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The RAPID Technique: A New Method for Evaluating Downstream Effects of Forest Practices on Riparian Zones

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Abstract

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The RAPID (riparian aerial photographic inventory of disturbance) technique is a method for using measurements made on aerial photographs of patterns of riparian canopy disturbance to evaluate changes in channel conditions through time and to link such changes with their possible upstream causes. The RAPID technique. provides resource specialists and managers with a relatively quick way of identifying stream reaches that are chronically or recently disturbed by a variety of channel processes, including increased peak flows and sedimentation from point and non-point sources. With examples from western Oregon, this paper describes how to apply the RAPID technique and analyze the results to evaluate downstream or cumulative effects of forest practices.

Keywords: Riparian zones, cumulative effects, aerial photograph interpretation, channel changes, monitoring, geomorphology, hydrology.

Contents

Introduction

Since the passage of the National Environmental Protection Act (NEPA) of 1969, Federal resource managers have been required to assess the cumulative and long-term effects of proposed actions on the environment. Procedures and guidelines for implementing this directive have been vague and not generally founded on scientific grounds. This leaves managers in the unenviable position of trying to assess and mitigate potential cumulative effects without many tools. Recently, monitoring the effects of past and present activities has become an explicit part of forest plans, and again, relatively few methods are available to accomplish this task.

One aspect of the problem of cumulative effects is the downstream effects from harvest activities occurring further upstream. Downstream effects are the off-site changes in the volume or pattern of water and sediment movement through a basin that result from forest practices. Such changes can cause the physical structure of channels and riparian communities to be modified. Downstream effects include a complex and interrelated set of hydrologic, geomorphic, and biologic processes, and researchers do not agree on how they should be measured.

This paper describes the RAPID (riparian aerial photographic inventory of disturbance) technique--a method for using aerial photographs to evaluate changes in channel conditions through time and to link such changes with their possible upstream causes. The theory is discussed briefly below; a more detailed treatment of the theoretical framework is given by Grant and others (1984). In the following sections, the methods used to collect and analyze data and apply the results are described.

As its name implies, the RAPID technique offers a relatively quick way to inventory channel conditions. Besides providing information about how upstream activities may affect downstream channels, it is useful for identifying channel segments with histories of instability, evaluating basinwide effects of major storms, monitoring recovery of riparian areas following channel disturbances, and comparing the effectiveness of different management treatments in mitigating downstream effects.

This technique as developed for analyzing geomorphic processes in the densely forested west side of the Cascade Range, Oregon. Differences in geology, vegetation, landforms, and hydrology in other regions are likely to result in different patterns of disturbance on aerial photos. This technique has not been tested in areas other than the west side of the Cascades, and its application to other regions should be considered experimental.

Background and Theory

The RAPID technique was developed to help sort out the relative importance of different processes producing downstream effects. It is therefore useful to consider how downstream effects might be distinguished from each other.

What Are Downstream Effects?

Downstream effects are one element in what I call the management-modified disturbance system (fig. 1). This system is a cascading series of causes and effects, with each link in the chain both an effect of preceding causes and a cause of subsequent effects. In this model, different classes of effects are distinguished by whether they occur at the site or away from the site of primary modification.

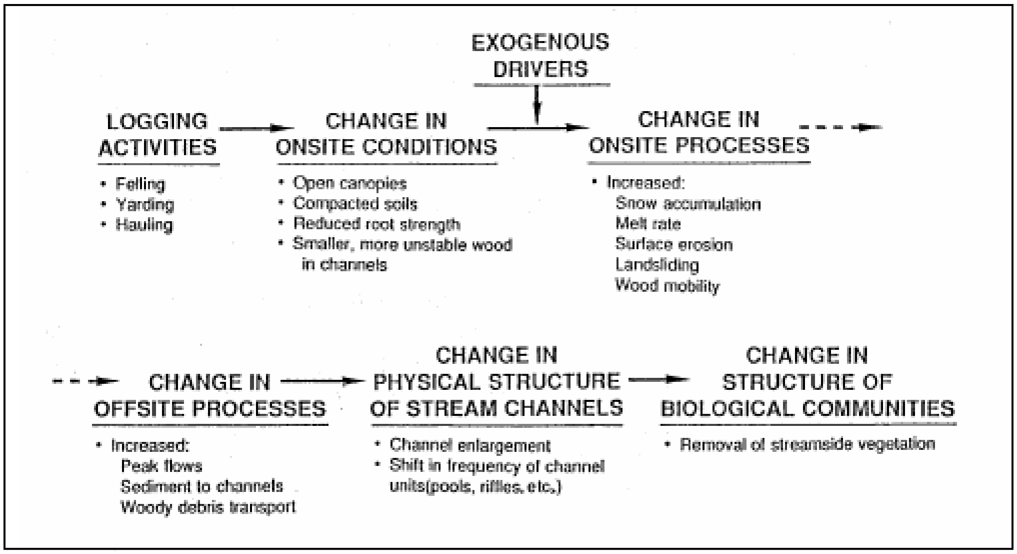


Figure 1—General model of the management-induced disturbance system.

The disturbance system begins with a modification to the primary site for timber harvest activities; modifications might include constructing logging roads and landings, falling and yarding timber, and preparing planting sites. These activities produce changes in local site **conditions**, such as compacted soils, altered ground cover, reduced root strength, opened canopies, and changes in the size distribution and volume of dead and downed woody debris. Such changes in site conditions can, in conjunction with exogenous driving events such as storms, cause changes in onsite **processes**, resulting in **onsite effects**. In the Pacific Northwest, these effects include reduced infiltration and subsurface flow, altered patterns of snow accumulation and melt, expanded drainage networks, and accelerated erosion from both surface and mass movement processes. In the disturbance system (fig.1), an external storm event may be required for such changes to become apparent.

Onsite effects can produce changes in quantities or patterns of water, sediment, and wood movement through the basin as a whole. The translation of onsite effects occurs through changes in specific supply mechanisms that route water and sediment; these changes are referred to as offsite or **downstream effects**. Although onsite effects are clearly linked in space and time with their management cause, downstream effects can produce changes that are spatially removed or delayed. Reported downstream effects include increasing peak flows, landslides, frequency of debris flows in channels, chronic sedimentation from roads and clearcut surfaces, and frequency of wood movement through channels.

The evidence suggests that timber harvest activities can affect the volumes, rates, and timing of water, sediment, and wood movement through a drainage basin. Not clearly understood is how stream channels respond to such changes in regime. Reported channel responses include aggradation, widening and braiding, streambank failures, increased deposition of fines, and reduction in pool volume and number. Such physical changes may, in turn, cause biological responses, such as loss of streamside vegetation or spawning habitat, or a change in composition of lotic communities.

How Can Downstream Effects Be Assessed?

With such complex interactions, how can downstream effects be assessed? The links between specific upstream disturbances and changes to downstream channels must be determined. In most studies, links between upstream activities and downstream channel changes are assumed, and the relative importance of specific water, sediment, and wood delivery mechanisms are not described. For management, distinguishing among different supply mechanisms can be important in designing improved strategies that moderate long-term environmental damage.

The technique described here is based on two hypotheses: (1) different water, sediment and wood delivery processes produce different types of channel response; and (2) channel response is distinctive enough to be used as an indicator of the delivery processes involved and, therefore, can provide a way to determine whether specific downstream effects are active in a given basin. Preliminary tests along the west side of the Cascade Range in Oregon suggest that these hypotheses are valid (Grant and others 1984).

Downstream effects must be classified by the mechanisms delivering water, sediment, and wood to the channel. Table 1 presents a general framework for analyzing channel and basin behavior resulting from management-induced disturbances. Column 1 describes on-site effects responsible for generating downstream effects (detailed in adjacent columns). The delivery mode classification (column 2) is based on whether the primary causative agent is water, sediment, or wood. Where increased sediment delivery is the primary mechanism, a further distinction is made because different rates of sediment delivery to channels may produce different downstream effects. The effect of material delivered over long periods from road and clearcut surfaces may differ from the effects of an instantaneous delivery, for example, by landslide. In this analysis, I distinguish between "chronic" and "pulse" sedimentation. In the first case, sediment is delivered to channels by surface erosion, creep, root throw, and small, onsite failures not entering channel ways. Sediment delivery via these mechanisms is likely to be relatively slow and prolonged. Although delivery processes themselves may produce little adjustment within the channel, persistent input of sediment over several years may produce channel changes.

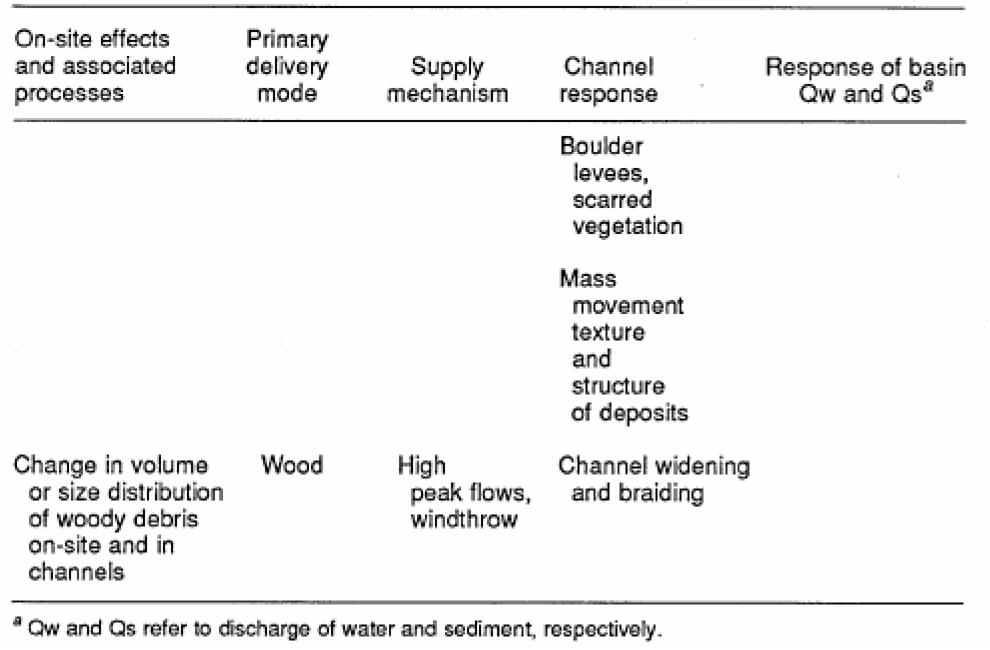
Pulse sedimentation, by contrast, involves rapid transfer of large amounts of predominantly coarse sediment and organic debris directly into the stream network. It is usually associated with mass movements, such as landslides or debris flows. High sediment loads, coarse debris, abrupt delivery, and the shear forces generated by mass movement within the channel all may playa role in determining channel response. In addition, emplacement often occurs during extreme hydrologic events when secondary mobilization and transport of deposited material is possible.

Table 1— Predicted channel and basin behavior resulting from changes in water and sediment delivery caused by on-site effects

On-site effects and associated processes	Primary delivery mode	Supply mechanism	Channel response	Response of basin Qw and Qs[a]
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 the percentage of basin area in bare soil that is connected with the 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	

See footnote on page 5.

Table 1— Predicted channel and basin behavior resulting from changes in water and sediment delivery caused by on-site effects (continued)



On-site effects and associated processes	Primary delivery mode	Supply mechanism	Channel response	Response of basin Qw and Qs[a]
			Boulder levees, scarred vegetation Mass movement texture and structure of deposits	
Change in volume or size distribution of woody debris on-site and in channels	Wood	High peak flows, windthrow	Channel widening and braiding	

[a] Qw and Qs refer to discharge of water and sediment, respectively.

Different types of mass movements may affect channels differently. Those that travel into the channel and stop, such as landslides, may cause channel adjustment from high quantities of sediment and debris supplied by the hillslope. In contrast, mass movements that travel down the channel, such as debris flows, may cause channel changes from the impact force of coarse sediment and woody debris traveling downstream on streambanks and riparian vegetation.

Effects of changes in frequency or size distribution of wood input on channel morphology are poorly understood and difficult to separate from effects of water and sediment movement. Any decrease in the size of wood pieces left in channels after logging may result in an increased tendency for wood to become mobile during high flow events. Increased mobility of wood pieces may cause large unstable debris jams to form; these in turn deflect flow laterally, thereby causing bank instability and erosion. Increased braiding may also occur as debris forms temporary blockages of main and secondary channels.

Physical changes in channel morphology produced by these supply mechanisms are given in table 1, column 4. Although some parameters are unique to specific supply mechanisms, considerable overlap occurs in the ways that channels adjust. In particular, some channel widening or enlargement is predicted for all supply mechanisms. Thus, more refined criteria are needed to distinguish between different supply processes; these are discussed in the next paragraphs. Predicted changes in basin water and sediment yields associated with specific supply mechanisms are given in table 1, column 5, and can be used as corroborating evidence for determining the active mechanisms.

Using Aerial Photographs to Monitor Changes in Channel Conditions

Interpretation of aerial photographs is one way to quickly inventory channel conditions over large areas. Most National Forests have aerial photo records for the last 30 to 40 years. In many cases, these photos, usually taken at 5- to 10-year intervals, offer the best and least expensive way of reconstructing histories of channel changes relative to management activities, and they may be the only way on some National Forests to review past activities, long-term trends, and cumulative effects.

Problems arise, however, in using aerial photographs. In the steep forest lands of the Pacific Northwest, channel changes on small- to intermediate-sized (second- to fifth-order) streams are difficult to detect because of steep hillslopes, dense riparian cover, and shading effects. In old-growth forest stands, even seeing the channel under the riparian canopy is often difficult. Identifiable changes in channel conditions on these streams are limited to those that disturb the streamside canopy. Along larger streams or streams in clearcuttings, the channel is usually visible, and shifts in location, pattern, and geometry can often be observed directly. But even for these channels, the small scale of photos and the shading effects of riparian vegetation limit the usefulness of aerial photos.

Fairly broad criteria have to be used to interpret channel response from aerial photographs. The RAPID method relies on changes in the width of the riparian canopy to indicate disturbance to the channel system (fig. 2). RAPID is able to detect only those disturbances that disrupt streamside stands: major floods, debris flows, and landslides. It does not detect changes in stream morphology when adjacent stands are not affected, such as aggradation or degradation (except where these result in mortality of streamside stands), minor shifts in channel location, or changes in channel geometry.

Changes in the width of unvegetated streamside area or **riparian canopy opening** nonetheless provide an indicator of major events of channel disturbance. Floods, for example, are likely to result in channel widening and bank instability with consequent opening of riparian canopies. During floods, large organic floating debris can cause canopy opening by battering and uprooting streamside vegetation. Debris flows similarly can scour channels and streamside areas and result in loss of canopy. Introduction of large amounts of coarse sediment by landslides or chronic sedimenttation can also induce channel widening; which leads to opened canopies. The pattern and extent of canopy opening can thus be used as a surrogate variable for whether the channel has experienced these types of disturbances. The width of the canopy opening also has important implications for riparian zone processes such as shading (hence temperature), addition of nutritional resources for aquatic communities, and delivery of large organic debris. The width of the canopy opening is an important factor influencing the health of stream ecosystems.

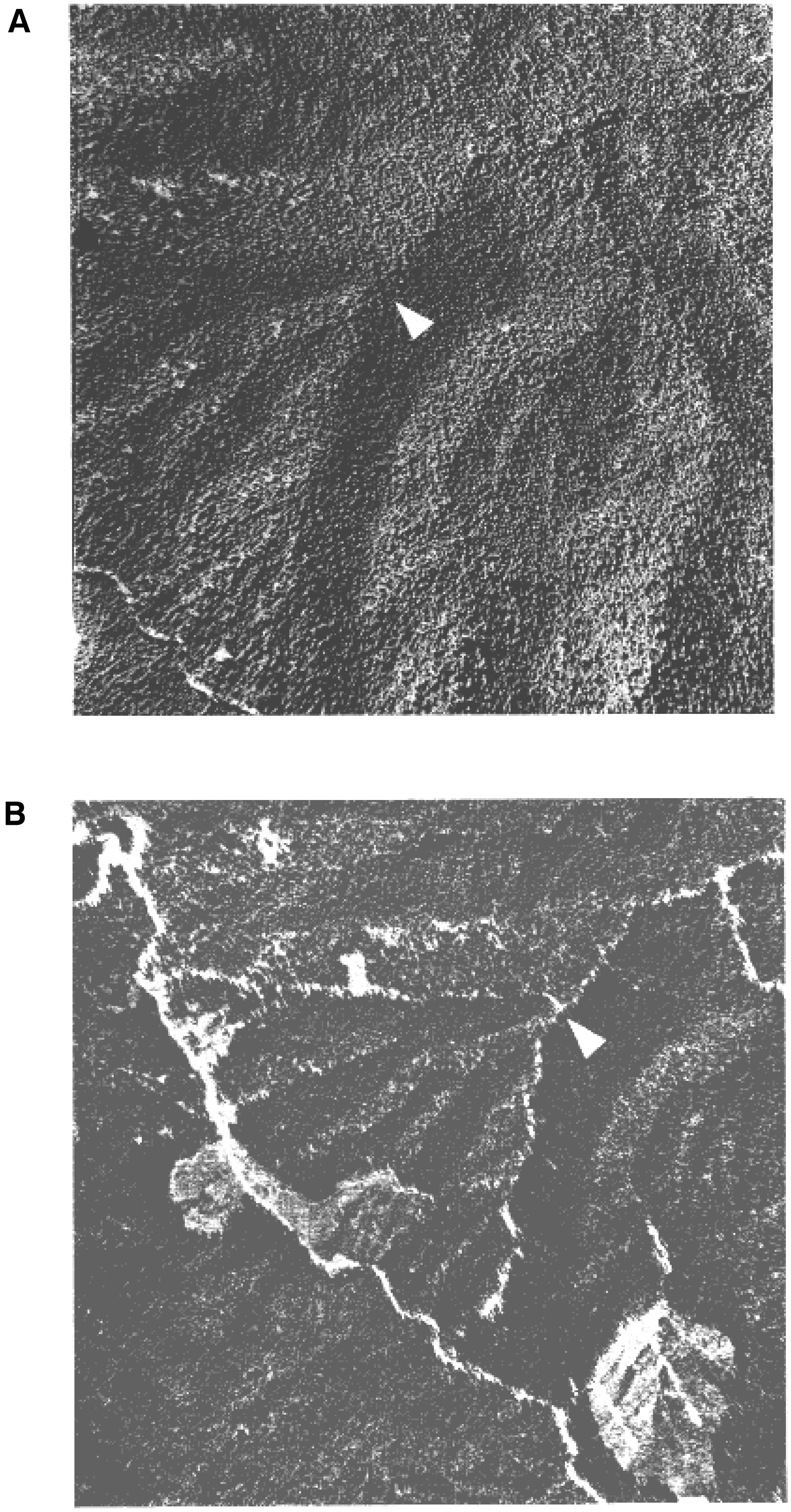


Figure 2—Aerial photographs of channel conditions on upper Bohemia Creek for (A) 1959 and (B) 1967 showing opening of riparian canopy. Scale is about 1 :20000.

If, as hypothesized, the pattern and extent of canopy opening is indicative of the kind of supply mode (table 1), a detailed set of diagnostic parameters sensitive enough to register the variety of induced channel disturbances is needed. In the technique out lined here, the critical parameters used are (1) the site conditions where the channel first shows some opening, termed the **initiation site**; (2) the degree of physical linkage or **contiguity** between the initiation site and open reaches further downstream; (3) the magnitude of canopy opening, expressed in the length and area of the open channel and the **continuity** of open reaches along the channel; and (4) the change in width of canopy opening with distance downstream (table 2).

Table 2—Physical parameters, detectable by aerial photography, predicted to be diagnostic for specific supply mechanisms

Supply mechanism	Mass movement at initiation site	Length of contiguous reach	Continuity of responding channels	Change in width downstream from initiation site
Increased peak discharges	No	Variable	Continuous to patchy	Increase or constant
Chronic sedimentation	No	Short	Patchy	Decrease
Pulse sedimentation:				
Into channel	Yes	Moderate	Continuous	Decrease
Within channel	Yes	Long	Continuous	Decrease
Change in wood input or mobility	Maybe	Variable	Continuous to patchy	Increase or constant

Although no one criteria is sufficient for a diagnosis (table 2), sets of parameters allow for distinguishing among supply mechanisms. For example, the high energy of transport and large amounts of organic and inorganic material delivered to streams during pulse sedimentation events (debris flows and landslides) are likely to result in a distinctive signature-a mass failure directly linked to open reaches extending continuously down the drainage network. Longer open reaches more likely result where input material mobilizes as a debris flow than where it stops near the site of introduction. Distinct depositional zones may be visible in aerial photos as wide flats bordering a channel and at the downstream end of disturbed reaches. The open canopy might diminish with distance downstream because of dilution of sediment-charged slurries and consequent changes in fluid dynamics or along with increasing opportunity for deposition with decreasing gradients.

The signature of canopy opening in response to increased peak water discharges, on the other hand, should include no mass failures at the initiation site and little continuous open reach because local channel constraints (that is, bedrock or differences in bank stability) are likely to determine where open canopies occur. If one assumes, moreover, that clearcuts and roads are distributed somewhat uniformly over the basin and that increases in peak flow generated locally are additive, canopy opening might be expected to increase or at least remain constant with distance downstream. In general, canopy opening in response to landslides and debris flows is predicted to be greater and more extensive than in response to either increased peak flows or chronic supply of sediment (table 2).

Differences between sediment delivery and transport by mass movement processes, as opposed to nonmass movement processes, may be particularly apparent at tributary junctions where changes in channel gradient and width are likely to cause debris flows to stop. This is especially true where the junction angle between tributary and mainstem is sharp (Benda 1985). An abrupt downstream terminus to the reach exhibiting open canopy might be expected at a tributary junction. Where higher peak flows or chronic sedimentation is the cause of open canopies, open reaches will likely extend downstream of tributary junctions and have less abrupt downstream boundaries. They may even show an increase in width of canopy opening below junctions as a result of the addition of water and sediment from other sources and increased opportunity for deposition in lower gradient reaches.

It is generally more difficult to ascribe channel changes directly to a wood supply mechanism because the effects tend to mimic those caused by increased water and sediment delivery (table 2). The RAPID procedure is not sensitive enough to evaluate whether channel changes are caused by wood movement alone. Wood should be considered as a contributing factor for all classes of downstream effects.

Open canopies do not necessarily indicate locations of channel instability. Some channels may be naturally open as the result of site factors, such as soil type or moisture availability, that limit establishment of riparian species. It is also fairly common to find channels with open canopies in areas not affected by basinwide disturbances, such as floods or extensive landslides. In some cases, open canopies may result solely from channel reworking of alluvial deposits, such as where a stream flows through an alluviated valley with a floor of glaciofluvial outwash deposits. Canopy opening is only an indicator of potential sites of channel instability. Field examination is often required to clearly identify the processes involved.

Collecting Data With the RAPID Technique

The three steps in collecting data with the RAPID technique—preliminary photo analysis, measurement, and tabulation—will be discussed separately. Before applying this technique, users may wish to study the general techniques of aerial photo interpretation (for references see appendix 2).

Preliminary Photo Analysis

Preliminary photo analysis involves selection and preliminary analysis of aerial photos to identify stream reaches for measurement, determine location and type of initiation sites, and classify stream reaches by type of and contiguity with initiation site. Figure 3 gives an example for part of the area shown in figure 2B.

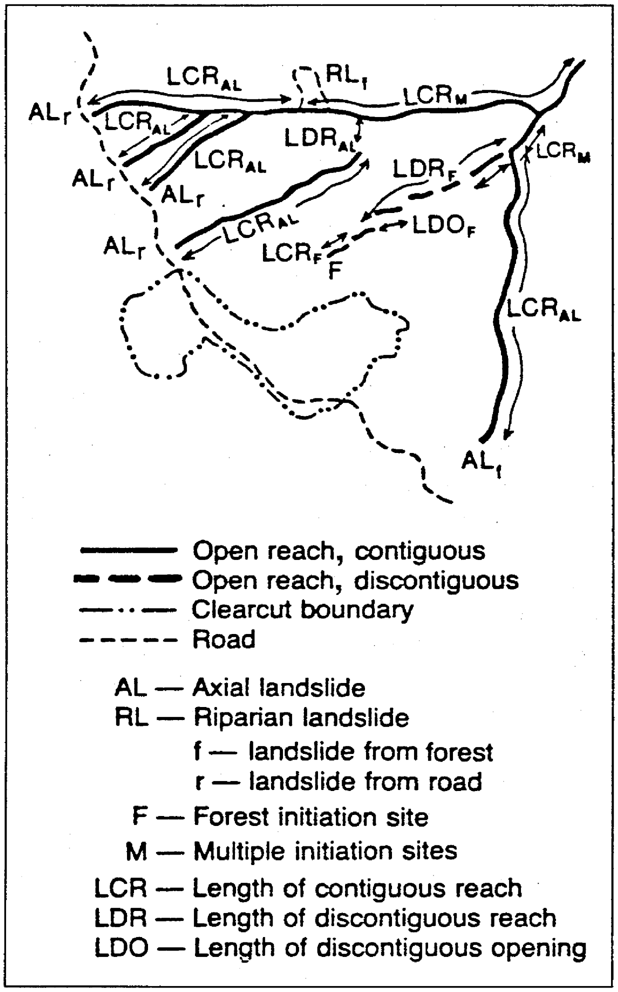


Figure 3—Initiation sites and stream reaches were classified for the area shown in figure 2B.

Selecting aerial photos--Aerial photos of the basin(s) of interest need to be collected. Photos selected for analysis ideally are high-resolution, large-scale photos with minimal shading and distortion and were taken directly over the stream. In reality, selection of photos will be governed by availability. The stream channel of interest should be as close to the center of each photograph as possible; successive and overlapping photos along the same flight line should be used to restrict to the center of the photograph measurements made on anyone photo; this will minimize edge distortion. The RAPID technique was developed on photographs with scales of 1:12,000 and 1:15,840. Larger scale photographs make identification of individual features easier; photos with scales smaller than 1:24,000 will be only marginally useful. Either color or black-and-white photos can be used, although color photos make deliniation of the unvegetated channel area somewhat easier.

The nominal photo scale, which is the scale commonly printed on the photos, is often inaccurate because of differences in topography, flight elevation, and camera focal length. To accurately determine the scale of the photos being used, it is necessary to measure a known distance on the photos. This is best done by measuring the distance between two points that can be clearly identified on both the photos and on a U.S. Geological Survey or USDA Forest Service map at a similar (though not necessarily the same) scale. Such points might include road intersections, clearcut boundaries, bridges, or tributary junctions; measured points should lie as close as possible to the channel being measured. The photo scale can then be calculated according to the following formula:

$$PS = (PD \times MS)/ MD ;$$

where PS is the photo scale, MS is the map scale, and PD and MD are the measured photo and map distances, respectively, in the same units. For a more indepth treatment of photo scale determination, see Ward and Dawson (1986, chapter 3).

Identifying open reaches--Aerial photos of the entire drainage basin of interest should be laid out and examined to identify initiation sites and open channel reaches. Examining photos in stereo or under low-power magnification may be required.

Identifying open reaches is fairly straightforward. In areas with dense riparian canopy, open reaches are identified by bare streamside areas with few, if any, trees (fig. 2B). Open reaches are identified by light-colored trimlines in clearcuttings and other areas of sparse vegetation (fig. 28). The color or tone of open reaches will vary according to the photography and nature of vegetation, soil, and parent materials. Open reaches will not necessarily appear white. Small, discontiguous openings (explained below) in dense canopy areas appear as breaks in the streamside canopy. These openings may be difficult to distinguish because of shading; comparison with other photos along the same flightline or with earlier photos may assist in determining whether openings are present. Closed canopy reaches, on the other hand, have woody riparian vegetation adjacent to the active channel; a small border of unvegetated streamside area may mark the location of the high-water channel in closed canopy reaches.

Classifying initiation sites--The point furthest upstream where a canopy opening along any tributary is observed is designated "the initiation site" for that tributary. Initiation sites are classed by whether open canopy begins at a landslide (L) in a forest (F) or clearcut (C), or near a road (R) without a landslide. Ambiguous site conditions (for example, failures in clearcut units immediately downslope from a road) should be noted. For landslide sites, the type of landslide is further classed as being axial or riparian: **axial landslides** (AL) are those that failed essentially parallel to or within the axis of the creek, drainage depression, or zero-order basin; **riparian landslides** (RL) are those that failed more or less perpendicular to the axis of the creek. Both types of landslides can be seen in figure 2B. For landslide initiation sites, the site condition (forest, clearcut, or road) is also noted with a subscript (fig. 3). Initiation sites correspond to the supply mechanisms shown in table 2.

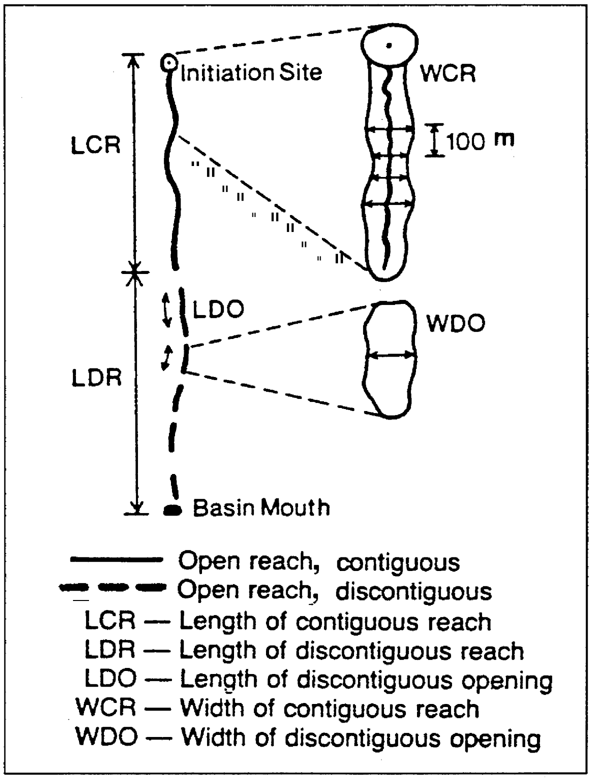


Figure 4—Measurements of length and width are made on aerial photographs of contiguous and discontiguous reaches.

Classifying stream reaches---The next step in characterizing the condition of the channels involves the degree of linkage between the initiation site and affected or open channel reaches. If a section of channel immediately downstream from an initiation site exhibits continuous canopy opening along its course and incorporates no sections of closed canopy reaches, it is termed a **contiguous reach** (CR) (fig. 4). The section of channel from the first visible canopy closure downstream is termed a **discontiguous reach** (DR). Channel openings that occur along a discontiguous reach are termed **discontiguous openings** (DO) (fig. 4).

Both contiguous and discontiguous stream reaches are classified according to their initiation site(s) (fig. 3). To tabulate data for basins with multiple open reaches, the longest contiguous reach is defined as the main stem. The locations where other open reaches, either contiguous or discontiguous, join the mainstem are noted, as are the locations of riparian landslides next to the channel (fig. 3). Where two reaches with different classes of initiation sites join, the channel below the junction is classified as having **multiple** initiation sites. Where two tributaries of the same class of initiation site join, the classification of the downstream channel does not change and is tabulated as a continuation of the tributary having the longer contiguous reach (fig. 3).

The location and classification of initiation sites and open reaches should be mapped from the photos onto a drainage network map of about the same scale. If no map is available, the stream network can be traced directly from the photos by using a light table. Each stream segment exhibiting open reaches, beginning with the mainstem (as previously defined), should be numbered to assist in tabulation.

Measurement Techniques

Lengths and widths of contiguous and discontiguous reaches and discontiguous openings are measured and recorded on the data form (table 3) after initial data preparation. Measurement is best done under low-power magnification by using an analytical stereoplotter, stereoscope, or a dissecting microscope. A hand lens or eye loupe with a graduated scale can also be used. Aerial photos should be taped to a light table for easy viewing.

Length measurements-- The channel length is measured on the photos along the channel axis of each tributary with open reaches, beginning at the upstream initiation site and extending downstream to either the basin mouth or a previously measured channel, whichever comes first. Points along the channel where width measurements will be made are also identified at this time, as described below. To provide a common location on successive photos for width measurements, channel lengths are measured in uniform increments, termed the "photo measurement interval". The photo measurement interval (in centimeters) is a function of a predetermined ground increment distance (in meters) according to the following formula:

photo measurement interval = (ground increment distance /photo scale reciprocal) x 100.

The photo scale reciprocal is the inverse of the photo scale; for example, if the photos are at a scale of 1:15,840, the photo scale reciprocal is 15,840. At this scale, the photo measurement interval corresponding to a ground increment distance of 100 meters (330 ft) is (100/15,840) x 100 or 0.63 centimeters (0.25 in).

Selection of a ground increment distance depends on the inherent variability of widths of opening along the channel and the objectives of the study. Generally, a smaller ground increment distance means more accurate results but greater time required to make measurements.

Where widths of openings are highly variable or where the purpose of the study is to detect small changes in width of canopy opening, a ground increment distance of 100 meters (330 ft) is used. Longer increments of 200-300 meters can be used where the width of openings is less variable or where a less detailed view of channel conditions is desired.

Table 3—Data recording form showing worked example, Bohemia Creek

RAPID PROCEDURE: PRIMARY DATA FORM

SEGMENT 1

SHEET 1 OF 4

STREAM BOHEMIA CK

BASIN MIDDLE FORK WILLAMETTE

PHOTOS USED:

YEAR 1967

SERIES ESF

NUMBERS 31-87

SCALE 1:15,840

MEASUREMENT UNITS: ft, in, [✓ m], cm (Circle one)

OPEN REACH CLASSIFICATION	CONTIGUOUS				DISCONTIG REACH NUMBER	DISCONTIGUOUS			
	DISTANCE	WIDTH	INFLUENCES R	INFLUENCES L		DISTANCE	WIDTH	INFLUENCES R	INFLUENCES L
ALc	0	25							
	100	11		CC					
	200	21		"					
M	300	29	OT(4)	"					
	400	35		"					
	500	27	OT(5)	"					
	600	36							
	700	38							
	767								
M					1	835	14		
						913			
					2	1025	10		
						1100	8		
						1200	8		
						1245			
						1628	0	basin	mouth

SUMMARY

REACH CLASSIFICATION	CONTIGUOUS		DISCONTIGUOUS			
	LCR	AVG WCD	LDR	NDD	SUM LDD	AVG WDD
ALc	300	19				
M	467	33				
M			861	2	298	10
TOTALS	767	28	861	2	298	10

CODING LEGEND

OPEN REACH CLASSIFICATION
(Based on initiation site type)

AXIAL LANDSLIDE	AL
Axial landslide from forest	ALf
Axial landslide from clearcut	ALc
Axial landslide from road	ALr
RIPARIAN LANDSLIDE	RL
Riparian landslide from forest	RLf
Riparian landslide from clearcut	RLc
Riparian landslide from road	RLr
FOREST (No landslide)	F
CLEARCUT (No landslide)	C
ROAD (No landslide)	R
MULTIPLE (Below junctions of tributaries having different classes of initiation sites)	M

INFLUENCES

OPEN TRIBUTARY (where n = segment number)	OT(n)
CLOSED TRIBUTARY	CT
CLEARCUT	CC
ROAD CROSSING	RX
MARGINAL ROAD	RM

SUMMARY VARIABLE ABBREVIATIONS

LCR	Length of contiguous reach
LDR	Length of discontiguous reach
AVG WCD	Average width of contiguous opening
AVG WDD	Average width of discontiguous opening
SUM LDD	Sum of the lengths of discontiguous openings
NDD	Number of discontiguous openings

Channel lengths and the locations for width measurements can be measured and marked off at intervals corresponding to the ground increment distance by using a wheel or electronic planimeter, if available. Otherwise, a strip of clear or frosted Mylar[1] can be used. To do this, a line corresponding to the calculated photo measurement interval is drawn on the Mylar. The Mylar is laid on the channel with one end of this line at the initiation site. The channel length is then measured by following the channel along the line, rotating the Mylar strip around a pin placed wherever the channel course deviates from the line until the line intersects the channel again (fig. 5). When the end of the line is reached, the pin is used to make a small hole in the photograph, the Mylar strip is rotated 180°, and the process is repeated until the entire channel length downstream from the initiation site to the basin mouth has been measured and marked. The locations of the pin holes are numbered with a grease pencil to correspond with their ground distances, and the lengths of contiguous and discontiguous reaches are read directly from the photos. Lengths between pin holes can be interpolated where necessary. Lengths of contiguous and discontiguous reaches for each class of initiation site are tabulated separately (table 3).

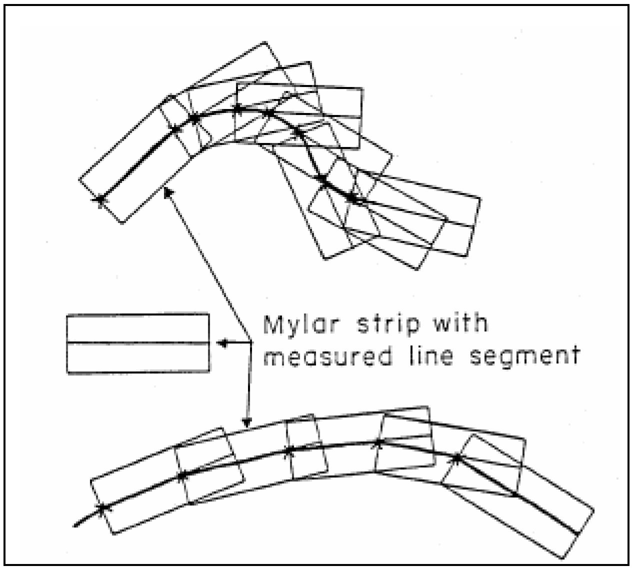


Figure 5—How a clear Mylar strip can be used to measure sinuous channel lengths.

Width measurements--Widths of canopy openings in both contiguous and discontiguous reaches are measured and recorded at intervals corresponding to the chosen ground increment distance as marked by the pin holes. An analytical stereoplotter is the ideal tool for making these measurements. If not available, an eye loupe with a scale in 0.1-millimeter increments or electronic planimeter set to point-to-point mode can be used; a ruler with a scale readable to ±0.1 millimeters can also be used. If an electronic planimeter is used, measurements should be repeated until at least two measurements agree, then all should be averaged.

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[1] Use of a trade name does not imply endorsement or approval of any product by the U.S. Department of Agriculture to the exclusion of others that may be suitable.

The width of canopy opening is measured perpendicular to the channel axis to the nearest 0.1 millimeter (0.004 in). Photo distances are converted to ground distances in meters by the following formula:

ground distance in meters = photo distance in millimeters x photo scale reciprocal/1000.

Calculated ground distances should be rounded off to the number of significant digits in the calculated photo scale; for example, a nominal photo scale of 1:12,000 has two significant digits. A measurement of 1.6 millimeters (0.06 in) on these photos would therefore be rounded off to 19 meters (62 ft).

Accurate determination of width of canopy opening may be difficult along some channel sections because of shading or camera angle. Sequential photos taken along the same flight path should be examined to reduce the effects of the latter; however, in some cases it may be necessary to extrapolate widths at measurement sites from adjacent stream reaches where shading is not a factor.

Widths are measured along all contiguous reaches and discontiguous openings beginning at the initiation site (fig. 4). Widths normally are not measured for closed canopy reaches because the unvegetated area cannot be easily seen. Widths of discontiguous openings should be made at the beginning and end of the opening if the opening is shorter than the photo measurement interval and at photo distances corresponding to the photo measurement interval for larger openings.

The site condition (forest, clearcut, partial cut, or road) for each streambank should be recorded at each measurement site (table 3); this makes it possible to determine whether streamside management activities affect the extent of canopy opening. The locations where other open- or closed-canopy tributaries join should also be noted (table 3).

Tabulation

One of the major advantages of the RAPID technique is its flexibility. Depending on the type of analysis desired, the data can be used to examine the pattern of canopy openings extending downstream from a specific initiation site to analyze the extent of canopy opening resulting from a class of initiation sites in a particular basin (that is, all road-related landslides), or to compare the total canopy opening resulting from a storm in two basins with different histories or management treatments (that is, logged and unlogged).

Data summaries--The raw data provide information on patterns of canopy openings associated with specific initiation sites. A summary of lengths and average widths for contiguous and discontiguous reaches and discontiguous openings should be made for each initiation site (table 3). Average width of canopy opening is calculated for each contiguous reach and discontiguous opening and widths of discontiguous openings, respectively, by averaging individual width measurements weighted by the proportion of total reach length corresponding to that width measurement. A program for the Hewlett-Packard (HP) 41 series calculators that computes weighted averages is given in appendix 1. For discontiguous reaches, the number and sum of the length of discontiguous openings are also calculated, along with the total length of discontiguous reach (table 3).

By summing measurements made on individual initiation sites over an entire basin, summary statistics for the basin as a whole can be developed (table 4). These summaries are useful for comparing basins with different treatments or for analyzing time trends in an individual basin. The widths of contiguous openings and widths of discontiguous openings for the basin are determined by averaging the weighted means from individual reaches weighted by the total contiguous or discontiguous reach length.

The data can also be summarized by initiation site class so that the effectiveness of specific types of initiation sites in producing canopy openings can be analyzed (table 5). This is particularly useful for evaluating the relative importance of specific downstream effects operating in a basin.

Computation of canopy opening indices-- To quantify relations between patterns of canopy openings and initiation site types, indices are developed from the measurements outlined above (table 6). These indices are used to evaluate the extent and type of canopy opening associated with particular initiation site classes and to test hypotheses about the relative importance of different mechanisms for producing canopy openings in a given basin or among a population of basins. Computation of indices is simplified by using a program for HP-41 calculators (appendix 1) or a computer spreadsheet program.

Indices can be generated for (1) individual, responding channel reaches; (2) all reaches in a particular basin; and (3) all reaches in a basin having a particular initiation site class. Methods for calculating each of these types of indices is discussed below; interpretation of indices is discussed in the section "Analyzing and Interpreting Results."

Individual responding reaches--Indices are calculated from the data summaries for individual reaches (table 3). Mean widths used in these calculations are averages of individual measurements weighted by the proportion of total reach length associated with each measurement. For channel segments without discontiguous openings, the discontiguity index is undefined, not zero. Indices derived in this manner are used to compare the effectiveness of specific initiation sites in producing open canopies.

All reaches in a basin-- These indices are developed from the data summary for the entire basin (table 4) and are used to describe basin response as a whole. Indices are calculated using column totals from table 4. In particular, the area of canopy opening index (table 6) should be calculated by summing the area of canopy opening values for the individual reaches, rather than by multiplying the total reach length by the average width for the basin as a whole; because of the weighted averaging procedure, some discrepancy between these two methods is likely.

All reaches having a particular class* of *initiation site--Indices can also be calculated for all reaches having specific classes of initiation sites by using the data summary table (table 5). Such indices are useful in comparing the relative importance of specific types of initiation sites for producing canopy opening. Column totals are used to calculate indices, and average widths are weight averaged.

Table 4—Data form for basin summary by segment, Bohemia Creek

RAPID PROCEDURE: BASIN SUMMARY BY SEGMENT
BASIN Bohemia Ck

PHOTOS USED:
YEAR 1967
SCALE 1:15,840
MEASUREMENT UNITS: ft, in, [✓ m] cm (Circle one)

SUMMARY VARIABLES BY SEGMENT

RESPONSE INDICES

SEGMENT NUMBER	OPEN REACH CLASSIFICATION	CONTIGUOUS		DISCONTIGUOUS									
		LCR	AVG WCO	LDR	NDO	SUM LDO	AVG WDO	LRC	ACO	RCO	CI	DI	PI
1	ALc	300	19										
	M	467	33										
	M			861	2	298	10						
	TOTAL	767	28	861	2	298	10	1628	24456	65.4	0.47	5.78	2.32
2	F	235	30	322	2	195	20	557	10950	77.2	0.42	3.30	6.21
3	ALr	408	20										
	M	135	19										
	M			624	3	277	23						
	TOTAL	543	20	624	3	277	23	1167	17231	70.3	0.47	6.76	4.81

	LCR	WCO	LDR	NDO	SUM LDO	WDO	LRC	ACO	RCO	CI	DI	PI
BASIN TOTALS	1545	25	1807	7	770	17	3352	52637	69.1	0.46	16.43	3.87

CODING LEGEND

OPEN REACH CLASSIFICATION
(Based on initiation site type)

AXIAL LANDSLIDE	AL
Axial landslide from forest	ALf
Axial landslide from clearcut	ALc
Axial landslide from road	ALr
RIPARIAN LANDSLIDE	RL
Riparian landslide from forest	RLf
Riparian landslide from clearcut	RLc
Riparian landslide from road	RLr
FOREST (No landslide)	F
CLEARCUT (No landslide)	C
ROAD (No landslide)	R
MULTIPLE (Below junctions of tributaries having different classes of initiation sites)	M

SUMMARY VARIABLE ABBREVIATIONS

LCR	Length of contiguous reach
LDR	Length of discontiguous reach
AVG WCO	Average width of contiguous opening
AVG WDO	Average width of discontiguous opening
SUM LDO	Sum of the lengths of discontiguous openings
NDO	Number of discontiguous openings

RESPONSE INDICES

LRC	Length of responding channel
ACO	Area of canopy opening
RCO	Responding channel opening
CI	Contiguity index
DI	Discontinuity index
PI	Patchiness index

Table 5—Data form for basin summary by initiation site type, Bohemia Creek

RAPID PROCEDURE: BASIN SUMMARY BY INITIATION SITE CLASS

BASIN Bohemia CK
SHEET 1 OF 1

PHOTOS USED:
YEAR 1967
SCALE 1:15,840
MEASUREMENT UNITS: ft, in, [✓ m], cm (Circle one)

SUMMARY VARIABLES BY INITIATION SITE — RESPONSE INDICES

OPEN REACH CLASSIFICATION	SEGMENT NUMBER	CONTIGUOUS LCR	CONTIGUOUS AVG WCD	DISCONTIGUOUS LDR	DISCONTIGUOUS NDD	DISCONTIGUOUS SUM LDD	DISCONTIGUOUS AVG WDD	LRC	ACD	RCD	CI	DI	PI
ALc	1	300	19										
ALr	3	408	20										
All AL		708	20										
F	2	235	30	322	2	195	20						
M	1	467	33	861	2	298	10						
M	3	135	19	624	3	277	23						
ALL M		602	30	1485	5	575	16						

TOTALS BY INITIATION SITE

	LCR	WCD	LDR	NDD	SUM LDD	WDD	LRC	ACD	RCD	CI	DI	PI
AXIAL LANDSLIDES (AL)	708	20					708	14160	100	1.00	—	—
AL-forest												
AL-clearcut	300	15					300	5700	100	1.00	—	—
AL-road	408	20					408	8160	100	1.00	—	—
RIPARIAN LANDSLIDES (RL)												
RL-forest												
RL-clearcut												
RL-road												
FOREST	235	30	322	2	195	20	557	10950	77.2	0.42	3.30	6.21
CLEARCUT												
ROAD												
MULTIPLE	602	30	1485	5	575	16	2087	27260	56.4	0.29	12.91	3.37

SUMMARY VARIABLE ABBREVIATIONS

LCR	Length of contiguous reach
LDR	Length of discontiguous reach
AVG WCD	Average width of contiguous opening
AVG WDD	Average width of discontiguous opening
SUM LDD	Sum of the lengths of discontiguous openings
NDD	Number of discontiguous openings

RESPONSE INDICES

LRC	Length of responding channel
ACD	Area of canopy opening
RCD	Responding channel opening
CI	Contiguity index
DI	Discontinuity index
PI	Patchiness index

Table 6-Quantitative indices for measuring degree of channel opening[a]

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	$\frac{LCR + \sum_{j=0}^{n} LDOj \times 100\%}{LRC}$ 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 x WCR) + (LDO x WDR)
Relative basin channel opening (RBCO)	An approximation of the proportion of a basin in open condition, treated as a percentage	$\frac{ACO \times 100\%}{\text{total basin area}}$
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 discontiguous channel	$\frac{NDO \times 1000}{LDR}$

[a] Abbreviations are as follows: LCR = length of continuous response; LDR = length of discontiguous response; LDO = length of discontiguous openings; WCR = average width of contiguous response; WDR = average width of discontiguous response; and NDO = number of discontiguous openings. Example of measurements used to derive indices is shown in figure 3.

Analyzing and Interpreting Results

Several different types of analyses can be performed by using the RAPID technique. These range from relatively rapid assessment of riparian canopy conditions for an individual stream or group of streams to time-trend analyses for a channel or basin and quantification of the degree of canopy opening associated with specific initiation sites. From these analyses, the relative importance of different mechanisms for producing downstream effects can be interpreted. Analysis procedures differ depending on the questions being asked. In this section, use of the data summaries and indices for both within-basin and interbasin analyses are discussed; analysis procedures are summarized in table 7.

Table 7—Suggested approaches for different types of analysis using the RAPID technique

Analysis type	Objective	Suggested approaches
Within-basin: At a given Point in time	Analyze pattern of canopy opening along individual channels	Plot width of canopy opening as a point in time of canopy opening function of distance downstream from along individual initiation site, location of tributary channels junctions, road crossings, and so forth
	Compare patterns of canopy opening among different channels within same basin at a single point in time	1. Order streams by ACO, CI, or RBCO of canopy opening indices to compare magnitude of opening among different on different streams 2. Plot ACO, RCO, and number or type single point in of initiation site as a function of time drainage area or stream order
Time trend	Compare patterns of canopy opening within same basin over a period of time	1. Successive plots of width of of canopy opening canopy opening for the same stream within same basin reach through time showing location over a period of landslides, roads, tributaries, and time so forth 2. Plot ACO, CI, and PI as functions of time, percentage of basin in cutover condition, and miles of road
Cumulative effects analysis	Interpretation of causative factors contributing to open canopies, channel changes	1. Calculate frequency distributions ACO, LRC, CI, or PI by type of initiation site 2. Compare composite response indices for each initiation site class
Interbasin analysis	Analyze effects of different geologic, hydrologic, climatic, or management conditions on degree of canopy opening	Calculate and compare composite indices of basin response, notably RBCO and CI, as a function of management intensity (percentage of basin havested or roaded); intrinsic geomorphic stability (proportion of basin in unstable geologic or soil units); or storm history

Within-Basin Analysis

Within-basin analysis includes patterns of canopy opening for both individual and multiple stream reaches, time-trends, and interpretation of factors producing canopy openings on a basin scale.

Individual stream reaches--Patterns of canopy openings for a specific stream reach can be analyzed by plotting the width of the canopy opening as a function of distance downstream from the initiation site. An example from Bohemia Creek, a tributary to the Middle Fork of the Willamette River, is shown (fig. 6). A plot of this kind is useful for interpreting causal mechanisms of canopy openings. According to table 2, the width of canopy opening should decrease away from mass movement initiation sites and increase or remain constant where increases in the peak flow are the primary cause. The decreasing trend of width of canopy opening with distance downstream on Bohemia Creek suggests that, in this case, the former mechanism is the dominant one (fig. 6).

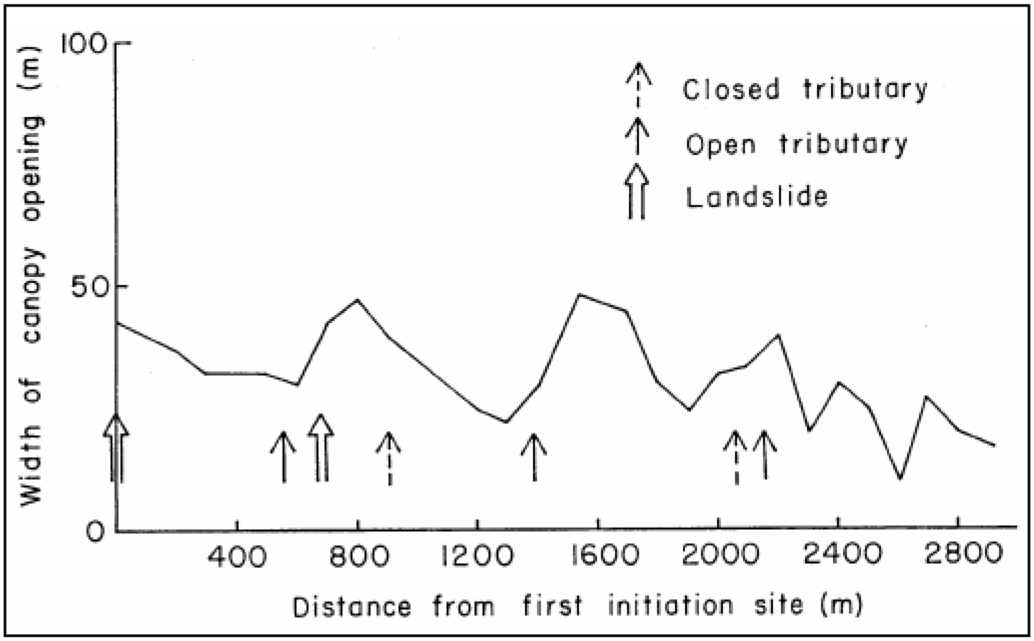

Figure 6—Change in width of canopy opening, Bohemia Creek, relative to sites of sediment and water introduction to the channel, as measured from aerial photographs.

Plotting the locations of other factors that may influence the extent of canopy opening, such as landslides, roads, clearcuts, and open and closed tributary junctions, directly on the graph may also be useful (fig. 6). In this way, it is possible to determine whether other processes (for example, runoff from road surfaces or point introduction of sediment from landslides) contribute to canopy opening.

Multiple stream reaches--One of the simplest uses of the RAPID technique is to quickly evaluate riparian canopy conditions among several streams. This approach might be called for when the objective is to identify the location of stream reaches that have in the past or are now exhibiting open canopies. Different streams or stream segments can be ordered by their area of canopy opening index (table 6), a measure of the total area of canopy opening. This measure is somewhat biased, however, in favor of larger streams. A less biased measure is the relative basin channel opening index (table 6) because this is the total area of canopy opening divided by the basin (or subbasin) drainage area. Stream segments can also be ordered by their contiguity index, which is the ratio of length of contiguous opening to total length of downstream channel; this can be used as a measure of the amount of a channel in open condition (table 6).

Identifying which parts of a drainage basin are particularly susceptible to canopy opening may be useful. Two different approaches can be followed: The first is to plot the location of initiation sites, perhaps stratified by type of site (landslide or nonlandslide) on a drainage network map, compute the drainage area for each initiation site (using an areal planimeter), and plot the number of initiation sites in different drainage area classes. A second approach is to determine the stream order of all open reaches by using a Horton-Strahler analysis (see Dunne and Leopold 1978, p. 498-499) and plot the percentage of total length of stream order in open condition for each stream-order class; an example of this latter approach is shown (fig. 7). Either method is useful for analyzing where open reaches are within a basin, and each can provide corroborating evidence for interpretation of causes of canopy opening. Open reaches located along higher order streams, for example, are more likely to be the result of fluvial factors rather than mass movement factors because debris flows and torrents are usually limited to steeper, lower order drainages.

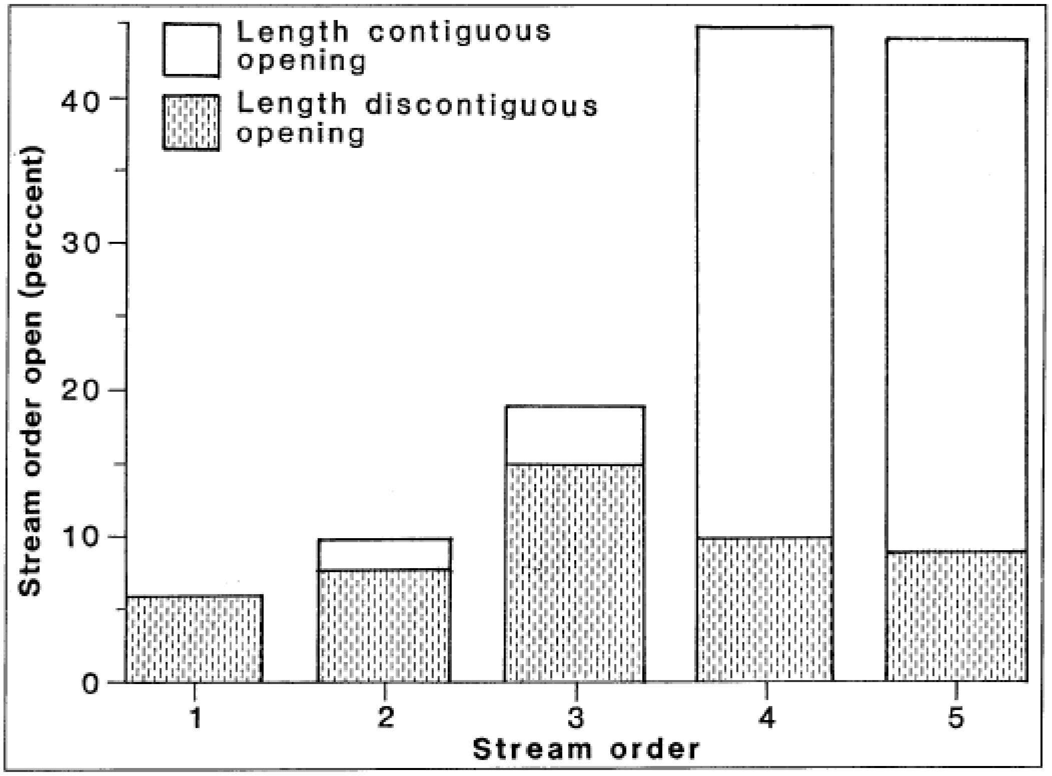

Figure 7—Percentage of channel length in different stream orders exhibiting canopy opening on 1967 photos, tributaries to Middle Fork of the Willamette River.

Time trend analysis--Changes through time in riparian conditions for either an individual channel or an entire basin can also be evaluated. From aerial photos taken in successive years, the width of riparian canopy opening along a channel can be plotted as a function of distance downstream from a fixed location. Plots for successive years allow time trends in magnitude of canopy opening to be analyzed. Channel conditions along the Breitenbush River, Willamette National Forest, were analyzed from aerial photos at a scale of 1:12000 in 1959 and at 1:15,840 for 1967, 1972, and 1979 (fig. 8). The upper channel of the Breitenbush is in a Wilderness Area, and the lower channel was subjected to intensive salvage logging operations in the riparian corridor from 1960 to 1985; the most intensive salvaging occurred downstream of the bridge (see fig. 8). Width of the canopy opening in the upper (wilderness) channel of the Breitenbush was about twice that of the lower channel under natural conditions in 1959 (fig. 8a). Between 1959 and 1967, the width of the canopy opening increased over the entire channel, most markedly in the reach below the bridge (fig. 8b). Much of this can be attributed to a major storm in December 1964. Comparison of width of canopy opening between 1972 and 1979 shows a general decrease presumably caused by new riparian vegetation in flood- affected areas (fig. 8c). Major salvage operations in the lowest reaches of the stream coupled with a major storm in 1977 appear to have been responsible for the dramatic increase in width of canopy opening seen in the 1979 photos in the section below the bridge (fig. 8d).

To accurately superimpose plots of widths of canopy openings from different photo series, the locations of several clearly identifiable points visible on all photos should be used as references for orienting the plots. The plots may have to be aligned by hand to achieve the best fit between successive years.

Time-trend analysis for a basin as a whole is accomplished by using indices of basin response. The basin's length of responding channel, area of canopy opening, contiguity index, or patchiness index can be plotted for successive years, thereby providing a measure of how basin riparian conditions have changed over time. For this kind of analysis, it is helpful to also plot management and natural disturbance factors of interest, such as the percentage of the basin in cutover condition, the miles of road in the basin, the timing of large storms, and the number of landslides visible on photos, if such information is available. In this way, relations among management activities, storm history, and basin response indices can be explored.

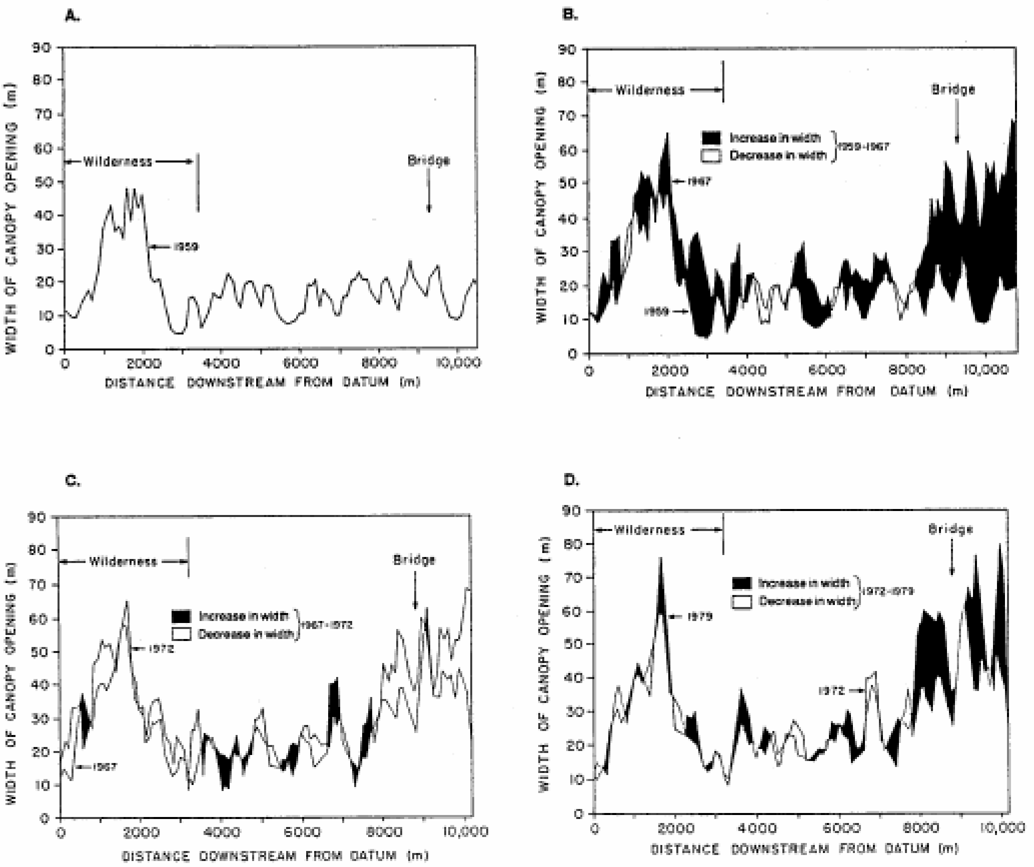

Figure 8—Change in width of riparian canopy from 1959 to 1979, Breitenbush River, Oregon.

Interpretation of causative factors--The RAPID technique was originally developed to distinguish among potential causes of downstream or cumulative effects. Interpretation of factors contributing to downstream effects in a given basin is aided by using response indices (table 6) calculated for all reaches having a particular class of initiation site (table 5). Two approaches are used. First, statistics for the entire population of reaches having a particular class of initiation site are generated and compared with those having a different type of initiation site; for example, the frequency distribution of lengths of contiguous reaches for reaches with and without mass movement initiation sites can be compared to examine the relative effectiveness of different classes of initiation sites in producing canopy openings (fig. 9). It is clear from figure 9 that the length of contiguous reach for sites with mass movements is greater than the length of contiguous reach for sites without mass movements. Mean length of contiguous reach for mass movement sites is 430 meters (1,410 ft) compared to 130 meters (430 ft) for sites without mass movements; this indicates that processes associated with mass movement initiation sites are more effective in producing open canopies. In a similar fashion, one could look at the frequency distribution of contiguity index, area of canopy opening, or patchiness index for all reaches in a basin, stratified by type of initiation site. These indices can be used to compare patterns of canopy openings associated with landslide initiation sites from forests, clearcuts, and roads to determine if certain classes of landslides are more effective in producing open canopies.

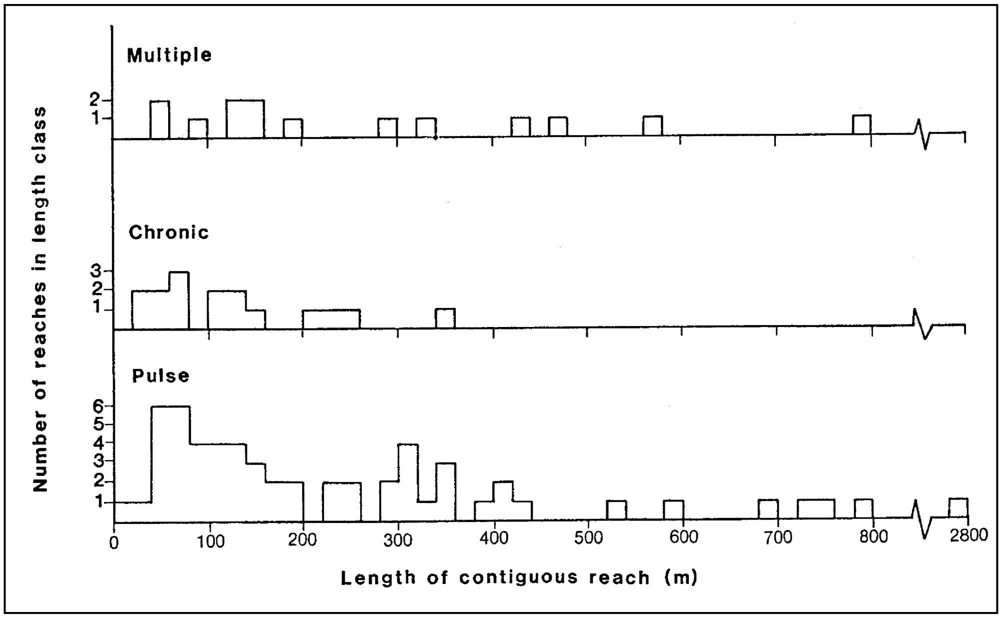

Figure 9—Distribution of lengths of open reaches contiguous with their initiation sites for different supply mechanisms. Pulse sites include all axial and riparian landslide initiation sites; chronic sites include all other initiation sites; and multiple sites include two or more initiation sites of different types.

Composite-response indices can also be calculated and compared for each type of initiation site (that is, axial landslides, riparian landslides, or forest, clearcuts, and roads without landslides). For this purpose, data summaries, such as table 5, are used. In a study (Grant 1986, p. 73) of fourth- and fifth-order streams draining into the Middle Fork Willamette River in Oregon, it was found that the composite contiguity index for all mass movement initiation sites (0.87) was over twice that for initiation sites without mass movements (0.41). Because both length of contiguous reach and contiguity index measure the amount of canopy opening spatially linked to the initiation site, the results seem to confirm that a canopy opening downstream from a mass failure initiation site is likely to be more continuously open for longer distances than when no mass movements are present. In this sense, landslide-related sedimentation events appear to be more effective in producing canopy opening, as predicted (table 2).

Interbasin Analysis

Interbasin analysis is used to compare patterns of canopy openings among several basins. In this way, effects of differing geologic, hydrologic, or management conditions can be assessed. Comparing amounts of canopy opening across several basins subjected to the same storm may help identify those basins that are particularly susceptible to canopy opening and those basins that are relatively resistant.

The approach for comparing basins is straightforward: data summaries for basins (table 4) are used to generate composite indices of channel response for the entire basin. These indices are plotted against basin parameters of interest, such as the percentage of basin harvested or proportion of basin area in unstable terrain. The relative basin channel opening index for eight basins in and near the Middle Fork Willamette River area was plotted against area of basin harvested by using 1967 photos (fig. 10) (Grant 1986). Results suggest an increase in the proportion of total channel area open with increasing area harvested. One creek (Bohemia) was plotted as an outlier to this general trend, though, and exhibited a much higher proportion of open channel area. Subsequent analysis revealed that the Bohemia Creek basin had the highest proportion of unstable terrain as defined by Soil Resource Inventory units (Legard and Meyer 1973). This technique thus makes it possible to identify basins particularly sensitive to canopy opening because of intrinsic geological factors.

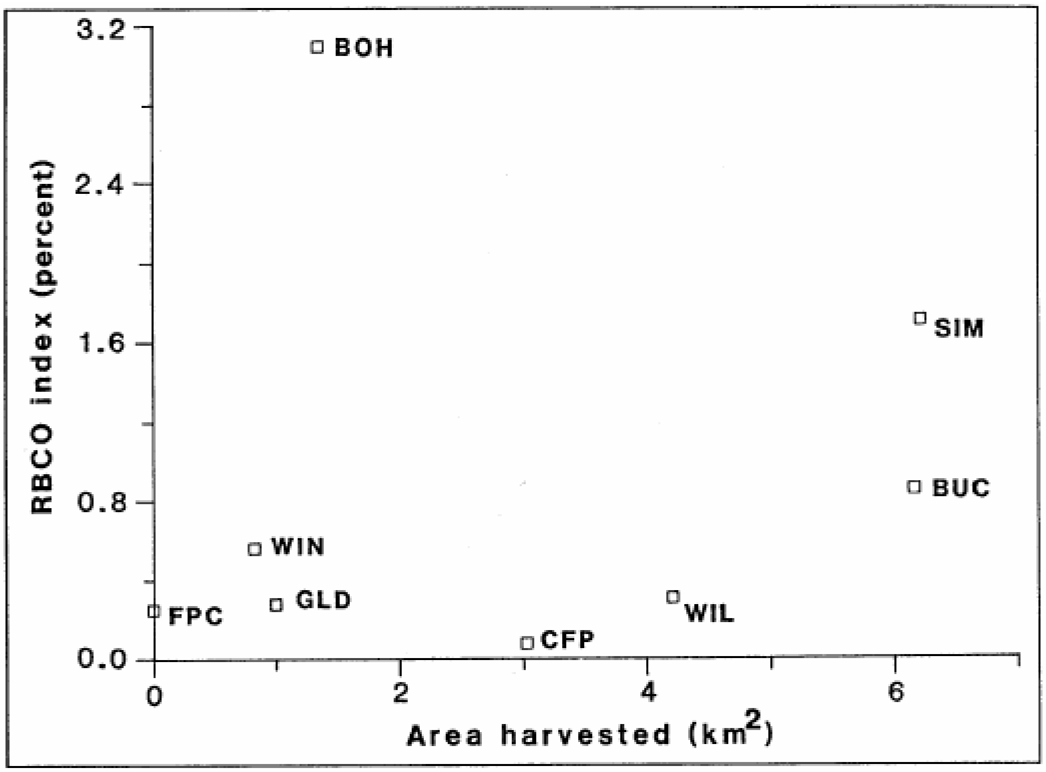

Figure 10— Relation of the relative basin canopy opening index, computed as the percentage of basin area in open condition, to area harvested in 1964. Individual basins are BOH = Bohemia Creek, SIM = Simpson Creek, WIN = Windfall Creek, GLD = Gold Creek, BUC = Buck Creek, WIL = Willow Creek, CFP = Coffeepot Creek, and FPC = French Pete Creek.

Conclusions

Through measurements made on aerial photographs of riparian canopy conditions, the RAPID technique allows resource specialists and managers to identify stream reaches chronically or recently disturbed by a variety of channel processes. Patterns of disturbed canopy are used as indicators of specific processes involved. This technique can be used to both inventory channel conditions and assess causes of channel changes.

The RAPID technique offers a quick, inexpensive, yet quantitative approach for evaluating changes in riparian canopy conditions through time and space. Changes in riparian conditions can be assessed over periods ranging from years to decades, time scales over which land management histories and techniques may have changed and the forest may have experienced storms of various magnitudes.

The technique also offers ways to rapidly assess streamside conditions across a large area. It is useful for scoping or identifying sensitive stream reaches and basins. Flexibility in calculating response indices allows for evaluation of individual stream reaches, entire channels, entire basins, or multiple basins.

Finally, the RAPID technique provides a tool for assessing the relative importance of different processes producing effects downstream. It can provide only one type of evidence, however. Corroborating evidence, such as ground surveys, are required to confirm interpretations made from aerial photographs. The RAPID techniques can help the resource specialist decide where to look and what to look for to determine if downstream effects are present. The most useful application may be framing and testing hypotheses about the location and prevalence of and processes responsible for disturbances in riparian areas.

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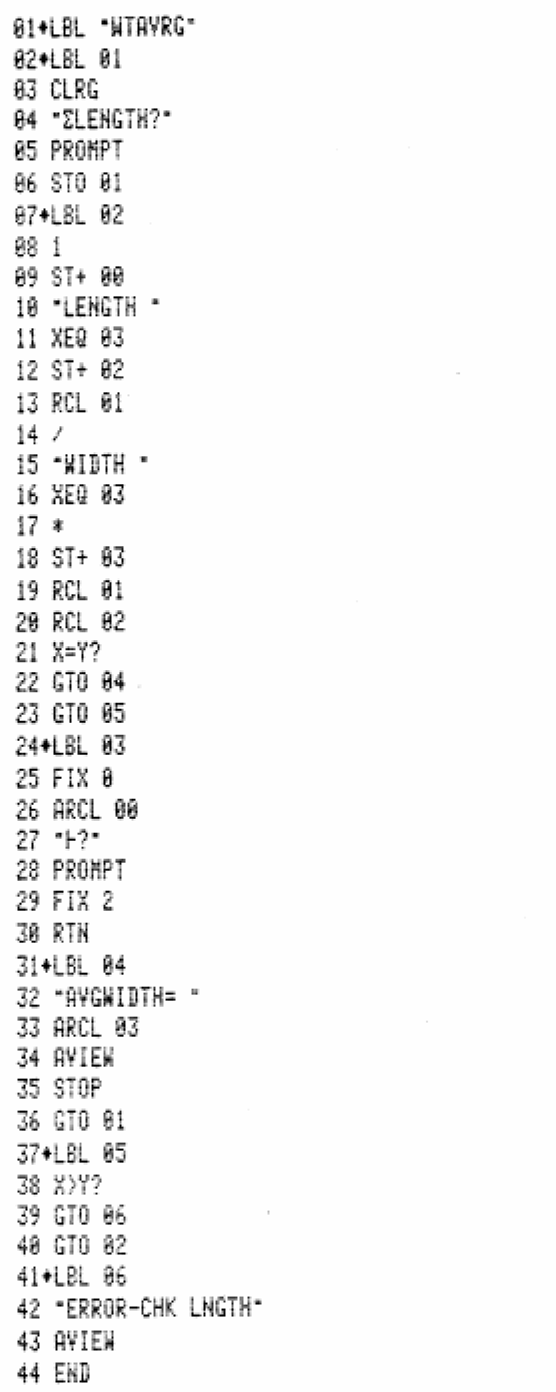
APPENDIX 1

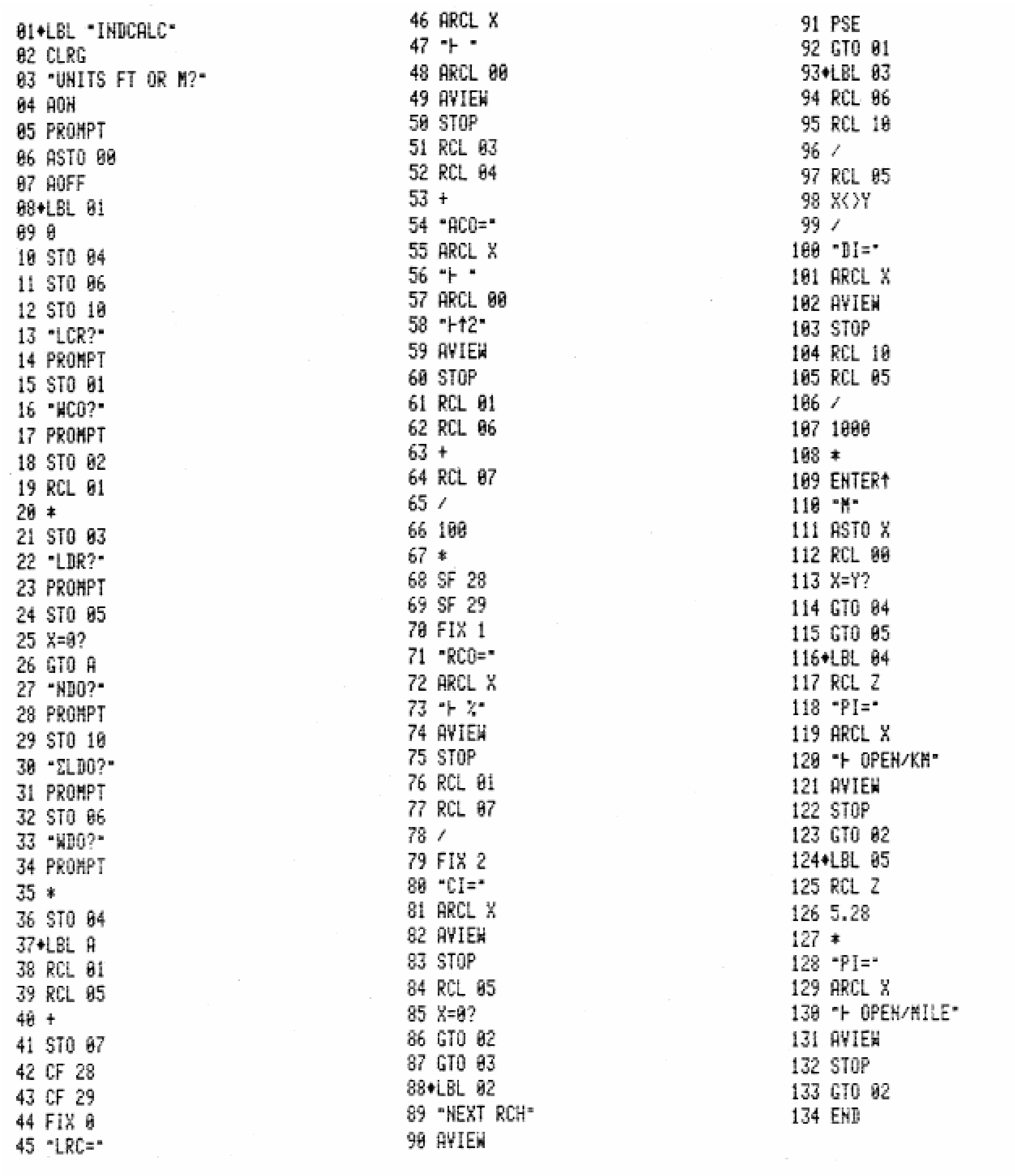
Programs for Calculations Used in the RAPID Procedure

The following two programs (figs. 11 and 12) were written for Hewlett-Packard (HP)-41 series calculators to expedite calculations used in the RAPID procedure. They can also be used with the HP-97 desktop calculator. Program lines should be keyed into the calculator exactly as written. The owners handbook should be consulted for more explanation of the key codes and abbreviations.



```
01♦LBL "WTAVRG"
02♦LBL 01
03 CLRG
04 "ΣLENGTH?"
05 PROMPT
06 STO 01
07♦LBL 02
08 1
09 ST+ 00
10 "LENGTH "
11 XEQ 03
12 ST+ 02
13 RCL 01
14 /
15 "WIDTH "
16 XEQ 03
17 *
18 ST+ 03
19 RCL 01
20 RCL 02
21 X=Y?
22 GTO 04
23 GTO 05
24♦LBL 03
25 FIX 0
26 ARCL 00
27 "⊢?"
28 PROMPT
29 FIX 2
30 RTN
31♦LBL 04
32 "AVGWIDTH= "
33 ARCL 03
34 AVIEW
35 STOP
36 GTO 01
37♦LBL 05
38 X>Y?
39 GTO 06
40 GTO 02
41♦LBL 06
42 "ERROR-CHK LNGTH"
43 AVIEW
44 END
```

Figure 11—Program listing for INDCALC program.



```
01♦LBL "INDCALC"
02 CLRG
03 "UNITS FT OR M?"
04 AON
05 PROMPT
06 ASTO 00
07 AOFF
08♦LBL 01
09 0
10 STO 04
11 STO 06
12 STO 10
13 "LCR?"
14 PROMPT
15 STO 01
16 "WCO?"
17 PROMPT
18 STO 02
19 RCL 01
20 *
21 STO 03
22 "LDR?"
23 PROMPT
24 STO 05
25 X=0?
26 GTO A
27 "NDO?"
28 PROMPT
29 STO 10
30 "ΣLDO?"
31 PROMPT
32 STO 06
33 "WDO?"
34 PROMPT
35 *
36 STO 04
37♦LBL A
38 RCL 01
39 RCL 05
40 +
41 STO 07
42 CF 28
43 CF 29
44 FIX 0
45 "LRC="
46 ARCL X
47 "├ "
48 ARCL 00
49 AVIEW
50 STOP
51 RCL 03
52 RCL 04
53 +
54 "ACO="
55 ARCL X
56 "├ "
57 ARCL 00
58 "├↑2"
59 AVIEW
60 STOP
61 RCL 01
62 RCL 06
63 +
64 RCL 07
65 /
66 100
67 *
68 SF 28
69 SF 29
70 FIX 1
71 "RCO="
72 ARCL X
73 "├ %"
74 AVIEW
75 STOP
76 RCL 01
77 RCL 07
78 /
79 FIX 2
80 "CI="
81 ARCL X
82 AVIEW
83 STOP
84 RCL 05
85 X=0?
86 GTO 02
87 GTO 03
88♦LBL 02
89 "NEXT RCH"
90 AVIEW
91 PSE
92 GTO 01
93♦LBL 03
94 RCL 06
95 RCL 10
96 /
97 RCL 05
98 X<>Y
99 /
100 "DI="
101 ARCL X
102 AVIEW
103 STOP
104 RCL 10
105 RCL 05
106 /
107 1000
108 *
109 ENTER↑
110 "M"
111 ASTO X
112 RCL 00
113 X=Y?
114 GTO 04
115 GTO 05
116♦LBL 04
117 RCL Z
118 "PI="
119 ARCL X
120 "├ OPEN/KM"
121 AVIEW
122 STOP
123 GTO 02
124♦LBL 05
125 RCL Z
126 5.28
127 *
128 "PI="
129 ARCL X
130 "├ OPEN/MILE"
131 AVIEW
132 STOP
133 GTO 02
134 END
```

Figure 12—Program listing for WTAVRG program.

1. INDCALC program: This program (fig. 11) calculates response indices shown in table 6 after being prompted for measured parameters. It can be used to calculate response indices for individual sites, entire basins, or particular classes of initiation sites, as explained in the text. Measurements can be entered in feet or meters; units of indices will vary depending on the measurement system used. See table 6 for definitions and formulas of variables. Abbreviations for variables used in the program are as follows:

Input variables	**Units of measurement**
LCR, length of contiguous reach	m or ft
WCO, average width of contiguous opening	m or ft
LDR, length of discontiguous reach	m or ft
NDO, number of discontiguous openings	
LDO, sum of the length of discontiguous openings	m or ft
WOO, average width of discontiguous openings	m or ft
Output variables	
LRC, length of responding channel	m or ft
ACO, area of canopy opening	m^2 or ft^2
RCO, responding canopy opening	Percent
CI, contiguity index	m/m or ft/ft
DI, discontinuity index	m/m or ft/ft
PI, patchiness index	Openings/km or openings/mile
ft	Feet
m	Meters

Running the program: After keying in the program, press the SHIFT key followed by the RTN key. Then execute SIZE (XEQ SIZE). When prompted for the size, key in 015. To begin the program, press the R/S key. The program will first prompt for the measurement units used (feet or meters) and then prompt for the input variables. Appropriately labeled output data will then follow. The PI and DI are calculated only when discontiguous reaches are present; they are undefined otherwise. After running through the calculations, the program will loop back; it is then ready for another set of measurements. To terminate the program, press CLX.

2. WTAVRG program: This program (fig. 12) computes the average width of an open reach, which is calculated by averaging individual width measurements weighted by the proportion of total reach length associated with each measurement. The total reach length must be determined before the program is run and be entered at the prompt. The program then prompts for lengths and corresponding widths of individual measurements. It checks for whether the sum of individual length measurements entered equals the total reach length. If so, it calculates the weight-averaged width for the reach; if not, it prompts for the next pair of measurements. An error message is printed if the sum of input lengths exceeds the total reach length.

Input variable	**Description**
LENGTH	Total reach length over which widths are to be averaged
LENGTH (N) WIDTH (N)	.ength and measured width at each measurement site, where N = 1, 2 ... total number of sites
Output variable	
AVGWIDTH	Average weight-averaged width for the reach

Running the program: After keying in the program, press the SHIFT key followed by the RTN key. To begin the program, press the R/S key. The program will first prompt for the total reach length. It will then prompt for pairs of length and width measurements. The average width will automatically be calculated when the sum of the individual length measurements equals the total reach length. If the sum of individual length measurements exceeds total reach length, the message ERROR-CHK LNGTH will appear; it indicates that either the total reach length or the individual measurement lengths were improperly entered.

APPENDIX 2

General References on Aerial Photograph Interpretation

Caylor, Jule A. 1984. Basic aerial photograph utilization techniques course workbook and manual. San Francisco: U.S. Department of Agriculture, Forest Service, Pacific Southwest Region, Engineering Office.

Paine, D.P. 1981. Aerial photography and image interpretation for resource management. New York: John Wiley and Sons.

Ray, R.G. 1960. Aerial photographs in geologic interpretation and mapping. U.S. G.S. Prof. Pap. 373. Washington, DC: U.S. Government Printing Office.

Ward, J.F.; Dawson, R.O. 1986. Aerial photograph interpretation techniques: Region 6 basic training manual. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 230 p.

APPENDIX 3

Blank Forms

RAPID PROCEDURE: PRIMARY DATA FORM

SEGMENT ______________

SHEET ___ OF ___

STREAM ______________

BASIN ______________

PHOTOS USED:

YEAR ______________

SERIES ______________

NUMBERS ______________

SCALE ______________

MEASUREMENT UNITS: ft, in, m, cm (Circle one)

OPEN REACH CLASSIFICATION	CONTIGUOUS				DISCONTIG REACH NUMBER	DISCONTIGUOUS			
	DISTANCE	WIDTH	INFLUENCES			DISTANCE	WIDTH	INFLUENCES	
			R	L				R	L

SUMMARY

REACH CLASSIFICATION	CONTIGUOUS		DISCONTIGUOUS			
	LCR	AVG WCD	LDR	NDO	SUM LDO	AVG WDO
TOTALS						

CODING LEGEND

OPEN REACH CLASSIFICATION
(Based on initiation site type)

AXIAL LANDSLIDE	AL
Axial landslide from forest	ALf
Axial landslide from clearcut	ALc
Axial landslide from road	ALr
RIPARIAN LANDSLIDE	RL
Riparian landslide from forest	RLf
Riparian landslide from clearcut	RLc
Riparian landslide from road	RLr
FOREST (No landslide)	F
CLEARCUT (No landslide)	C
ROAD (No landslide)	R
MULTIPLE (Below junctions of tributaries having different classes of initiation sites)	M

INFLUENCES

OPEN TRIBUTARY (where n = segment number)	OT(n)
CLOSED TRIBUTARY	CT
CLEARCUT	CC
ROAD CROSSING	RX
MARGINAL ROAD	RM

SUMMARY VARIABLE ABBREVIATIONS

LCR	Length of contiguous reach
LDR	Length of discontiguous reach
AVG WCD	Average width of contiguous opening
AVG WDD	Average width of discontiguous opening
SUM LDD	Sum of the lengths of discontiguous openings
NDD	Number of discontiguous openings

RAPID PROCEDURE: BASIN SUMMARY BY INITIATION SITE CLASS

BASIN ____________________

SHEET ___ OF ___

PHOTOS USED:

YEAR ___________

SCALE ___________

MEASUREMENT UNITS: ft, in, m, cm (Circle one)

SUMMARY VARIABLES BY INITIATION SITE

RESPONSE INDICES

OPEN REACH CLASSIFICATION	SEGMENT NUMBER	CONTIGUOUS		DISCONTIGUOUS									
		LCR	AVG WCO	LDR	NDO	SUM LDO	AVG WDO	LRC	ACO	RCO	CI	DI	PI

TOTALS BY INITIATION SITE

	LCR	WCO	LDR	NDO	SUM LDO	WDO	LRC	ACO	RCO	CI	DI	PI
AXIAL LANDSLIDES (AL)												
AL-forest												
AL-clearcut												
AL-road												
RIPARIAN LANDSLIDES (RL)												
RL-forest												
RL-clearcut												
RL-road												
FOREST												
CLEARCUT												
ROAD												
MULTIPLE												

SUMMARY VARIABLE ABBREVIATIONS

LCR	Length of contiguous reach
LDR	Length of discontiguous reach
AVG WCO	Average width of contiguous opening
AVG WDO	Average width of discontiguous opening
SUM LDO	Sum of the lengths of discontiguous

RESPONSE INDICES

LRC	Length of responding channel
ACO	Area of canopy opening
RCO	Responding channel opening
CI	Contiguity index
DI	Discontinuity index

RAPID PROCEDURE: BASIN SUMMARY BY SEGMENT

BASIN ____________________

PHOTOS USED:
YEAR ____________________
SCALE ____________________
MEASUREMENT UNITS: ft, in, m, cm (Circle one)

		SUMMARY VARIABLES BY SEGMENT						RESPONSE INDICES					
		CONTIGUOUS		DISCONTIGUOUS									
SEGMENT NUMBER	OPEN REACH CLASSIFICATION	LCR	AVG WCD	LDR	NDD	SUM LDD	AVG WDD	LRC	ACD	RCD	CI	DI	PI

	LCR	WCD	LDR	NDD	SUM LDD	WDD	LRC	ACD	RCD	CI	DI	PI
BASIN TOTALS												

CODING LEGEND

OPEN REACH CLASSIFICATION (Based on initiation site type)	
AXIAL LANDSLIDE	AL
Axial landslide from forest	ALf
Axial landslide from clearcut	ALc
Axial landslide from road	ALr
RIPARIAN LANDSLIDE	RL
Riparian landslide from forest	RLf
Riparian landslide from clearcut	RLc
Riparian landslide from road	RLr
FOREST (No landslide)	F
CLEARCUT (No landslide)	C
ROAD (No landslide)	R
MULTIPLE (Below junctions of tributaries having different classes of initiation sites)	M

SUMMARY VARIABLE ABBREVIATIONS	
LCR	Length of contiguous reach
LDR	Length of discontiguous reach
AVG WCD	Average width of contiguous opening
AVG WDD	Average width of discontiguous opening
SUM LDD	Sum of the lengths of discontiguous openings
NDD	Number of discontiguous openings

RESPONSE INDICES	
LRC	Length of responding channel
ACD	Area of canopy opening
RCD	Responding channel opening
CI	Contiguity index
DI	Discontinuity index
PI	Patchiness index

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Grant, Gordon. 1988. The **RAPID** technique: a new method for evaluating downstream effects of forest practices on riparian zones. Gen. Tech. Rep. PNW-GTR-220. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 36 p.

The **RAPID** (riparian aerial photographic inventory of disturbance) technique is a method for using measurements made on aerial photographs of patterns of riparian canopy disturbance to evaluate changes in channel conditions through time and to link such changes with their possible upstream causes. The **RAPID** technique provides resource specialists and managers with a relatively quick way of identifying stream reaches that are chronically or recently disturbed by a variety of channel processes, including increased peak flows and sedimentation from point and non-point sources. With examples from western Oregon, this paper describes how to apply the **RAPID** technique and analyze the results to evaluate downstream or cumulative effects of forest practices.

Keywords: Riparian zones, cumulative effects, aerial photograph interpretation, channel changes, monitoring, geomorphology, hydrology.

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