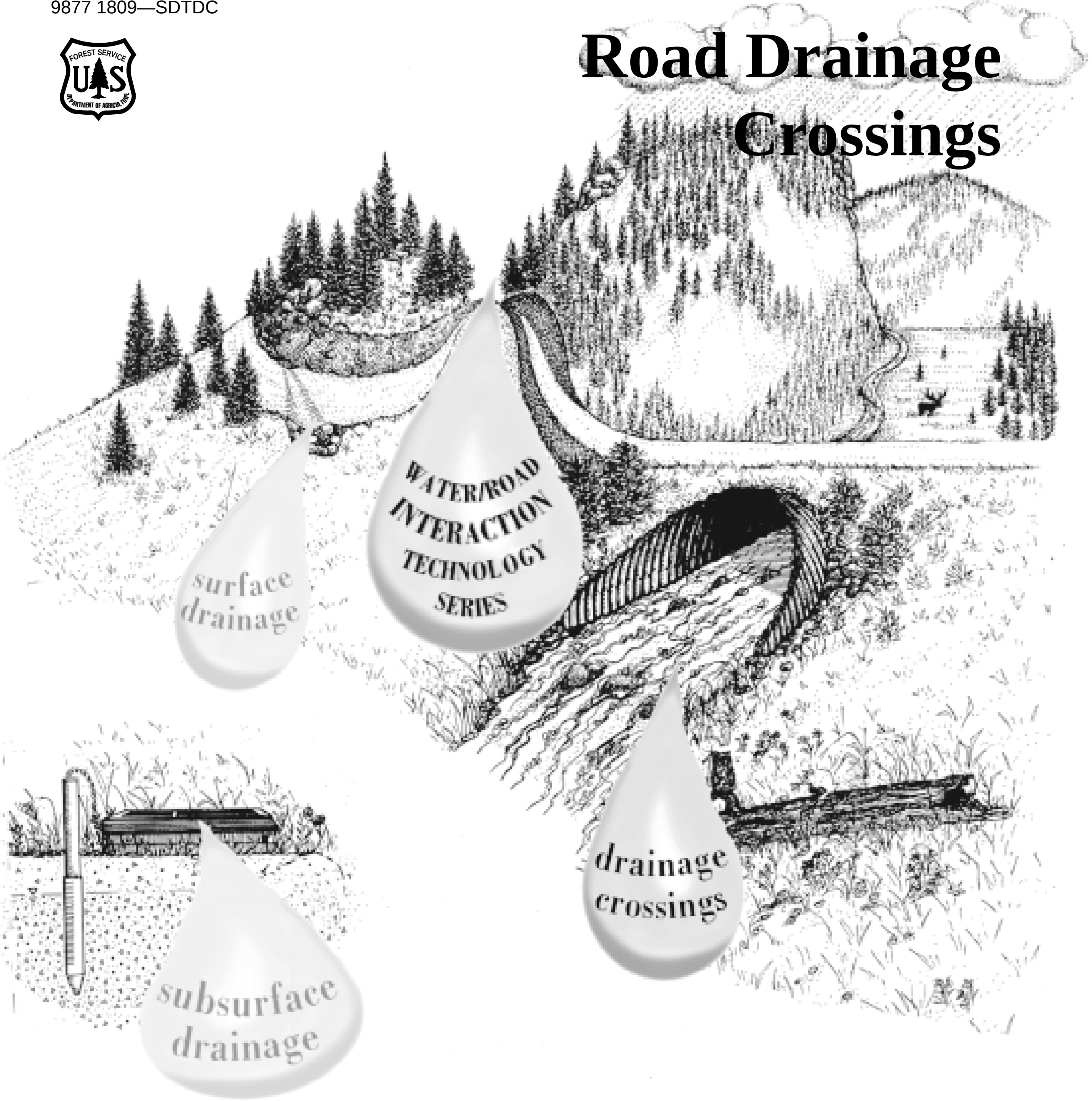
United States
Department of
Agriculture

Forest Service

Technology &
Development
Program

7700—Transportation Systems
2500—Watershed and Air Management
December 1998
9877 1809—SDTDC

Methods for Inventory and Environmental Risk Assessment of Road Drainage Crossings



Methods for Inventory and Environmental Risk Assessment of Road Drainage Crossings

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December 1998

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ACKNOWLEDGMENTS

An early draft of this document benefited from reviews by Walt Megahan. Greg Bundros and Mary Ann Madej of Redwood National Park offered valuable comments and critique. Jan Werren and Jim Lugosi of the Six Rivers National Forest and Americorps Watershed Stewards program, respectively, provided G.I.S. support for the North Fork Eel assessment. The California Department of Forestry and Fire Protection (CDF), through Pete Cafferata, provided funding for the early stages of this project. Gordon Grant and Beverley Wemple provided many ideas and invaluable encouragement throughout the project. Finally, many thanks to Bill Trush for his extensive comments and constructive criticism through the development of this document.

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INTRODUCTION

Road-stream crossings and ditch-relief culverts are commonly sites of ongoing or potential erosion. Erosion from failures of these structures can be a source of significant impacts to aquatic and riparian resources far removed from the initial failure site. The inventory and assessment of culvert installations are necessary for locating sites with potential impacts to aquatic and riparian environments for possible treatment. With restricted budgets for road maintenance and repair, locating those sites that have the greatest likelihood of causing adverse impacts is necessary to prioritize the expenditure of funds to reduce or eliminate risks.

This guidebook discusses procedures for assessing the erosional hazards and risks to aquatic and riparian ecosystems of road-stream crossings, ditch-relief culverts, and other road-drainage features. *Hazard assessment* is the estimation of the potential *physical consequences* (e.g., volume of material eroded) for one or more sites. Incorporation of the potential impacts to valued resources, or *endpoints*, is *environmental risk assessment*. This approach is not intended to be a rigorous or inflexible procedure, but rather to suggest appropriate data and assessment techniques that can be adapted to a wide range of settings.

The purposes of this guidebook are to

- Review inventory and analysis methods in current or recent use in wildland settings
- Suggest various inventory procedures for the assessment of existing culvert installations and other road-drainage features, both unfailed and failed
- Provide analytical methods for predicting the potential hazards and environmental risks of road-drainage failure
- Provide background information on road-stream crossing performance.

The assessment methods discussed here are useful for a screening approach where data on a large number of drainage features are collected, typically at the scale of a watershed less than 500 km^2. Culverts are the most common structure employed for wildland road-stream crossings and ditch drainage. Such culverts are the focus of this document. However, the procedures discussed are adaptable to other road-drainage structures as well.

The following road crossing terminology is used:

Road-stream crossing is where a road crosses a natural drainage channel or unchanneled swale.

Stream crossing is used synonymously with road-stream crossing.

Cross drain is a ditch-relief culvert or other structure such as a grade dip designed to capture and remove surface water from the traveled way or other road surfaces.

Crossing is used here to cover both stream crossings and cross drains.

Hydrologically connected road is a segment of road that is connected to the natural channel network via surface flowpaths.

THE ENVIRONMENTAL RISK OF ROAD-STREAM CROSSINGS AND THE NEED FOR INVENTORY AND ASSESSMENT

Road-stream crossings are a common feature throughout wildland roads and have enormous potential erosional consequences. For federally managed lands in the Pacific Northwest, the Forest Ecosystem Management Assessment Team (FEMAT) (1993) estimated that 250,000 road-stream crossings exist, but systematic analysis of cumulative environmental risks are rare. Most of these structures have the potential to function as earthen dams, with a small hole or culvert at the base. Such configurations are rare in natural channels. In the absence of maintenance and replacement, all these structures will eventually fail as they plug or the culvert invert deteriorates. Financial resources for maintaining or upgrading the existing network are limited. Therefore, it is necessary that those sites that pose the greatest risk to aquatic and riparian resources be located and treated to reduce hazard and environmental risk.

Crossings can cause both chronic sedimentation impacts during typical water years and catastrophic effects when floods trigger crossing failure (figure 1). When water overtops the road fill, it may divert down the road or ditch and onto hillslopes unaccustomed to concentrated overland flow and produce erosional consequences far removed from the crossing. Erosion from diverted stream crossings in the 197-km^2 lower Redwood Creek basin in northwestern California accounted for 90 percent of the total gully erosion (Weaver et al. 1995). Best et al. (1995) found that road-stream crossings accounted for 80 percent of all road-related fluvial erosion in a 10.8-km^2 tributary basin to lower Redwood Creek. Erosion from failed or improperly designed road-drainage structures accounted for 31 percent of the total sediment inputs (Best et al. 1995). Identifying those sites with the greatest potential of erosional consequences (e.g., potential to divert stream flow) can direct restoration efforts.

Abandoned roads represent an unknown, but potentially high, erosional hazard. Failures often go unseen in the absence of inspection or maintenance. Where stream diversions have occurred, erosion is likely to continue for decades as new stream channels are incised. Determining the extent of abandoned roads in an area is necessary for assessing the entire road-related erosional hazards.

Previous assessments of existing road-stream crossings have examined the hydraulic capacity of the culverts (Piehl et al. 1988 and Pyles et al. 1989). These results show that culverts were installed without consistent design standards, and


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Figure 1—Road-stream crossings can alter channel form and processes. They are sites of both chronic and catastrophic erosion.

that design flow capacities were often below standards established by the Oregon Forest Practice Rules (Piehl et al. 1988). In a recent survey of road-stream crossings in Redwood Creek, northwest California, 60 percent of the culverts could not pass a 50-year peak flow (Redwood National Park, unpublished data).

Nonstream crossing drainage structures are also of concern. These include ditch-relief culverts, waterbars, and rolling dips. An expanded discussion on rolling dips is provided by the companion document in this series, "Diversion Potential at Road-Stream Crossings" (Furniss et al. 1997). Detailed design considerations for dips are provided by Hafterson (1973). Not only do these structures present similar hazards and environmental risks as those discussed for road-stream crossings, they are also capable of extending the natural drainage network if not properly configured (Wemple 1994). Extension of the drainage network occurs when ditch flow and road surface runoff are conveyed to a stream channel. Where roads are hydrologically connected to the drainage network, road-produced sediment and runoff are delivered directly to the channel network. Hydrologic connectivity often involves extensive gullies linking roads and channels (Wemple 1994).

Assessing the hazards and environmental risks of crossings involves substantial inventory costs. Roads are not a direct reflection of the underlying landscape, and, as such, remote sensing techniques cannot provide necessary information on existing hazards. Simply locating the installed system using remote sensing techniques provides little information on potential erosional consequences. Several techniques are presented for inventorying roads and crossings at various levels of effort.

What are the Environmental Risks of Road-Drainage Features?

It is useful to think about the environmental risk of road-stream crossings, cross drains, and other drainage structures (e.g., waterbars and rolling dips) in four parts (figure 2). The four parts of the environmental risk assessment model used in this guide are

- *Inputs* are the materials presented to the crossing. These are water, organic debris, sediment, and fish. *(This document does not discuss fish/amphibian passage.)*

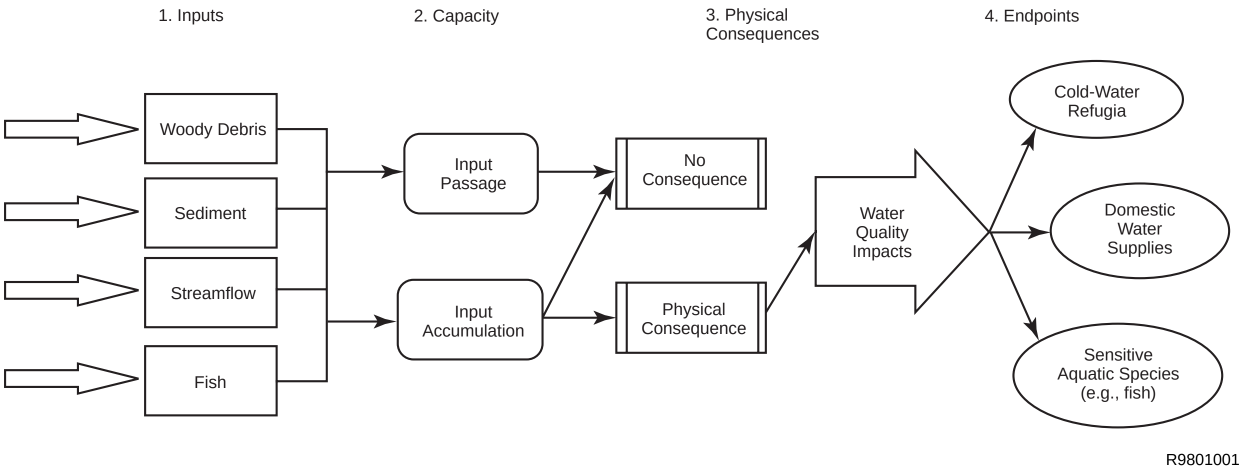

Figure 2—Road-stream crossing and cross drain environmental risk can be expressed as a four part model consisting of inputs—those materials delivered to the culvert; capacity—the ability of the structure to maintain the natural transport regime of the delivered inputs; physical consequences—the erosional and/or depositional consequences occurring when capacity is exceeded; and endpoints—potentially affected aquatic and riparian resources, human uses, and other values.

- *Capacity* is the ability of the culvert to pass the inputs.
- *Consequences* are the physical effects of capacity exceedance, often expressed as a volume of material eroded (or deposited).
- *Endpoints* are the valued resources. Some endpoints may be:
  - Fish or other species of concern
  - Domestic water supply
  - Aquatic species refugia value (e.g., cool waters in a warm water basin, access to spawning areas).

The hazard of a crossing failure is a combination of the inputs and the structure's capacity to accommodate them, which defines the probability of exceedence, and the potential physical consequences of exceedence. Capacity must be considered separately from the potential erosional consequences. In the absence of maintenance or replacement, all crossings will eventually fail. Therefore, it is imperative that potential erosional consequences not be ignored simply because capacity has been judged "sufficient." Alternately, a site with a very limited capacity may possess relatively little erosional hazard. Treatments to increase capacity at such a site may be impractical and ineffective in reducing the cumulative environmental risk of crossings (figure 3).

Environmental risk of a crossing is the combination of existing hazard and endpoints. Environmental risk assessment identifies the relative likelihood of a site adversely affecting one or more endpoints.

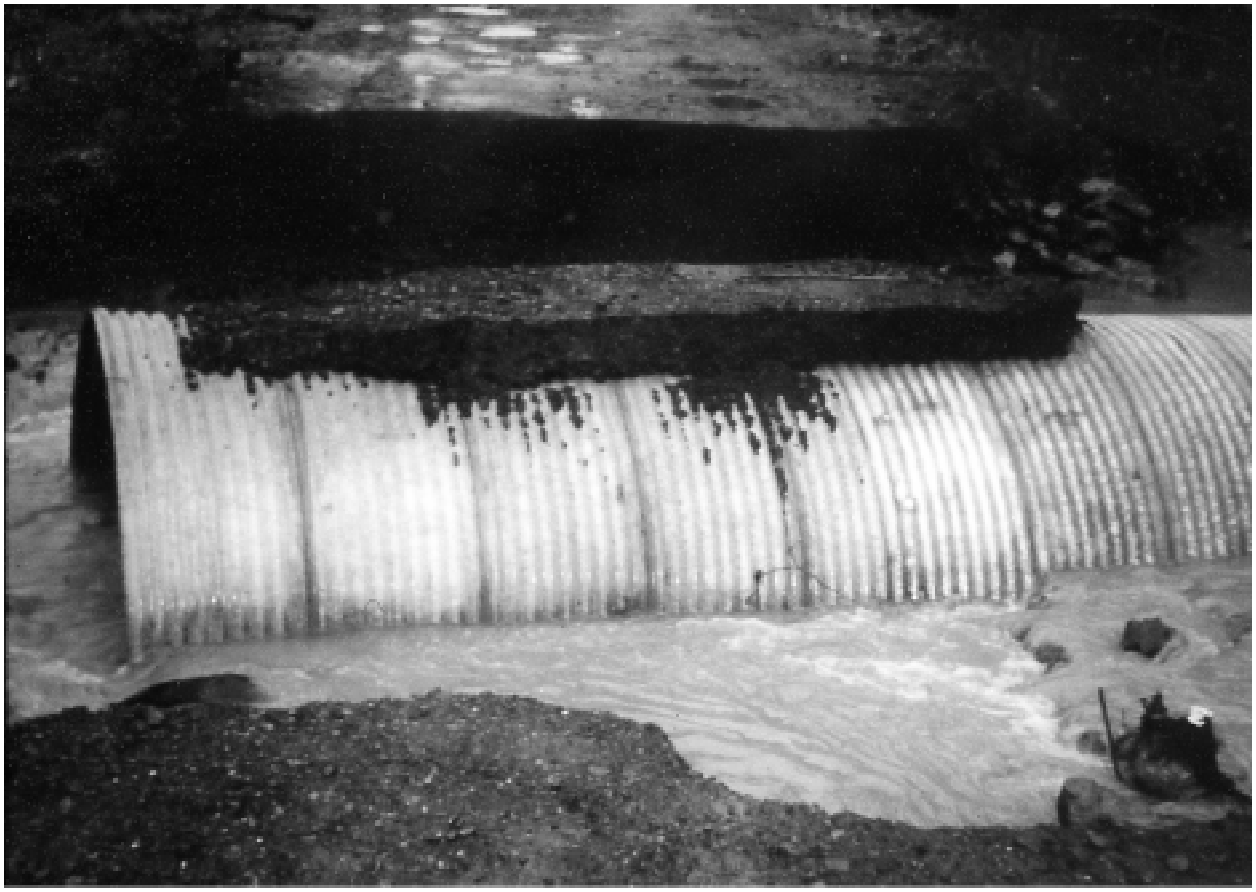

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Figure 3—The physical consequences of this road-stream crossing failure are low when compared to sites with much larger fills or where stream diversion occurs.

REVIEW OF EXISTING ROAD-STREAM CROSSING ASSESSMENT TECHNIQUES

Eight road-stream crossing assessment techniques are reviewed here. These were collected as part of a road-stream crossing questionnaire mailed to USDA Forest Service and USDI Bureau of Land Management engineers and hydrologists throughout the U.S. In the descriptions below, minor modifications were made to standardize the terminology with that used in this report. Techniques are summarized in table 1.

Table 1—Summary of existing drainage crossing assessment techniques reviewed in text.

Technique	Inputs	Capacity	Physical consequences	Endpoints	Diversion potential	Expertise required (H-M-L)	Comments
Umpqua N.F. Shockey (1996)	X	X	X	X		H	Diversion potential not explicit but can be incorporated into physical consequences
Umpqua N.F. Hanek (1996)	X	X	X		X	H	Drainages less than 0.4 km^2 are considered low effect
Siskiyou N.F. Weinhold (1996)	X	X	X			H	Determining failure potential requires engineering/geology skills
Payette N.F. Inglis et al. (1995)			X	X		M	Intermittent streams are excluded
Mt. Baker-Snoqualmie N.F. (1997)	X		X	X		M	A road segment assessment with crossings as one component
Huron-Manistee N.F. Stuber (1996)			X			L	Primarily assesses road surface erosion
Kennard (1994)	X	X	X			M	Significant features potentially lost in matrix
Stanislaus N.F. (1996)					X	L	A road segment approach with emphasis on road location and configuration

Broda and Shockey (1996) of the Umpqua National Forest use a “risk rating table” (table 2) to rank road-stream crossings on the Umpqua National Forest.

Using this approach, each crossing is assigned a score from 1 to 5. Factors considered in this approach are shown in table 2.

Hazards

- Hydrology/hydraulics—flows, culvert capacity
- Plugging potential—wood and debris (soil and rocks)
- Slope stability—channel slopes, road fill.

Physical consequences/endpoints

- Sediment delivery (amount)
- Resource damage—trees, fish, habitat (cost)
- Capital investment losses (cost).

Table 2—Umpqua NF risk rating table.

		Hazard		
		low	medium	high
Physical consequences/ endpoints	low	1	2	3
	medium	2	3	4
	high	3	4	5

Hanek (1996), also of the Umpqua National Forest, uses a similar approach (table 3). Factors considered in this approach in order of decreasing priority are:

Effects

- *High*
  - Large drainages (1.2 km^2+) with diversion potential
  - Medium drainages (0.4–1.2 km^2) with diversion potential.
- *Medium*
  - Large drainages without diversion potential but with larger fills (i.e., over 1.5 m from inlet invert to grade)
  - Medium drainages without diversion potential but with larger fills.
- *Low*
  - Everything else (i.e., large and medium drainages without diversion and small fills and all small drainages (<0.4 km^2).

Hazards

- Hydraulic capacity of the culvert and associated fill prior to overtopping or diversion (using 100-year design storm)
- Culvert plug potential
- Existing culvert condition
- Embankment stability under no-pool, full-pool, and half-pool conditions
- Diversion potential.

Table 3—Umpqua NF hazards versus effects approach.

		Effects		
		low	medium	high
Hazards	low	1	2	3
	medium	2	3	4
	high	3	4	5

An approach used by Weinhold (1996) of the Siskiyou National Forest involving potential eroded fill volume is shown in table 4.

Here, high failure potential is represented by an undersized culvert, evidence of past plugging by debris, and slope and channel having potential to generate debris flows.

Table 4—Siskiyou NF hazard rating table.

High Failure Potential	High Failure Potential	High Failure Potential
Volume > 150 m^3	Volume 40 to 150 m^3	Volume < 40 m^3
High Hazard	**High Hazard**	**Low Hazard**
Moderate Failure Potential	Moderate Failure Potential	Moderate Failure Potential
Volume > 150 m^3	Volume 40 to 150 m^3	Volume < 40 m^3
High Hazard	**Moderate Hazard**	**Low Hazard**
Low Failure Potential	Low Failure Potential	Low Failure Potential
Volume > 150 m^3	Volume 40 to 150 m^3	Volume < 40 m^3
Moderate Hazard	**Low Hazard**	**Low Hazard**

Stuber et al. (1994), working in the Huron-Manistee National Forest in Michigan, assigns each crossing a severity ranking based on a point system (table 5).

Scores over 30 points are placed in the severe category. Scores under 15 points are considered minor.

Table 5—Huron-Manistee NF point system.

Factors contributing to severity	Condition	Points
Road surface	Paved	0
	Gravel	3
	Sand and Gravel	6
	Sand	9
Length of approaches (total)	0–10 m	1
	10–300 m	3
	301–600 m	5
	> 600 m	7
Slope of approaches	0 %	0
	1–5 %	3
	6–10 %	6
	> 10 %	9
Width of road, shoulders, and ditches	< 5 m	0
	5–7 m	1
	> 7 m	2
Extent of erosion	Minor	1
	Moderate	3
	Extreme	5
Embankment slope	Bridges	0
	> 2:1 slope	1
	1.5–2:1	3
	Vertical or 1:1 slope	5
Stream depth	0–1 m	1
	> 1 m	2
Stream current	Slow	1
	Moderate	2
	Fast	3
Vegetative cover of shoulders and ditches	Heavy	1
	Partial	3
	None	5

The Mt. Baker-Snoqualmie National Forest (1997) uses a road segment approach where crossings are one component of the method (table 6). An effects of failure score (K) is a combination of sediment delivery and valued resources. It functions as a multiplier to the failure potential score.

Table 6—Mt. Baker-Snoqualmie NF road segment approach.

Potential for Failure (A-I)	(SUM A-I)	(Effects of Failure)		Risk Rating
A B C D E F G H I	J	(x) K*	=	(J * K)

* Note that effects of failure is a multliplier

A = Snow Zone: Location of road segment and contributing upslope area. Washington State rain-on-snow zones. Rain on Snow = 2; Rain or Snow Dominated = 1; Lowland = 0; Highland = 0.

B = Geology and soil stability: Percent of area occupied by road on unstable soils, highly eroded glacial, alluvial fan, or recessional outwash deposits and highly fractured and unstable base geology. Under 10 percent = 0; 10–30 percent = 2; 31–50 percent = 3; Over 50 percent = 5.

C = History of road associated failures from sources which have not been corrected: None = 0; Some = 1; Repeated = 2.

D = Major stream crossings: Number of large (>900 mm) or deep (>1 m over top of pipe inlet) culverts. None = 0; One = 1; More than one = 2

E = Number of stream channel crossings / 150 m of road: 0–1 = 0; 2 =1; 3+ = 2.

F = Method of construction: Generally, if constructed before 1970 assume sidecast excavation, if constructed after 1970 assume layer placement excavation. Full Bench = 0; Layer Placement = 1; Sidecast = 2.

G = Average sideslope where at road: Related to both potential and consequence, but used here to indicate potential for failure. Under 40 percent = 0; 40–60 percent = 2; Over 60 percent = 3.

H = Vegetative cover: Percent of area above the road segment (basically the contributing area) having a stand of over 35 years. Over 70 percent = 0; 50–70 percent = 1; 20–49 percent = 2; Under 20 percent = 3.

I = Road stacking: Road(s) upslope from this road? No road segments above = 0; the road is at a mid-slope location, or road segment above is on ridgetop = 1; One road segment above = 2; Two or more segments above = 3.

Determining K involves the use of a short dichotomous key (table 7). The score is based on the proximity of the road to streams, wetlands, infrastructure, or other valuable natural resources.

Table 7—K values for Mt. Baker-Snoqualmie NF road segment approach.

		Percent Sideslopes					
		< 20%		21 – 40%		> 40%	
	Distance to stream (m)	Int[a] Stream	Per[b] Stream	Int[a] Stream	Per[b] Stream	Int[a] Stream	Per[b] Stream
Bench or terrace between road & stream, wetlands, infrastructure, or other valuable resource.	N/A	1	1	1	1	1	1
No bench or terrace present between road & stream, wetlands, infrastructure, or other valuable resource.	< 15	1	2	2	3	3	4
	15 – 150	1	1	2	3	3	4
	150 – 300	1	1	2	2	2	3
	300 – 450	1	1	1	1	2	3
	> 450	1	1	1	1	1	2

a. Intermittent stream

b. Perennial stream

Inglis et al. (1995) of the Payette National Forest ranks the condition of stream crossings as either high, medium, or low. Crossings are rated high priority if three or more of the following criteria are met:

- The stream at the crossing is fish bearing;
- Road use is heavy;
- There is a chance of road loss at the crossing; or
- The culvert at the crossing is failing.

Medium priority crossings have to meet at least two of the following criteria:

- The stream at the crossing is nonfish bearing;
- Road use is low;
- There is little to no chance of road loss at the stream crossing, and
- The culvert at the crossing is not failing.

All other crossings needing work are listed as low priority.

The following matrix (table 8) is part of a larger road assessment package developed by Kennard (1994) for the Weyerhauser Corporation. A "weight of evidence" approach shown below is taken to assess the hazard from combinations of indicators.

Table 8—Weyerhauser Corporation weight of evidence approach.

	Indicators	Initiation hazard		
		Low	Medium	High
Hydrologic factors	Ponding	(0.5) < (HW/D)	(0.5) < (HW/D) ≤ (1.0)	(1.0) < (HW/D)
	Rust line	(1/3) < (R/D)	(1/3) ≤ (R/D) ≤ (1/2)	(1/2) < (R/D)
	Culvert size	(1) < (D/BMP)	(0.7) ≤ (D/BMP) ≤ (1)	(D/BMP) < (0.7)
	Culvert blockage	0%	> 0% to < 20%	≥ 20%
	Potential blockage	clean out > 30 m	clean out 15 to 30 m	clean out ≤ 15 m
Landuse and landscape factors	Channel gradient (low)	< 2 or ≥ 20 degrees	2 to < 20 degrees	*
	Upstream fill height	≤ 2 meters	2–5 meters	> 5 meters
	Fillslope surface gradient	< 25 degrees	25–35 degrees	> 35 degrees
	Channel width	40 meters < (CW)	40 ≤ (CW) ≤ 15	(CW) > 15 meters
	Entrenchment	(VD) < 2 (bfd)	(VD) ≥ 3 (bfd)	*
	Channel gradient (high)	< 20 degrees	20 to ≤ 30 degrees	> 30 degrees
	Maximum fill height	< 2 meter	2–5 meter	> 5 meters
	Fillslope surface gradient	< 25 degrees	25–35 degrees	>35 degrees
	Confinement	(VW/CW) > 2	2 ≥ (VW/CW) > 1	(VW/CW) = 1

The following are abbreviations used in the weight of evidence approach.

HW/D = Headwater depth (HW) to culvert diameter (D) ratio

R/D = Culvert rust line height (R) to culvert diameter (D) ratio

D/BMP = the ratio of the culvert diameter (D) to the estimated needed diameter (BMP). In this case, the estimated needed diameter is based on the 50-year flood.

CW = channel width

VD = valley depth

bfd = bankfull discharge

VW/CW = the ratio of valley width (VW) to channel width (CW).

* Not documented in the approach.

The road rating system used by the Stanislaus National Forest (1996) (table 9) addresses individual roads. Eight factors are scored and totaled.

Table 9—Stanislaus NF road rating system.

Factor	Score
1. Location	0 = road within 30 m of base of slope 1 = bottom 1/3 of slope 2 = middle 1/3 of slope 3 = top of slope.
2. Alignment	0 = 20 percent + grades 1 = grades 15–20 percent 2 = grades 10–15 percent 3 = grades < 10 percent.
3. Design	0 = diversion potential exists 1 = insloped, including berms 2 = outsloped 3 = paved.
4. Maintenance	1 = level 1 2 = level 2 3 = level 3+ drop rating one point for plugged culverts or blocked ditches.
5. Soils	1 = granitic 2 = volcanic 3 = meta-sed.
6. Topography	1 = slope 40 percent+ 2 = 30–40 percent slope 3 = slope <30 percent.
7. Hydrology	1 = rain on snow 900–1,500 m 2 = rain 3 = snow 1,500 m+.
8. Vegetation	0 = in burn area, below clear cut, or lavacap 1 = barren 2 = grasses / brush 3 = timber canopy.
Total Score:	<8 = high hazard 8–16 = warrants professional review >16 = OK.

SUGGESTIONS FOR INVENTORY AND ASSESSMENT

The road-drainage network can be inventoried at various intensity levels depending on objectives of the inventory and time and monetary constraints. A baseline inventory will, at a minimum, provide the locations of the installed drainage system. At the other end of the spectrum is a complete crossing environmental risk assessment that addresses all the components displayed in figure 2. Four increasingly intensive levels of inventory and assessment are presented here. These suggested inventory techniques are synthesized from the review of existing techniques presented in the previous section and other studies examining the performance of road-stream crossings.

- **Consequences inventory**—This approach is designed to locate and document the installed system and identify the occurrence of diversion potential over the area of inventory. This is the quickest inventory technique. Because remediation of diversion potential is often inexpensive and straightforward, it is meant to identify sites where large erosional consequences can be easily minimized.
- **Connectivity/cross drain inventory**—This inventory procedure determines the amount of road hydrologically connected to the natural channel network. It is meant to 1) identify areas of chronic erosion where sediment is being delivered directly to stream channels and 2) identify opportunities to reduce sediment impacts to aquatic ecosystems by "disconnecting" roads from streams.
- **Hazard assessment**—This approach addresses the likelihood and potential erosional volume of crossing failure based on a more extensive data collection effort.
- **Environmental risk assessment**—Building on the results produced from a hazard assessment, resources of concern (endpoints) are incorporated to locate sites with the greatest probability of impacting those resources.

A summary of these data fields is presented in table 10 for the four levels of inventory. For cross drains, a smaller data set is suggested (table 10). Note that these data sets can be tailored to suit specific needs and satisfy time and financial constraints.

Materials Required

All that is required for a consequences inventory is a tape for measuring culvert diameter and a means of locating the site (e.g., topographic map or aerial photo).

For a more intensive hazard or environmental risk assessment, a clinometer or hand level and stadia rod is required for obtaining fill slopes and culvert slopes. A range-finder is useful for obtaining potential diversion distances or for very large fills.

The drainage area is most easily determined if the site is located on a topographic map. Locating the site on aerial photos should also be done to facilitate potential geographic information system (GIS) applications. Site location can also be accomplished with a global positioning system (GPS), and this approach is discussed on page 18.

Table 10—Summary of suggested data fields for various levels of road-stream crossing and cross drain inventory and assessment.

Feature	Description/example entries	Consequences inventory	Hazard assessment	Environmental risk assessment	Connectivity/cross drain inventory
Site number	Road i.d. number odometer reading GPS coordinates	X	X	X	X
Crossing Type	Stream crossing cross drain other drainage feature	X	X	X	X
Crossing inputs					
Channel type	perennial intermittent unchanneled swale inboard ditch	X	X	X	
Mean annual precipitation	The user should determine the variables needed to calculate design flows for the area. Typically, mean annual precipitation is used in regional regression equations.		X	X	
Drainage area	Not all sites will have a definable drainage area.		X	X	
Channel width	Measure the width from bottom of bank to bottom of bank. Three measurements can be taken to get an average width. The smallest swales will often have no definable channel.		X	X	
Channel slope	Taken above the influence of the culvert inlet.		X	X	

Table 10—Continued.

Feature	Description/example entries	Consequences inventory	Hazard assessment	Environmental risk assessment	Connectivity/cross drain inventory
Upslope roads	Failure of upslope roads can contribute to failure at downstream sites.		X	X	
Contributing ditch length(s)	This is useful for estimating channel network extension (Wemple 1994) in the inventory area. Cross drains should have only one contributing ditch. Note that hydrologic connectivity at cross drains is addressed in the consequences section below.		X	X	X
Ditch slope	Coupled with ditch length, ditch slope provides an estimate of the transport capacity of the ditch.				X
Culvert capacity					
Culvert type	corrugated metal concrete pipe concrete box pipe arch bottomless pipe arch corrugated plastic	X	X	X	X
Entrance type	projecting mitered flush in headwall beveled inlet side tapered inlet drop inlet	X	X	X	X
Culvert diameter	This will require two measurements for box culverts and pipe arches.	X	X	X	X
Percent dent/crush	Percent of inlet cross sectional area reduced.		X	X	X

Table 10—Continued.

Feature	Description/example entries	Consequences inventory	Hazard assessment	Environmental risk assessment	Connectivity/cross drain inventory
Culvert slope	Note downspouts, etc.		X	X	X
Culvert skew angle	Angle at which culvert is oriented to channel.		X	X	
Outlet drop	This is for sites with fish passage concerns.		X	X	
Outlet pool depth	This is for sites with fish passage concerns.		X	X	
Potential erosional consequences					
Flood-prone channel width (W_c)	Record the width of fill material at the base of the fill corresponding to the expected peak flow width. Refer to figure 10.		X	X	X
Upstream and downstream fill slopes (S_u and S_d)	Refer to figure 10.		X	X	X
Upstream and downstream fill slope lengths (L_u and L_d)	Refer to figure 10.		X	X	X
Road width (W_r)	Refer to figure 10.		X	X	X
Fill width (W_r)	This is an average between the upstream and downstream edges of fill (taken from the centerline of the road). Refer to figure 10.		X	X	X

Table 10—Continued.

Feature	Description/example entries	Consequences inventory	Hazard assessment	Environmental risk assessment	Connectivity/cross drain inventory
Diversion distance	The distance the diverted flows will travel before entering a channel. Crossings that would not divert water and would only overtop the fill are given a value of zero. On low gradient roads, the flow path(s) may be difficult to discern.	X	X	X	X
Receiving feature	This is the point where the diverted water leaves the road surface or ditch. Examples are: adjacent crossing (record site number) and hillslope (note if water flows onto unstable slope).	X	X	X	X
Road slope through crossing	Where diversion potential exists, this is a useful measurement for dip design.	X	X	X	X
Hydrologically connected?	Determine whether the cross drain or other nonstream crossing feature delivers material to a channel by either a gully or plume.				X
Length of channel below outlet (for cross drains only)	This is useful for determining channel network extension due to roads (Wemple 1994). If the cross drain has created a channel that is hydrologically connected to the stream network, record the length. The average cross sectional area may also be obtained to calculate an eroded volume.				X
Geology	This field may be completed using existing maps. Where possible, geology should be stratified by erosion hazard.		X	X	X

Table 10—Continued.

Feature	Description/example entries	Consequences inventory	Hazard assessment	Environmental risk assessment	Connectivity/cross drain inventory
Potentially affected endpoints	*NOTE: Endpoints will vary. Interdisciplinary input is required to identify the endpoints of concern. The following are suggestions.*				
Fish at site (or other aquatic or riparian species of concern)	Where a sensitive fish species occurs at a site, a fish passage assessment should be conducted.			X	
Fish in basin (or other aquatic or riparian species of concern)	If a particular subdrainage within the assessment area is judged to have relatively higher aquatic ecosystem values, those crossings are noted.			X	
Domestic water supply	If domestic water supply exists, those crossings that could impair the supply are noted.			X	
Refuge area	If area has refuge value for aquatic and/or riparian dependent species (e.g., cold water), those crossing are noted.			X	
Planning area	If management or restoration efforts are concentrated in an area, adding extra weight to sites within these areas would help to guide further efforts.			X	

Time Required

The time required for the various levels of inventory and analysis will vary depending on the access, frequency of drainage structures, and method of data collection (i.e., use of a global positioning system, which is discussed in the next section). Estimates presented in table 11 assume vehicular access, an automated data logger, and a GPS.

Using a Global Positioning System for Crossing Inventory

The advantages of using a GPS include:

- Accurate location of drainage structures on unmapped or poorly mapped roads
- Site information directly input to a data logger without having to transfer the information later
- GPS points and associated data can go straight into a GIS.

The disadvantages include:

- Cost of equipment
- Less than complete reliability of equipment
- Potential for operator error
- Subject to satellite availability which can be affected by timing, canopy, and topography
- Need for specialized training of personnel in field use, data reduction, and analysis.

A crossing inventory can be conducted with or without the use of a GPS. The crossings must be accurately located so that the true drainage area can be calculated. This can be aided by using GPS although it is still worthwhile to have the location plotted on a topographic map and an air photo as backup and confirmation. If a GPS is not available, the topographic map and air photo should be sufficient to locate the crossing. Unfortunately some roads are not shown on topographic maps or are only approximately located. Without a GPS, this situation is probably best addressed by plotting the location on an air photo and transferring that point onto an orthophoto or a digital orthoquad.

DATA ANALYSIS AND INTERPRETATION

Using a Geographic Information System in Crossing Assessment

The advantages of using a GIS for a crossing assessment include:

- The ability to combine crossing information with other coverages for analysis and display
- Ease of updating the information as upgrades, decommissions, and failures occur
- Calculation of the contributing basin area for the crossing by using scanned contour lines to draw the area on-screen
- Sharing of information, which can be enhanced by the transfer of electronic data.

The primary disadvantage is that GIS experience is required to manipulate the data.

Once the crossing locations (points), drainage areas (polygons), and associated information (attributes) are in a GIS system, they are much

Table 11—Examples of time requirements for various inventories. Production rate assumes five crossings per mile. Analysis time assumes data for up to several hundred crossings have been collected.

Inventory type	Time per crossing (minutes)	Production rate (miles of road/day)	Analysis time required (days)
Connectivity inventory	7	10	15
Consequences inventory	5	12	20
Hazard assessment	15	6	25
Environmental risk assessment	15	6	26

easier to compare spatially. The crossing points can have additional attributes added from existing polygon coverages such as: bedrock geology, geomorphology, hillslope gradient, slope position, soils, vegetation, and precipitation. These attributes may be useful in predicting the characteristics of crossings that have not yet been inventoried. Crossings can be checked for spatial accuracy on-screen using digital orthoquads or by comparing the crossing locations to road-stream or road-crenulation (the declivity where a channel may occur as expressed by contour lines) intersections. The crossing locations and attributes such as the hazard rating can be plotted in combination with other coverages like roads, crenulation, and slope position to show where the crossings are located in relation to these features. This can be useful for spatially analyzing the information. For instance, a plot may indicate that most of the higher hazard crossings are located in lower slope positions on certain geologic types in a specific portion of a watershed. On the other hand, a higher slope position on a different geologic type may have very few crossings, with those being low hazard.

Calculating Hydraulic Capacity

The hydraulic capacity of a culvert is the design flow it can accommodate at a specified headwater depth (the depth of water at the inlet with respect to the base of the culvert inlet). Capacity can be determined from nomographs presented in Normann et al. (1985) for a given headwater depth. For dented inlets, the diameter should be adjusted accordingly. Piehl et al. (1988a) used an equation to approximate the nomograph for inlet controlled, circular, and corrugated metal culverts.

With this equation, data can be taken from the inventory, transferred into a computer spreadsheet, and culvert capacities rapidly computed. If hydrologic data are collected for each site, flows for various recurrence intervals can be used to construct a flood frequency curve. This can be used to express culvert hydraulic capacity as an exceedence probability or a recurrence interval (T) (figures 4 and 5). This method is not applicable to cross drains or small drainages where the drainage area cannot be accurately delineated. For relatively large culverts in small drainages, calculation and extrapolation may produce unreasonably large recurrence intervals (or, improbably small exceedence probabilities). For convention, hydraulic capacity has a maximum value of $T = 250$ years ($p = 0.004$).

Caution must be exercised when interpreting the results. Discharges will vary depending on the method used to estimate peak flows, and the error for individual design flow estimates can be large. However, if considered as a *relative ranking* for all the road-stream crossings in an assessment area, the results can suggest possible high priority sites based on probability of exceedence. Because hydraulic exceedence may not be the principal mechanism of crossing failure (figure 5), hydraulic capacity assessment should be assumed to represent a minimum screening level for hazard assessment. If the culvert cannot pass the design peak flow, it is likely that associated debris and sediment cannot be passed either.

Increasing culvert hydraulic capacity typically requires either increasing pipe size or adding culverts or end treatments such as side tapered inlets (refer to AISI 1994 for a listing of end treatments).

Woody Debris Capacity

Plugging of culverts by organic debris is a common failure mechanism. Debris lodged at the culvert inlet reduces hydraulic capacity and promotes further plugging by organic debris and sediment. Sediment accumulation is often deemed the cause of failure. However, when excavated, one or more pieces of wood are often discovered to be the initiating mechanism. Furthermore, plugging may not depend on the transport of large debris. The length of pieces initiating plugging can be small limbs and twigs, readily transported by frequently occurring storms (Flanagan in review). Pieces initiating plugging are often not much longer than the culvert diameter (figure 6).

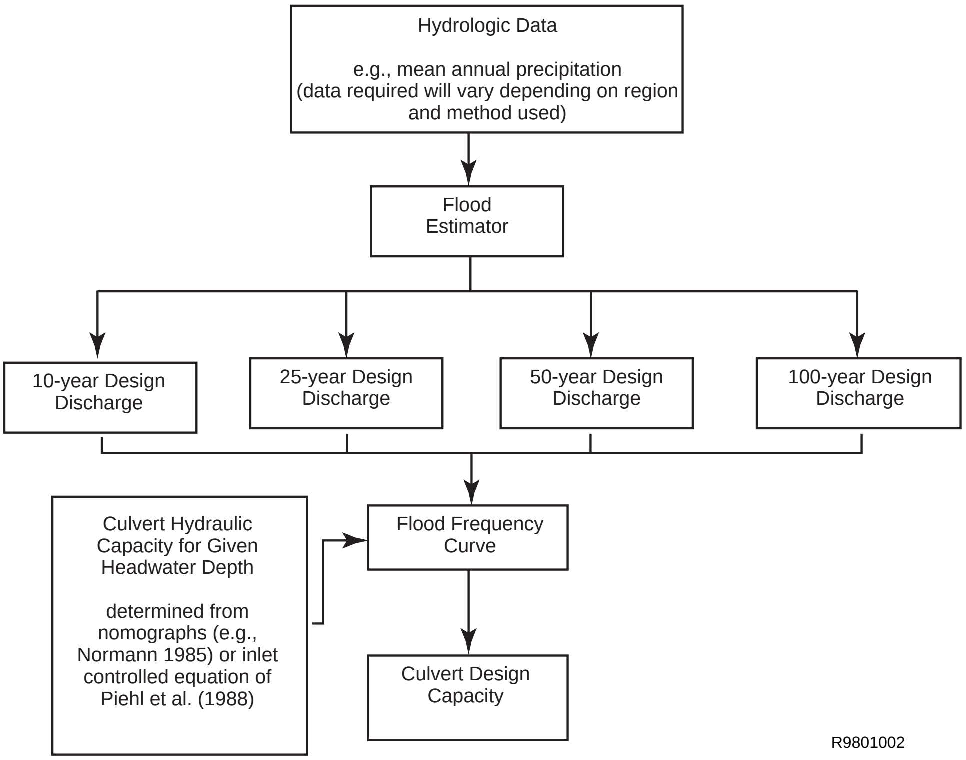


Figure 4. Determining the design storm capacity of existing culvert installations requires the use of a flood estimator and the hydraulic capacity of the culvert adjusted for any denting or crushing of the inlet. Using an equation presented by Piehl et al. (1988), this procedure is easily automated in a spreadsheet or similar application to assess a large number of culverts. Refer also to figure 5.

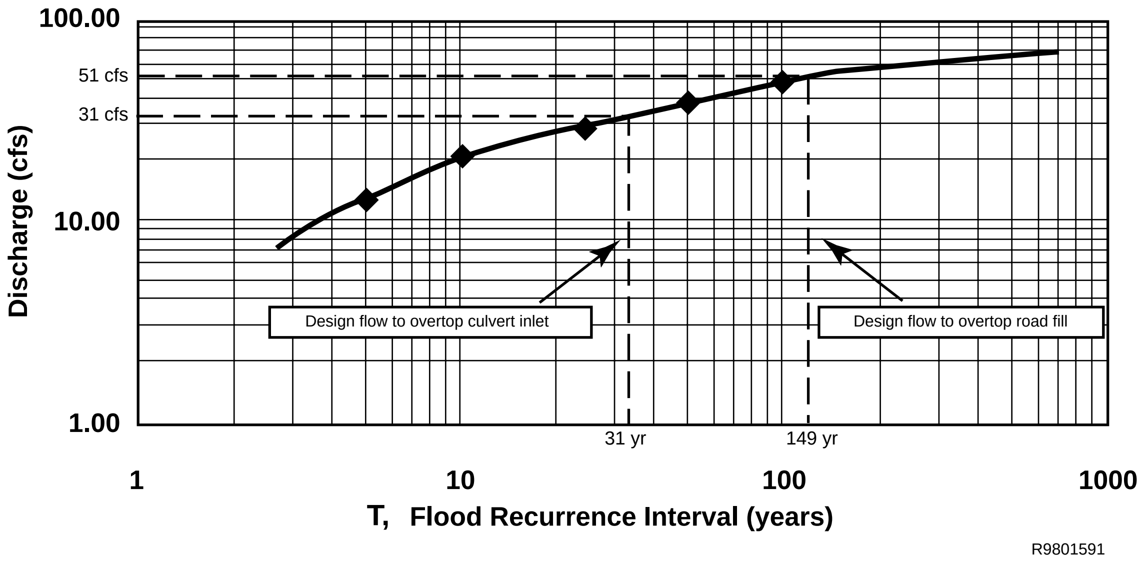


Figure 5. Culvert hydraulic capacity can be expressed as a recurrence interval (T). In this example, two design discharges are calculated for a 900-mm culvert. The discharge at HW/D = 1 is assigned a recurrence interval of 31 years (exceedence probability = 0.032). The discharge necessary to overtop the road (in this case, the fill height above the inlet invert is 1.5 m) is assigned a recurrence interval of 149 years (exceedence probability = 0.0067). This example flood frequency curve was generated using a regional flood estimator for northwest California (Waananen and Crippen 1978).

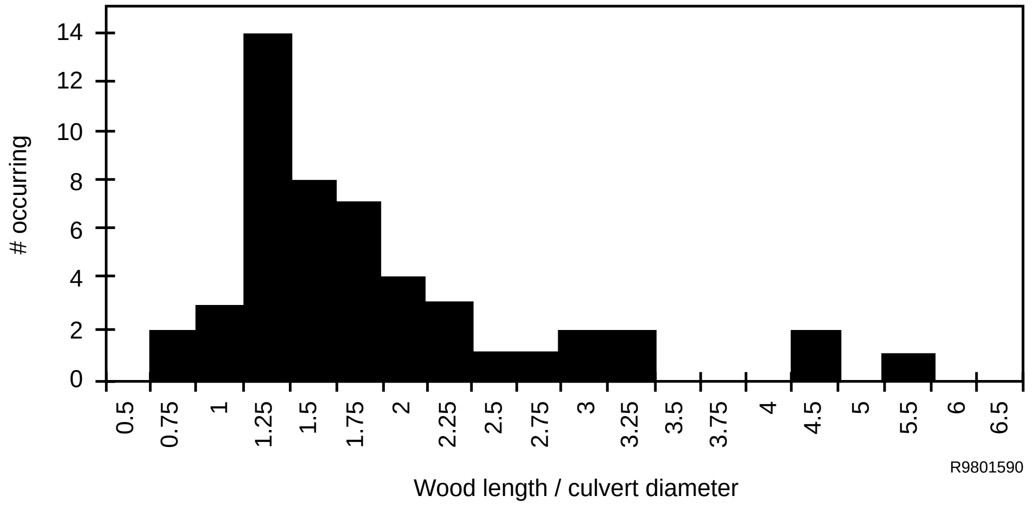


Figure 6—Woody debris lodged at culvert inlets is often only slightly longer than the culvert diameter. Note that wood length is expressed as a ratio to culvert diameter (n=50).

Stream channel width influences the size distribution of transported woody debris (e.g., Lienkaemper and Swanson 1987, Nakamura and Swanson 1994, Braudrick et al. 1997). In low-order channels of northwest California, 99 percent of transported wood greater than 300 mm long was less than the channel width (Flanagan in review). These findings suggest that culverts sized equal to the channel width will pass a significant portion of potentially pluggable wood. However, the remaining 1 percent of the pieces remain a hazard. Thus, wood plugging hazard can be reduced, but not eliminated. The woody debris capacity of a crossing can be assessed by taking the ratio of the culvert diameter to the channel width (w*). Crossings with low values of w* are more prone to debris plugging. Using the northwest California coast region as an example, sizing culverts equal to the channel width will, in most cases, satisfy a 100-year design peak flow (figure 7). However, on wider channels (e.g., >2 m), the cost of employing this strategy can be prohibitive.

The configuration of the inlet basin will also influence wood plugging. Inlet basin design should strive to maintain the preexisting channel cross section, planform, and stream gradient. Channel widening upstream of the inlet is typically undesirable (figure 8). During ponded conditions ($HW/D \geq 1$), debris in transport accumulates in the eddies formed by the widened channel. Piece rotation in the eddies promotes a perpendicular alignment to the culvert inlet. Furthermore, when the inlet is fully submerged, wood accumulates in the pond. When the inlet is reexposed, it is often presented an enormous, often interlocking, raft of debris (figure 9).

Channel approach angle, or culvert skew, also influences debris lodgment (figure 8). Where the channel enters the culvert at an angle, debris lodgment is increased (Weaver and Hagans 1994). During runoff events, wood in transport cannot rotate parallel to the culvert and pass through. Cross drains are susceptible to this because they often possess high approach angles (Garland 1983 and Piehl et al. 1988b).

Sediment Capacity

Three types of sediment inputs are discussed here: fluvial transport, sediment “slugs,” and debris flows (a viscous, flowing mass of water, sediment, and woody debris).

In general, culverts are efficient conveyors of sediment because of their narrow and relatively smooth, uniform cross section. Fluvially transported sediments generally present little

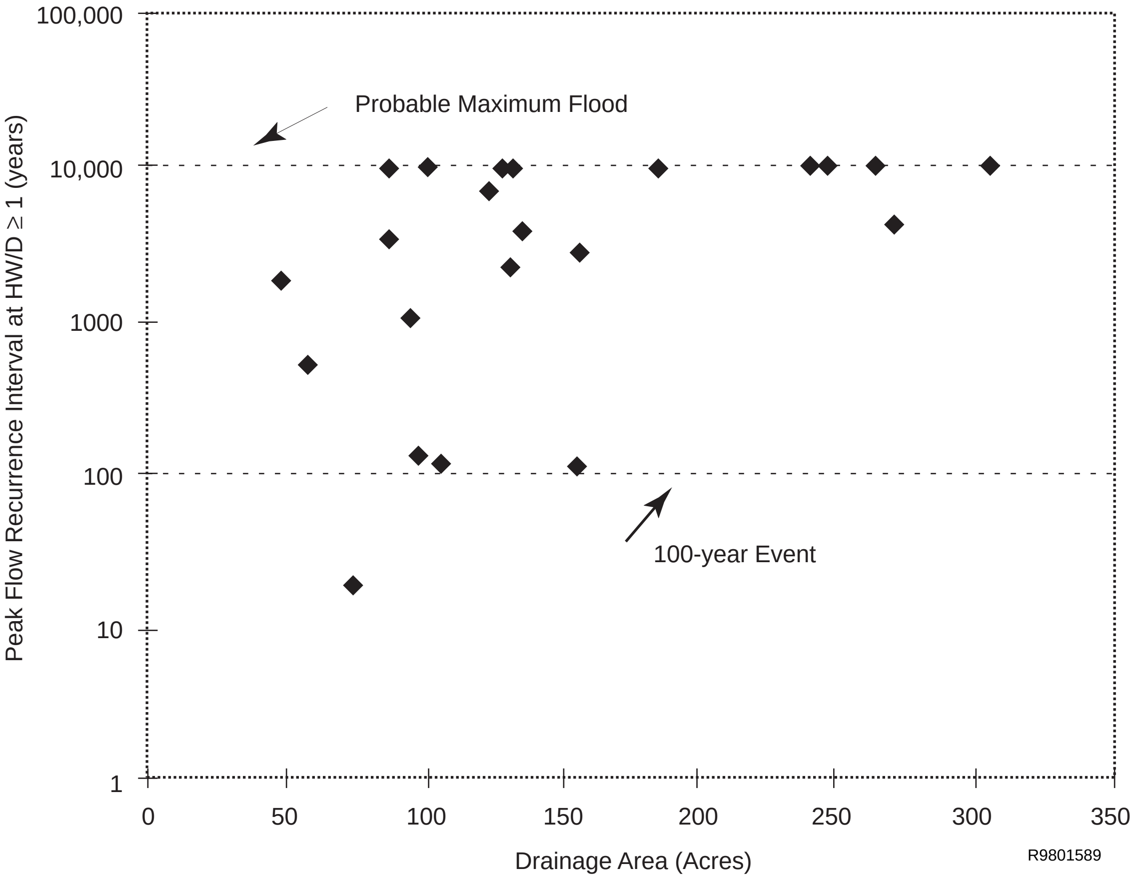


Figure 7—Hydraulic capacity (expressed as a recurrence interval) of 22 culverts with diameters equal to the channel width. Such a strategy to facilitate woody debris passage must be weighed with the costs of installing a large culvert on a wide channel. Costs are of less concern on smaller channels. Inlet modifications to promote passage can reduce the need for large culvert diameters. Data are from northwestern California.

hazard to stream crossing installations. Burial of the inlet by fluvially transported sediment is often the result of woody debris lodged at the inlet. Thus, sediment deposition is often a consequence, not a cause, of the failure. In designing and assessing culverts, thought must be given to the maximum particle sizes potentially mobilized during peak flows and ensuring sufficient diameter and slope to pass the load. In order to pass sediment, culverts should be set at a grade related to the stream channel (Weaver and Hagans 1994). An index value for sediment plugging hazard is the ratio of culvert slope to channel slope (**s***). This assumes relatively flat culverts on steep channels are more prone to sediment accumulations than steeper culverts.

Rapid, more catastrophic inputs of sediment (“sediment slugs”) are typically responsible for sediment-caused failure. Small failures from oversteepened cutslopes near the inlet may bury the entrances of cross drains and small stream crossings. Small culverts with relatively small inlet basins adjacent to steep cutslopes are most prone to this. However, predicting where such failures are likely to occur is difficult. If evidence suggests that failure of adjacent slopes is likely, the site should be noted for further inspection. During the design phase, inlets should be located away from unstable cut slopes. Enlarging the inlet basin to capture debris is an option. But, it should be implemented where no other treatment is possible because enlarged basins may alter stream hydraulics and promote woody debris and sediment deposition.

Assessment of debris flow hazard is difficult. Morphometric characteristics of debris flows and

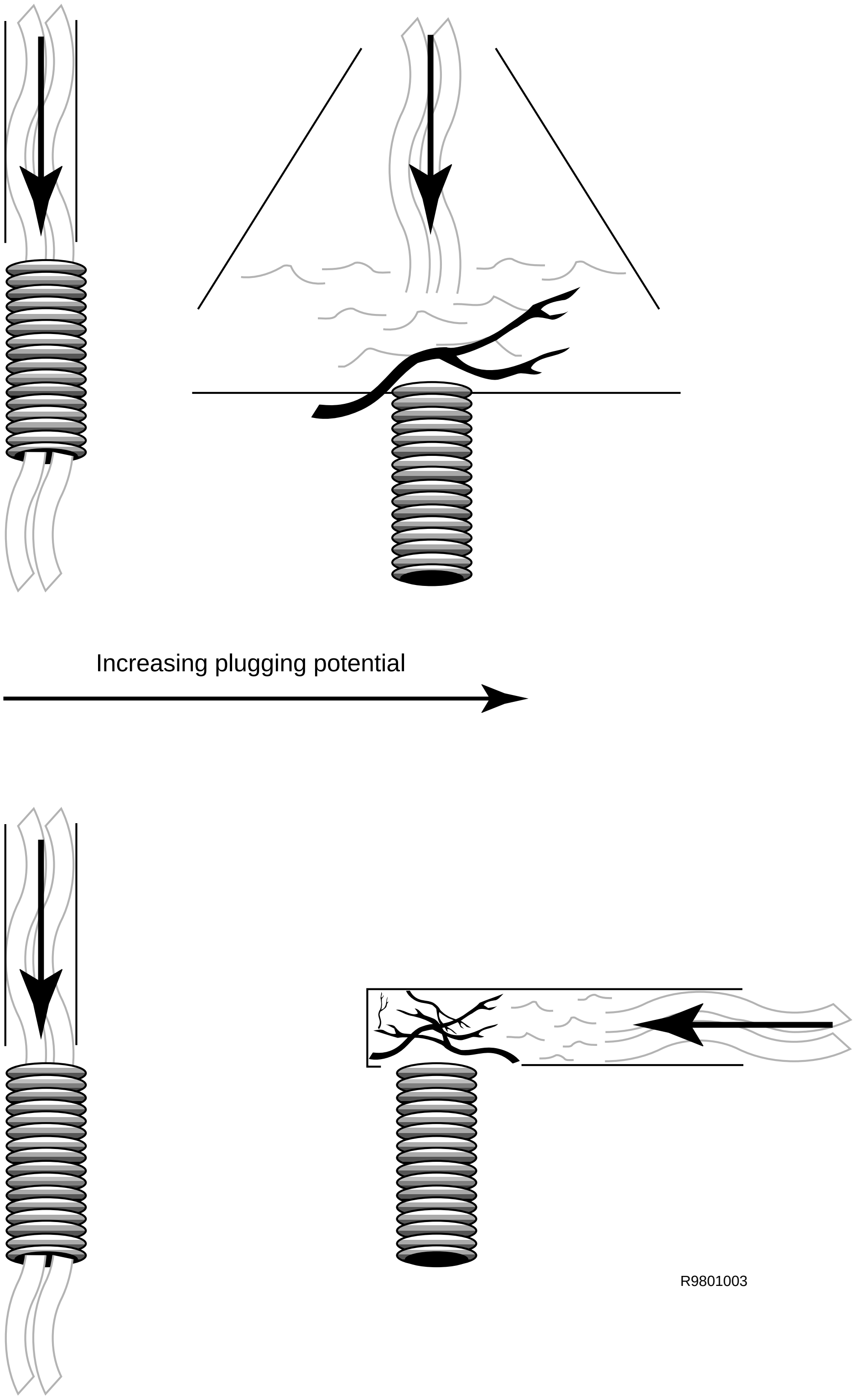


Figure 8—Inlet basin plan view. Inlet basins that maintain the natural channel configuration promote debris transport and passage through the culvert. Where the flow is allowed to spread laterally, debris can accumulate and increase the chance of plugging. Furthermore, debris rotation is promoted in the turbulent eddies of the widening flow. Similarly, where the channel abruptly changes direction, wood lodgment is enhanced. This is a common configuration for cross drains.

R9801008

Figure 9—In areas where woody debris is entrained in streamflow, crossings that pond water will pose a greater chance of plugging than crossings that do not pond water. Wood accumulates in the ponded area and plugging is likely when flows drop and expose the inlet to the mass of debris.

initiation areas are discussed by Costa and Jarret (1981) and Benda (1990). Debris flow hazard can be estimated from aerial photographs, digital terrain data, and evidence at the site (e.g., Chatwin et al. 1994). Debris flows interact with road-stream crossing fill prisms either by removing the fill or impounding against the fill. Fill volumes should be reduced to minimize replacement or excavation costs. Vented fords can be an effective solution for handling debris flows by minimizing the intervention in natural stream processes that the road fill presents. Another alternative is "hardening" the fill to minimize the chance of fill washout.

Erosional Consequences

When crossing capacity is exceeded, water, debris, and sediment accumulate in the inlet basin. If capacity exceedence is of sufficient magnitude, overtopping of the fill will occur with associated erosional consequences. Estimating the potential erosional consequences is relatively straightforward. The path the overflowing water takes during capacity exceedence will affect the magnitude of consequences. Erosion from flows that overtop the fill and reenter the channel near the outlet is constrained by the amount of road fill material spanning the channel. Calculating fill volume is discussed below. Where the road slopes away from the crossing in at least one direction, overtopping flows can be diverted out of the channel and away from the site via the road or ditch (figure 10). Recognizing diversion potential is important; large volumes of material may be eroded as flows enlarge the inboard ditch, overwhelm adjacent crossings, enlarge receiving channels and/or flow onto hillslopes unaccustomed to concentrated overland flows. For a more complete discussion of diversion potential refer to the companion document in this series, "Diversion Potential at Road-Stream Crossings" (Furniss et al. 1997).

R9801592

Figure 10—Diversion of streamflows at stream crossings can have large erosional consequences far removed from the initial failure site. Here water diverted along the inboard ditch for several hundred meters initiated additional crossing failures along the way. Photo courtesy of the Siskiyou National Forest.

Estimating Fill Volume

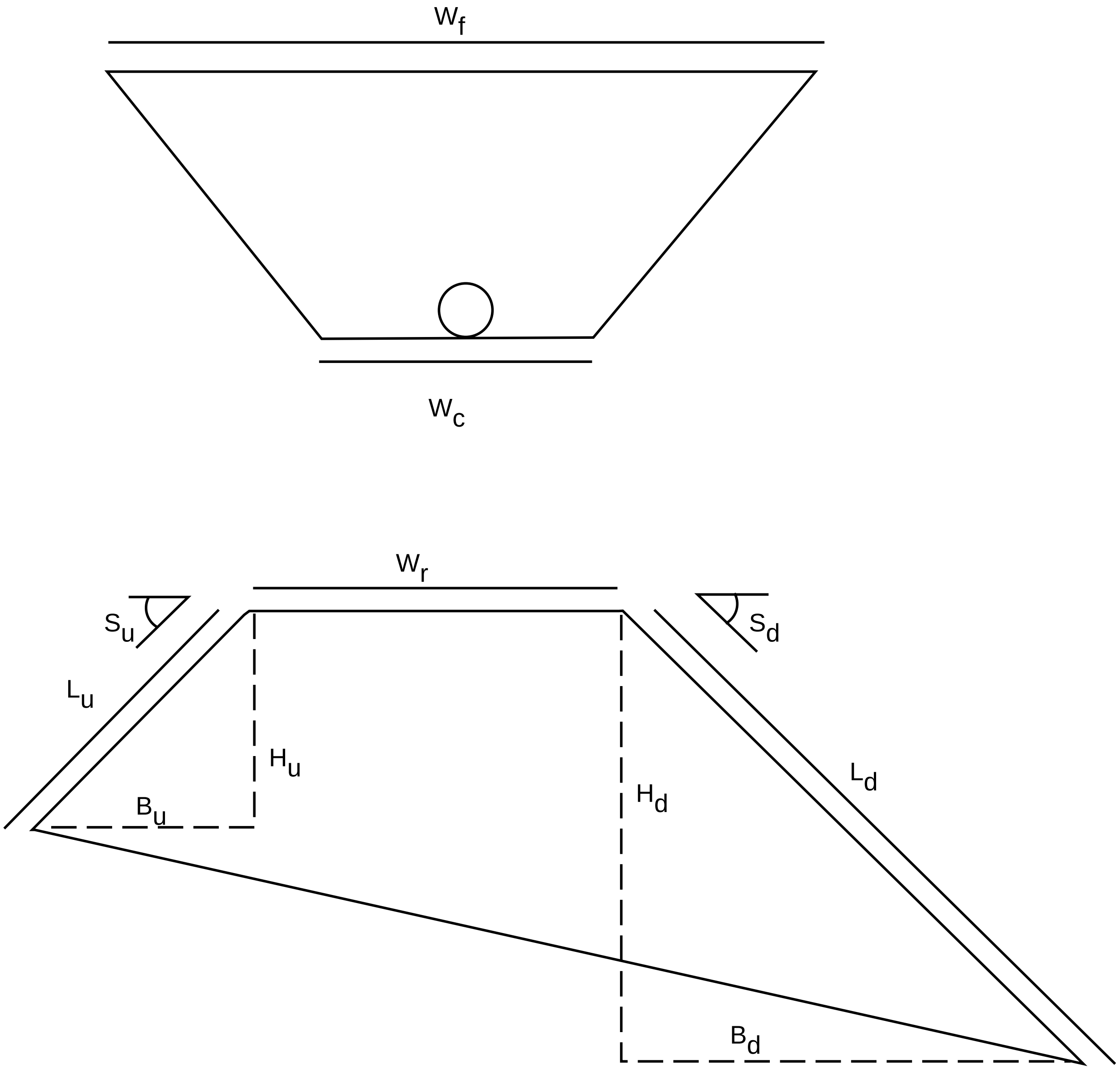
Fill volume calculations are required for hazard assessments and environmental risk assessments. The procedure described here for calculating fill volume is to be used only to estimate the quantity of potentially erodible material or the amount of material to be excavated for treatment. Crossing failure is assumed to remove the entire fill prism, and an approximation of this value is used for assessing erosional consequences. The method presented here should not be used for contract specifications where more detailed surveys are required. This volume is intended to be an estimate to help with comparisons among sites. This method does not include the potentially erodible aggraded stream reach upstream of crossings set above grade or the volumes associated with offsite impacts should the crossing fail. Further, the single measurement of fill width (W_f) along the road centerline will often overestimate the upstream portion of the fill (V_C) and underestimate the downstream portion (V_d). A more accurate volume can be calculated if the fill width is taken at both the inboard and outboard edge of the road. The average of these two measurements is used for calculating the volume under the road surface (V_r).

The following measurements are taken to calculate fill volume (see figure 11):

W_f = Width of the fill along the road centerline and perpendicular to the culvert axis

W_c = Width of flood prone channel

L_u = Fill slope length from inboard edge of road to inlet invert



R9801004

Figure 11—Crossing fill measurements—Solid lines are measured values, dashed lines are calculated. Note that L_d often extends below the culvert outlet. The method presented here is intended for estimating fill volume. Some underestimation will occur on the downstream side while the inlet portion will be overestimated.

S_u = Slope of L_u (in degrees). If field data are collected in percent, conversion to degrees is accomplished using the arc tangent function.

The subscript "d" in the following equations refers to the above measurements taken on the downstream portion of the road fill.

(1) Upstream prism volume (V_u):

$$V_u = 0.25(W_f + W_c)(L_u \cos S_u)(L_u \sin S_u)$$

(2) Downstream prism volume (V_d):

$$V_d = 0.25(W_f + W_c)(L_d \cos S_d)(L_d \sin S_d)$$

(3) Volume under road surface (V_r):

$$V_r = \left(\frac{Hu + Hd}{2}\right)\left(\frac{Wf + Wc}{2}\right) W_r$$

where:

$$H_u = L_u \sin S_u$$

and

$$H_d = L_d \sin S_d$$

(4) Total fill volume (V):

$$V = V_u + V_d + V_r$$

HYDROLOGIC CONNECTIVITY—ASSESSING CHRONIC EROSION POTENTIAL

Cross drains represent a special case for erosional consequences. In addition to being subjected to the inputs discussed above, cross drains concentrate water draining from the road surface and intercept groundwater at the cut slope. This water is often conveyed to unchanneled hillslopes where a gully may form. This newly formed channel may connect to the natural channel network, extend it, and contribute road-derived sediment and additional surface runoff to the aquatic ecosystem. During the inventory process, cross drains with gullies or sediment plumes extending to a natural channel should be documented for possible treatment.

Length of road segments connected to the natural channel network are summed, and the proportion of the road network hydrologically connected is determined. Individual roads with high connectivity can be targeted for "disconnecting" by the appropriate treatment (e.g., grade dips or outsloping).

Channel network extension because of roads can also be calculated if the ditch length and road-caused gully/plume extent below the road is known. The proportional extension of the drainage network may be used to locate areas where the natural hydrologic regime is most affected.

Assessment Procedure

Assessments may proceed once the inventory and the calculations required for the level of inventory are complete. Techniques for each level of inventory are described below.

Connectivity/cross drain inventory

Results of a connectivity inventory will be a list of road segments hydrologically connected to the channel network. This level of inventory does not prioritize segments. Treatments to "disconnect" individual road segments will be based on availability of funds and transportation needs.

Consequences inventory

The primary product of a consequences inventory will be a list of sites with diversion potential. Treatments to eliminate diversion potential will be based on availability of funds and transportation needs. Further prioritization of sites can be based on potential length of diversion and receiving feature.

Hazard assessment

For hazard assessment, sites are assigned a hazard score based on several hazard elements. If data have been compiled into a spreadsheet or database structure, sorting on each of the elements or using an *if-then* command, can be performed to easily assign scores. The scoring system suggested below is meant to provide a flexible means of evaluating crossings. The user can adjust scores and add other factors to suit the needs of the inventory.

Hazard Score = Inputs + Capacity + Consequences

The inputs and capacity scoring elements are:

- T—an expression of hydraulic capacity (lowest T values are the greatest hazard)
    - T < 10 years: 3
    - T 10–100 years: 2
    - T > 100 years: 1
    - Site does not have definable drainage area or is an unchanneled swale: 0
- w*—an expression of woody debris capacity—culvert diameter/width of channel (lowest values are greatest hazard)
    - w* < 0.5: 3
    - w* 0.5–1.0: 2
    - w* > 1.0: 1
    - No definable channel: 0
- Skew angle—additional factor for debris capacity
    - Site with definable channel *and* skew angle > 45 degrees: 1
    - Site with no definable channel *or* skew angle ≤ 45 degrees: 0
- s* (slope of culvert/slope of channel)—may be used to assess the ability of the culvert to transport sediment (lowest values are highest hazard)
    - s* < 0.3: 2
    - s* 0.3–0.6: 1
    - s* > 0.6: 0
- R—if upslope roads are present
    - Upslope roads are present: 1
    - If no roads are present upslope: 0.

For consequence scores, crossings with stream diversion potential take priority over nondiversion potential culverts, because stream diversion typically results in much greater eroded volumes.

- Diversion distance (highest values are greatest hazard)
    - Distance > 300 m: 5
    - Distance 100–300 m: 3
    - Distance 50–100 m: 2
    - Distance < 50 m: 1
    - No diversion potential: 0
- Diversion onto unstable receiving feature (predetermined categories from existing data, e.g., earthflow, over-steepened sidecast)
    - Diversion onto unstable landform (may be same as unstable geology described below): 3
    - Diversion onto sidecast fill: 2
    - Diversion onto valley floor: 1
- Fill volume (largest volumes are greatest hazard)
    - Volume > 1000 m^3: 4
    - Volume 500–1000 m^3: 3
    - Volume 100–500 m^3: 2
    - Volume < 100 m^3: 1
- Unstable geology (predetermined categories from existing geologic data)
    - Site is located in unstable terrain: 3
    - Site is located in moderately unstable terrain (where applicable): 2
    - Site is located in relatively stable terrain: 0
- Hydrologically connected
    - Site is a road-stream crossing or a cross drain that is hydrologically connected to the drainage network: 1
    - Site is a cross drain that is not connected to the drainage network: 0.

Sites are prioritized based on their relative scores. However, significant features can become lost in the tallying of a hazard score. For example, a site with a high diversion potential score may have very low scores for the other elements. In this instance, the user may wish to automatically rank the site as high priority for treatment.

Environmental risk assessment

For environmental risk assessment, the score for a crossing uses predetermined endpoints in conjunction with the previously described hazard scores. Environmental risk is expressed as:

Environmental risk = Hazard $^{\text{Endpoints}}$

The endpoints value is the sum of individual endpoints values for a site.

A site is assigned a value of one if it affects an endpoint. Some endpoints may be:

- Fish (or other species of special concern) at site—this should also generate a separate fish passage assessment.
- Fish (or other species of special concern) within the basin being inventoried.
- Sub-watershed containing crossing has refuge value (e.g., cold water tributary).
- Domestic water supply in basin.
- Special management area—special use areas may warrant assigning extra weight to those sites.

The number of endpoints is not fixed and should be discussed and agreed on through interdisciplinary analysis. At least one endpoint should be identified for meaningful results.

Example of a preponderance table from an environmental risk assessment conducted on 383 road-stream crossings within a 295-km^2 area is presented in table 12. An observed tendency is for individual roads to have a majority of sites scoring similarly. This is favorable for upgrading or decommissioning programs where it is most practical to treat a single road segment or specific area.

Limitations

Final scores require careful interpretation. Significant features (e.g., fish at site) can be lost if no significant hazard elements exist at the site. Although the approach is designed to make environmental risk sensitive to the endpoints, the user must assess the reality of the environmental risk scenario generated by this approach. This approach is meant to *suggest* sites for further inspection.

Users may wish to adjust the scoring system to reflect local settings. The scoring system as presented is intended to assign higher hazard values to crossings with diversion potential. Elements not playing a large role in adding to the hazard of a site based on observations in mountainous regions (e.g., s*) add less to the overall hazard score. Again, it is up to the user to assess the magnitude of the scores and determine whether they represent the relative magnitude of hazard elements in the area of inventory.

Evaluating consequences by road segment

An alternative to the site-scale results presented previously is generating results for individual road segments. This approach is often desirable for transportation planning and decommissioning efforts where the unit of consideration is often the road segment. Hydrologic connectivity is well suited to this approach. A similar approach can be used for a hazard inventory as shown in table 13.

Data appropriate for assessing road segments in addition to those listed in table 13 are:

- Ditch length/km of road
- Mean ditch length/cross drain (or crossing)
- Mean hazard score
- Mean risk score.

Failed Crossing Assessments

Crossing failures provide a unique opportunity to assess design and installation procedures. Following large storm events, storm damage reports are often generated to assess the magnitude and extent of damage. Such efforts should provide the opportunity for adaptive design. This section discusses features of failed culvert installations useful for incorporating into an adaptive design and installation process.

Mechanisms of Road-Stream Crossing Failure

Determining the mechanism of failure at a site is important because the site will likely experience a

Table 12 —Example of a preponderance table from an environmental risk assessment of 382 road-stream crossings in the Upper North Fork Eel River, Northwest California. Note the tendency for particular roads to have clusters of either high or low risk sites (e.g., 3S09, 3S10, and 5S30). One limitation of this approach, however, is that sites with diversion potential may be overlooked as is the case for several sites with ‘low’ rankings. This data set consists only of road-stream crossings and does not include cross drains (thus, hydro. conn. always = 1).

		Hazard scores								Endpoint scores			
Risk score	Road # - milepost	Hydro [a] conn.	Div. [b] dist.	Fill [c] vol.	T	w*	s*	Geology	Receiving geology	Fish at site	Fish in basin	Planning area	Cold water sub-basin
1331	3S03-0.61	1	1	0	1	1	3	3	1	0	1	1	1
1331	3S10-1.44	1	0	2	3	0	2	3	0	0	1	1	1
1000	3S09-0.28	1	0	2	3	0	1	3	0	0	1	1	1
1000	3S33-0.06	1	0	3	1	0	2	3	0	0	1	1	1
729	2S08-0.35	1	0	3	3	0	2	0	0	1	1	0	1
729	3S09-0.14	1	0	3	0	0	2	3	0	0	1	1	1
512	3S03-0.92	1	1	0	1	0	1	3	1	0	1	1	1
512	3S10-1.22	1	1	0	1	0	1	3	1	0	1	1	1
343	3S09-0.17	1	2	0	2	0	2	0	0	0	1	1	1
343	3S10-0.41	1	1	0	3	1	1	0	0	0	1	1	1

Table 12—Continued.

Risk score	Road # - milepost	Hazard scores								Endpoint scores			
		Hydro conn.[a]	Div. dist.[b]	Fill vol.[c]	T	w*	s*	Geology	Receiving geology	Fish at site	Fish in basin	Planning area	Cold water sub-basin
3	5S30-2.69	1	1	0	0	1	0	0	0	0	1	0	0
3	5S30-4.56	1	1	0	0	1	0	0	0	0	1	0	0
2	5S30A-0.2	1	1	0	0	0	0	0	0	0	1	0	0
2	5S30-3.51	1	1	0	0	0	0	0	0	0	1	0	0
2	5S30-2.04	1	1	0	0	0	0	0	0	0	1	0	0
2	2S16-0.64	1	1	0	0	0	0	0	0	0	1	0	0
2	5S30C-0.3	1	1	0	0	0	0	3	0	0	1	0	0
2	5S32-0.01	1	0	1	0	0	0	0	0	0	1	0	0
2	2S16-0.29	1	0	1	0	0	0	0	0	0	1	0	0
2	2S17-2.9	1	0	1	0	0	0	0	0	0	1	0	0

a. Hydro conn. = hydrologic connectivity

b. Div. dist = diversion distance

c. Fill vol. = fill volume

Table 13—Inventory data can be expressed per road segment. Such an approach is often desirable to fit the needs of transportation planning and estimating overall treatment costs.

Route number	Number of stream crossings/km	Number of cross drains/km	Crossing fill volume/km	Proportion of road hydrologically connected (%)	Total potential diversion distance (m)
IS02e	8.4	1.3	987	15	1,250
26N11	2.2	0.7	53	7	340
27N40	6.3	1.1	557	39	2,170
2S05p	1.1	2.1	37	3	0

similar occurrence again unless designs are implemented to reduce future hazard. Table 14 lists the mechanisms, the post-failure evidence for the mechanism, and potential design criteria to reduce the hazards. In general, failure can be the result of the following:

- *Culvert capacity exceedence*—Water, wood, and sediment in excess of capacity can cause water to pond at the inlet. Most road-stream crossing fills function as dams but are not designed as such. The increased saturation of the fill may initiate a fill failure. When water overtops the road surface, some degree of fill erosion is likely (figure 12). However, ponded conditions or an inlet plugged with debris or sediment also promotes deposition within the

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Figure 12—Overtopping of the fill resulting in erosion of the roadway. Understanding the mechanisms that caused failure is useful for upgrading sites to avoid similar consequences in the future.

inlet basin, which often requires costly excavation. Determining the initial mechanism may be difficult when the inlet is buried or the fill has been completely removed leaving little evidence (figure 13).

- *Fill saturation*—Saturation of the fill by ponding, overtopping flows, or a rusted culvert invert increases the hazard of fill failure.

(a) (b)

Figure 13—Burial of culvert inlets is often due to woody debris lodged at the inlet. However, determining this often requires excavation (a) or examination from the outlet (b).

Table 14—Types and physical evidence of culvert crossing failures and potential design criteria to reduce the hazard of such a mechanism occurring again.

Failure mechanism	Visible evidence	Difficulty in discerning	Design criteria to reduce future hazard
Saturated fill failure	• Mass wasting of fill with or without overtopping flows • Culvert invert rusted through	Often difficult to distinguish from headward erosion from overtopping flows.	• Ensure that fill is properly compacted and drained • Keep all streamflow within culvert • Use small fills to reduce the amount of material that can enter the channel • Use course material in fill to reduce the amount of fine material entering the channel. However, if too course, water will pipe through fill and cause other problems
Debris flow	• Channel scoured to bedrock • Poorly sorted deposits, often mixed with large woody debris in run-out zones or where road fill impounded portion of flow • Unusually high scour marks or high water marks on banks and vegetation • Refer, also, to Costa and Jarret (1981)	Easy. Debris flow evidence is typically well preserved and extensive.	• Minimize fill interfering with debris flow path • Place diversion prevention dips to one side of channel to avoid being filled in by debris flows • Consider low-water crossing • Pronounced sag in vertical curve at crossing

Table 14—Continued.

Failure mechanism	Visible evidence	Difficulty in discerning	Design criteria to reduce future hazard
Woody debris lodgement	• One or more pieces lodged across culvert inlet • Deposition of fine sediments (up to small pebbles) in inlet basins, often moderately sorted and thinly bedded (<2 cm thick) commonly with organic-rich lenses	Easy to difficult (depending on magnitude of deposition and post-event maintenance). Often debris plugging is followed by progressive deposition of sediments at the inlet. Stratification, sorting, and grain size distribution are useful clues. The mechanism can be difficult to discriminate where excavation has ocurred and stratigraphic evidence has been removed. However, if the buried culvert is appropriately configured, a flashlight shone in from the outlet can indicate the mechanism. (figure 13).	• Maintain channel planform, longitudinal profile and cross section to the inlet • Retain vegetation that often maintains channel confinement • Avoid widening the inlet basin • Use channel width as a factor for sizing. Where feasible, culvert diameter should be equal to the channel width to facilitate debris passage. • Configure culvert inlets to facilitate alignment of debris with flow, such as with metal end sections or angled headwalls • Ensure a least-consequence flowpath for overtopping flows
Sediment “slug”	• Rapid, often catastrophic delivery of sediment to the inlet, deposition above the crown of the culvert • Adjacent hillslope failure delivering material a short distance to the inlet • Unsorted or poorly sorted deposits within inlet basin	Easy to difficult (depending on magnitude of deposition and post-event excavation). Rapid, catastrophic delivery of sediment buries the inlet. Although the particle sizes delivered to the inlet may be capable of fluvial transport through the culvert, rapid delivery overwhelms the transport capacity. See woody debris notes for problems distinguishing between wood and sediment.	• Avoid oversteepened cut slopes adjacent to the inlet • Ensure a least-consequence flowpath for overtopping flows • Create a catch basin for sediment such that it does not affect wood transport as discussed above

Table 14—Continued.

Failure mechanism	Visible evidence	Difficulty in discerning	Design criteria to reduce future hazard
Hydraulic exceedence	• High water debris accumulation • Draping of fine sediments within the ponded area • Inlet not plugged with debris	Moderate to difficult. Hydraulic exceedence requires careful examination of the inlet basin. Debris deposits at the high water line and fine sediment deposits are often of limited extent and rapidly covered with vegetation.	• Size culvert for at least a 100-year design flood with headwater less than or equal to the culvert diameter.
	• Consequences of overtopping - fill erosion or diversion evidence	Where fill erosion and diversion evidence exist, hydraulic exceedence is arrived by a process of elimination.	• Ensure a least-consequence flowpath for overtopping flows

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APPENDICES

APPENDIX A

AN EXAMPLE OF ROAD ENVIRONMENTAL RISK ASSESSMENT FOR USDA FOREST SERVICE LANDS IN THE UPPER NORTH FORK EEL RIVER WATERSHED, SIX RIVERS NATIONAL FOREST

Following are the results from inventory and assessment of road-stream crossings and cross drains on USDA Forest Service lands in the upper North Fork Eel River. Inventory was conducted on the 296-km^2 (114 mi^2) portion of USDA Forest Service land. Culvert diameters at road-stream crossings (308) were typically 450 mm or 600 mm. Drainage area was definable on a 7.5 minute topographic map for 207 (67 percent) of the road-stream crossings. For those sites, 63 percent are unable to pass a 100-year flood without submerging the culvert inlet, and 43 percent overtop the road fill for a 100-year peak flow.

Potential physical consequences include fill erosion and stream diversion. Median fill volume is 141m^3 per crossing with 15 percent having a volume greater than 500 m^3. Forty-five percent of the road-stream crossings and 67 percent of the cross drains have diversion potential. Influencing potential physical consequences was an unstable geologic unit. Inspection of roads and crossings within this unit revealed that past failures were of much greater erosional consequences, and ongoing chronic erosion was higher than surrounding areas within relatively stable geologic settings.

The following endpoints were identified in the analysis area:

- Anadromous fish (this applied to all sites as all failures are assumed to have an impact)
- Fish at crossing (sites overlapping with the distribution of anadromous fish)
- Cold water refuges (the North Fork Eel watershed is thermally impaired. Three sub-watersheds were identified in the analysis area as important cold water tributaries and refuge areas).

An environmental risk score was assigned to each crossing. Maps on the following pages (figures A-1 and A-2) display the distribution of road-stream crossings, cross drains, road-stream crossings with high diversion potential, and high risk road-stream crossings. In this example, sites were assigned into the high risk category if the risk score was > 100. This value should be adjusted to reflect watershed conditions and the number of endpoints considered. Note the clustering of high risk sites along road segments in the eastern portion of the basin. This clustering effect allowed for efficient treatment efforts.

Road - Stream Crossings and Cross Drains on Forest Service Lands - Upper North Fork Eel River, Northwest California Six Rivers National Forest

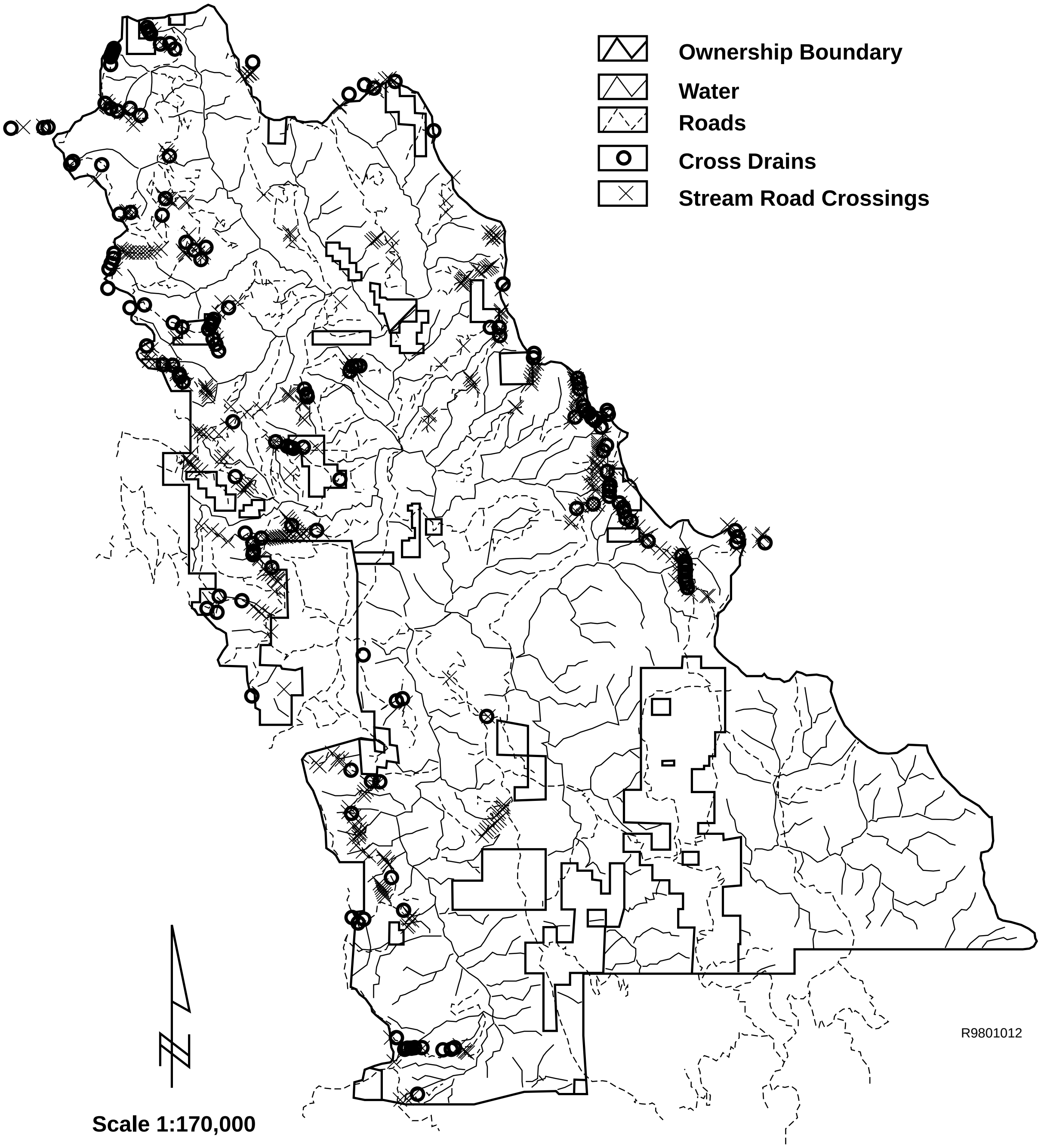
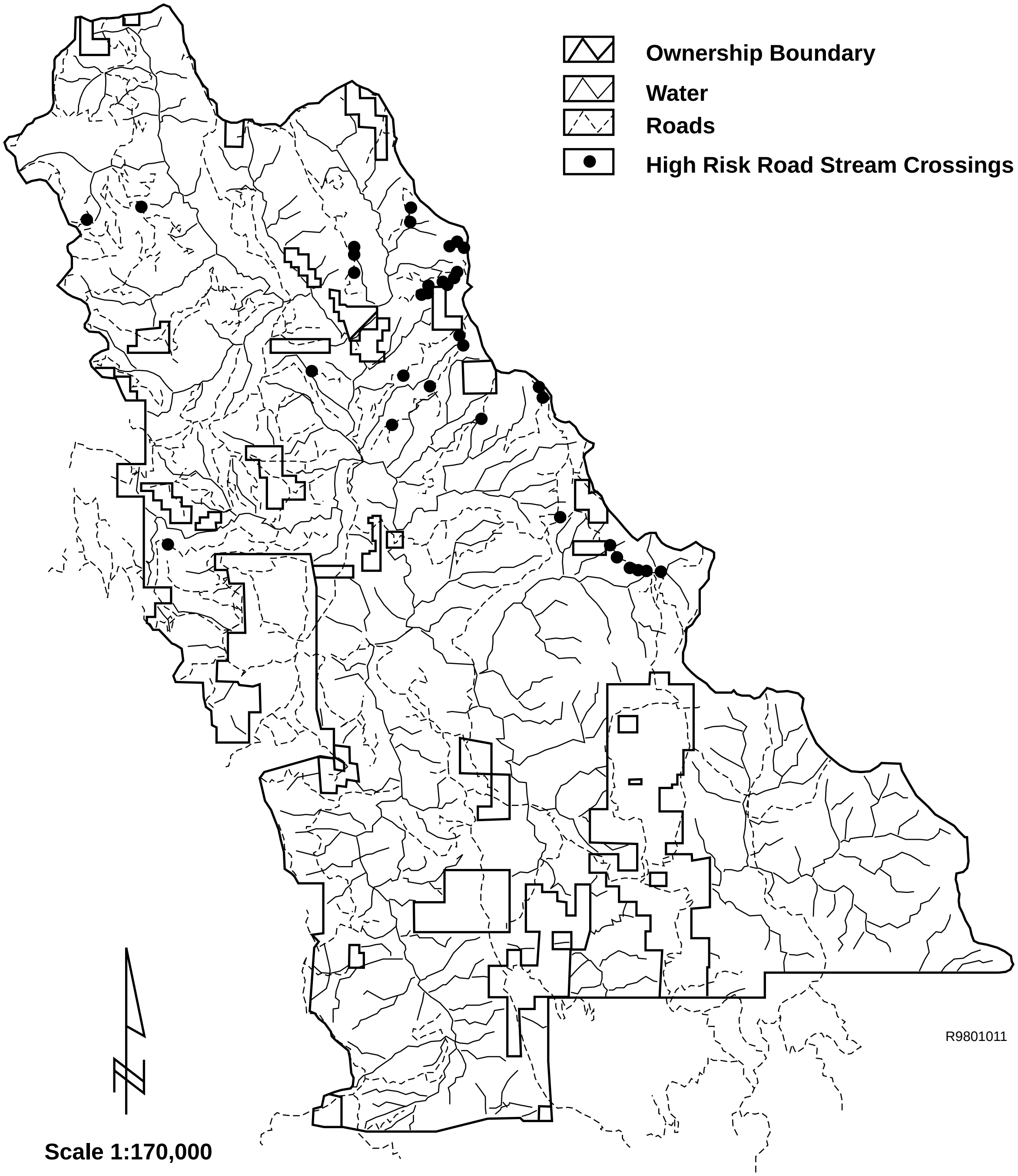


Figure A-1.

Map Compiled by GIS Group
Watershed Analysis Center
August 27, 1998

High Risk Road - Stream Crossings on Forest Service Lands - Upper North Fork Eel River, Northwest California Six Rivers National Forest



Map Compiled by GIS Group
Watershed Analysis Center
August 27, 1998

Figure A-2.

APPENDIX B

Sample Data Sheet For Road Drainage Inventory

date: ____________
surveyor(s): ____________

Location

Road # m.p. lat lon

Quad: T R Sec 1/4 1/4 photo

Crossing type: Stream Swale X-drain Other:

Channel type: Intermittent Unchanneled Ditch

Channel widths: ____ ____ ____ ____ ____

Channel depths: ____ ____ ____ ____ ____

Channel slope (%): ________

Contributing ditch length(s): L____ R____

Culvert type:

- CMP
- arch
- bottomless arch
- plastic
- concrete box

Diameter: __________

slope (%): __________

Entrance type:

- projecting
- mitered
- flush
- side tapered
- drop inlet
- other: ______________

% dent/crush: __________

skew angle (deg): ________

Fill volume:

flood prone width: _____

Upstr. fillslope len: _____

Upstr. fillslope (%): _____

Road width: _____

Fill width: _____

Dnstr. fillslope len: _____

Dnstr. fillslope (%): _____

Diversion potential: YES NO

potential distance: __________

road slope through crossing (%): ________

receiving feature:

- adjacent cross drain site# ________
- adjacent stream crossing site# ________
- hillslope
- other: ____________

Cross drains and other drainage features:

Gully below outlet? YES NO

Connected to channel? YES NO

Gully Legnth: _____

Avg. depth _____

Avg width: _____