OR. 45 p.

Harr, R. D. Some characteristics and consequences of snowmelt during rainfall in western Oregon. J. Hydrol. 53:277-304; 1981.

Harr, R. D.; Berris, S. Snow accumulation and subsequent melt during rainfall in forested and clearcut plots in western Oregon. Proceedings, Western Snow Conference; 1983 April 19-21; Fort Collins, CO. Colo. State Univ., Fort Collins, CO; 1983; p. 38-44.

Janda, R. Hydrologic and erosional impacts of tractor-yarded clearcut logged areas. M. A. Madej and H. Kelsey, eds. Proceedings, Workshop on techniques of rehabilitation and erosion control in recently roaded and logged watersheds, with emphasis to north coastal California; 1978 March 13-14; Arcata, CA. Resources Management Division, Redwood National Park; p. 5-10.

Kelsey, H. M. A sediment budget and an analysis of geomorphic processes in the Van Duzen River basin, north coastal California, 1941-75. Geol. Soc. Amer. Bull., Part II, 91:1119-1216; 1980.

Lisle, T. E. Recovery of aggraded stream channels at gaging stations in northern California and southern Oregon. In: Erosion and Sediment Transport in Pacific Rim Steeplands. T. Davis and A. Pearce, Eds. I.A.H.S. Publ. No. 132; Int. Assoc. Hydrol. Sci.; Washington, D.C.; 1981; p. 189-200.

Lyons, J. K.; Beschta, R. L. Land use, floods, and channel changes: Upper middle fork Willamette River, Oregon (1936-1980). WRR 19(2):463-471; 1983.

Megahan, W. F. Subsurface flow interception by a logging road in mountains of central Idaho. In: Pierce, Martin, Reeves, Likens, and Borman, eds. Proceedings, National Symposium on Watersheds in Transition, 1972a; Fort Collins, CO. Colorado State Univ.; Publ. by Am. Water Resour. Assoc., Urbana, IL. p. 350-356.

Megahan, W. F. Effects of logging and logging roads on erosion and sediment deposition from steep terrain. J. For. 70:136-141; 1972b.

Mersereau, R. C.; Dyrness, C. T. Accelerated mass wasting after logging and slash burning in western Oregon. J. Soil Water Conserv. 27(3):112-114; 1972.

Nolan, M.; Janda, R. Recent history of the main channel of Redwood Creek, Calif. In: A guidebook for a field trip to observe natural and management related erosion in Franciscan terrane of northern California. Cordilleran Group, Menlo Park, CA; 1979; p. x-1 to x-16.

O'Loughlin, C. L. Streambed investigations in a small mountain catchment. N.Z. J. of Geol. and Geophys. 12(4):684-706; 1969.

O'Loughlin, C. L. The effect of timber removal on the stability of forest soils. J. Hydrol. (N.Z.) 13(2):121-134; 1974.

Rice, R. M.; Rothacher, J. S.; Megahan, W. S. Erosional consequences of timber harvest: an appraisal. In: Proc. National Symposium on Watersheds in Transition. American Water Resources Assoc., Ft. Collins, CO: June 1972. p. 321-329.

Swanson, F. J.; Dyrness, C. T. Impact of clearcutting and road construction on soil erosion by landslides in the western Cascade Range, Oregon. Geol., 1:393-396; 1975.

Swanson, F. J.; Swanson, M. M.; Woods, C. Analysis of debris-avalanche erosion in steep forest lands: an example from Mapleton, Oregon. In: Erosion and Sediment Transport in Pacific Rim Steeplands. T. Davis and A. Pearce, Eds. I.A.H.S. Publ. 132; Int. Assoc. Hydrol. Sci.; Washington, D.C.; 1981; p. 67-75.

Swanston, D. N.; Swanson, F. J. Timber harvesting, mass erosion, and steepland forest geomorphology in the Pacific Northwest. In: D. R. Coates (ed.) Geomorphology and Engineering. Dowden, Hutchison, and Ross, Inc. Stroudsburg, PA; 1976; p. 199-221.

Waananen, A. O.; Harris, D. D.; Williams, R. C. Floods of December 1964 and January 1965 in the far western states, Parts 1 and 2. U.S. Geol. Survey Water Supply Pap. 1866 A, B. 1971.

Ziemer, R. R.; Swanston, D. N. Root strength changes after logging in southeast Alaska. Res. Note PNW-306. Portland, OR: Pac. Northwest For. and Range Exp. Stn., For. Serv., U.S. Dept. of Agric.; 1977. 10 p.

Ziemer, R. R. Storm flow response to road building and partial cutting in small streams of northern California. Water Resour. Res. 17:907-917; 1981.