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Water/Road Interaction: Examples from Three Flood Assessment Sites in Western Oregon

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ABSTRACT

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Assessments of damage from storms in 1995 and 1996 to three forest road segments on the Detroit Ranger District of the Willamette National Forest are reported. Consequences to roads and road-related structures are discussed. Changes are suggested, for the three example road segments, in the designs and materials used for road surfacing, and road drainage structures including ditches and cross drains. Information is based on that developed and reported for other publications in the Water/Road Interaction Technology Series.

Keywords: Forest roads, drainage, floods, ditches, culverts, road erosion

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SUMMARY — LEARNING FROM FLOOD EVENTS

From the fall of 1995 through the spring of 1996, intense storms caused widespread flooding to areas of the Pacific Northwest of the United States. This flooding provided an opportunity for USDA Forest Service staff to see where the "weak links" were in the integrity of the system of National Forest roads for which they have responsibility. Following the storms, assessments were made so that road segments could be repaired, rebuilt, decommissioned, or obliterated. Of particular interest for the Water/Road Interaction series of publications are examples afforded by these events of how forest road drainage facilities fail when stressed. The following key observations were made:

Providing "fail-safe" road drainage and stream crossing designs will minimize risk to down-stream values during intense runoff periods.

Damage from surface runoff during storms did not tend to be initiated on dense and well-graded gravel road surfaces. Rather, sediment and rock debris from eroded, unlined ditches were initially scattered onto road surfaces. Erosion of these ditches progressed to the point where severe gullying resulted. Ditches eroded rapidly because of the erosive nature (fine-grained, non-cohesive) of the soil.

Integrity of the road surface can be enhanced during high-runoff periods by using rock sources that produce well-graded material with adequate plasticity.

For the three sites surveyed here, forest vegetation tended to buffer the flow of debris and sediment so that it did not reach large streams. Relatively broad, flat areas adjacent to the eroded section of road (especially at the K-Creek site) caused water to pool and sediment to drop out.

In locations where obstructed crossings carry a high risk to downstream values, it may be necessary to consider structures other than pipe crossings, such as low-water fords.

Culvert inlet areas that had an abundance of vegetation, and that were wide and shallow, had the effect of slowing stream flows, thereby causing debris and sediment to settle and accumulate at the pipe entrance. These inlets often became obstructed.

Shallow fills over bedrock surfaces that are parallel to the slope and adjacent to roads are at high risk to initiate slides during periods of intense runoff. During construction of full bench roads, preventing these shallow fills over bedrock will reduce the risk of slide initiation. Existing steep, wet, relatively shallow fills should be watched closely by maintenance personnel.

A regular function of routine maintenance of forest roads is to assess road segments for conditions that could lead to damage during periods of high runoff. All too often there is a temptation to repair road damage by simply restoring the road and associated structures to a condition similar to what existed before the storm. In many cases this may be appropriate, but careful evaluation may also suggest improvements that could reduce risk of future damage.

INTRODUCTION

Between November 1995 and April 1996 the Pacific Northwest experienced a series of intense storms. Some of the effects of these storms included high runoff into drainage systems associated with forest roads. While there was widespread and extensive property damage and thousands of people were unfortunately affected in adverse ways, these storms provided natural resource professionals with opportunities to see first hand how roads and road-related structures performed in response to high-intensity events.

During the assessment of effects from the weather events of November 1995 and February 1996, patterns began to emerge regarding damage to roads and adjacent sites. This report describes and discusses examples of road damage caused by storms using three forest road segments in the Detroit Ranger District of the Willamette National Forest. The primary purpose here is to describe the road and road-related structures that were in place at the time of the storm events, highlight what happened to them, and discuss what is needed to improve the design and maintenance of road drainage.

BACKGROUND

Forest roads and surrounding areas of the Pacific Northwest experienced various types of storm-caused damage, depending on factors such as soil type, land steepness, vegetation, storm intensity, and road construction details. Various natural phenomena such as channel erosion, slope movement, snow avalanche, and surface erosion caused damage to roads. Conditions related to activities such as timber harvest, drainage modification, and harvest and road-related stream channel modification also caused damage to roads. Damage to forest and streams was also attributed to culvert plugging, stream diversion, erosion and sedimentation, and road-fill failures.

Although damage to facilities was costly and in some cases caused inconvenience and hardship, the percentage of land area or length of road that was damaged to the point of requiring repair was relatively small (less than one percent of total land area or length of road). National Forests that were affected by these storms concluded from their assessments that recent restoration and maintenance efforts probably reduced the number of road-related slides that deposited large amounts of sediment to streams. The flood damage, nevertheless, presented an opportunity to observe road-drainage features that were the most vulnerable to failure and to study the cause of those failures.

Surveys of damage to roads and to local areas surrounding roads on the Detroit Ranger District showed that plugged culverts and road-surface and road-fill erosion accounted for most of the damage to roads and road-stream crossings (Figure 1).

Culvert plugging by stream bedload and woody debris was the most common type of failure overall (28 percent). Often a small branch caught in the culvert inlet and resulted in stream bedload accumulation and eventual burying of the inlet. Culverts that were 600 mm (24 inches) diameter or less accounted for 81 percent of the plugged culverts.

The cause of flood damage to roads from erosion of road surfaces and stream channels adjacent to roads, fill failures, and forest slides contributed about equally to road damage, each comprising 14 to 18 percent of the number of sites that were damaged. Cutslope failures contributed only 6 percent of sites that were damaged.

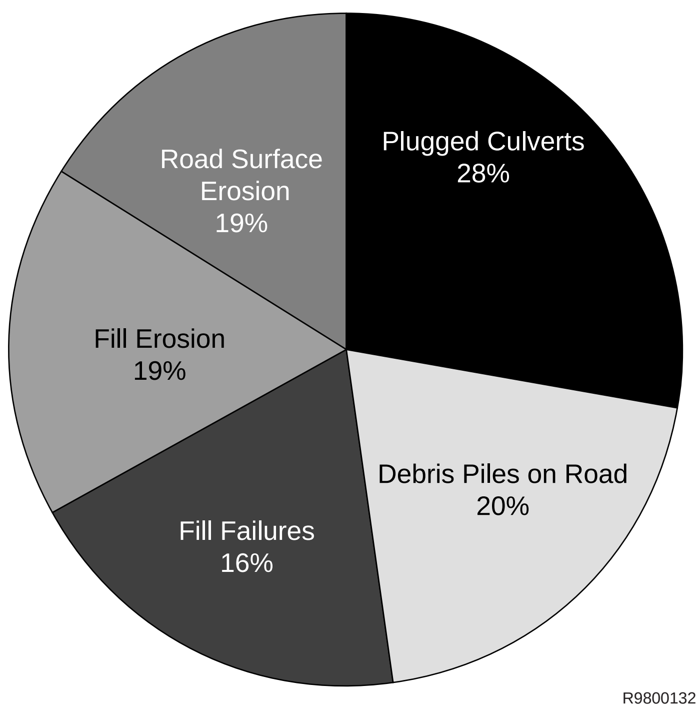

Figure 1—Road related storm damage by type (352 Sites on Detroit RD 1996).

Damage to roads in the form of fill failures, fill erosion, road surface erosion and debris piles were all found at about the same frequency and contributed to 16 to 20 percent of the damage sites.

SITE DESCRIPTIONS AND DAMAGE ASSESSMENT

Road surface materials for each of the three sites considered in this report are similar (Table 1). The basic geology in the area consists of mostly andesite and basalt lava flows intermixed with volcanic deposits of ash and tufts. Soils are derived from this material and include coluvium and glacial deposits. In terms of engineering soil gradation, these soils are mostly sand and silt mixtures (Unified Soil Classifications SM and ML), containing rock fragments up to cobble size. Low-plasticity soils derived from volcanic deposits tend to be quite erodible. Surfacing for all roads was derived from local andesite lava flows and was crushed to 20 mm- (3/4-inch-) minus, dense-graded aggregate. This material also has low plasticity. Roadside ditches were unlined and partially vegetated, primarily with grass, ferns, or other small plants.

BREITENBUSH SITE

The damage on this site began where two adjacent small streams carrying high flows and sand- to cobble-sized bedload plugged road culverts (Figure 2). Both of these 1.0 to 1.5 m-wide stream channels crossed the road with 450-mm (18-inch) diameter corrugated metal pipes lying on a 5 percent

Table 1—General description of three flood-assessment sites on the Detroit Ranger District, Willamette National Forest, Oregon.

Site	Breitenbush	K-Creek	Devil’s Creek
Road segment location	FS road 4600-040, km post 0.0 to 1.55	FS road 1003-416, km post 2.7 to 3.2	FS road 2231-870 km post 7.5
Type of construction and surface drainage features	Cut and fill Section 8-11% single lane crown surface v-ditch, 450 mm culverts aggregate surfacing	Cuts and fills 4-10% single lane crown surface v-ditch, 450 mm culverts aggregate surfacing	Full bench 2-4% single lane crown surface v-ditch, 450 mm culverts aggregate surfacing
Position on slope	Lower 1/3	Upper middle 1/3	Upper 1/3
Elevation	670-850	825-850	1,340
Typical overland flow path length above top culvert inlet (m)	975	1,585	[Did not involve a culvert failure]
Typical overland flow path slope above top culvert inlet (percent)	28	23	[Did not involve a culvert failure]
Two-year, 24-hour rainfall intensity (mm)	89	89	102
Predominant vegetation above the road	20 to 30 year-old second-growth forest	5 to 10 year-old second-growth forest	Clear-cut (1990)
Estimate of material eroded (m^3)	1,900 - 2,700	1,250	4,200
Material estimated that entered stream	1,700 - 2,500	< 50	3,500

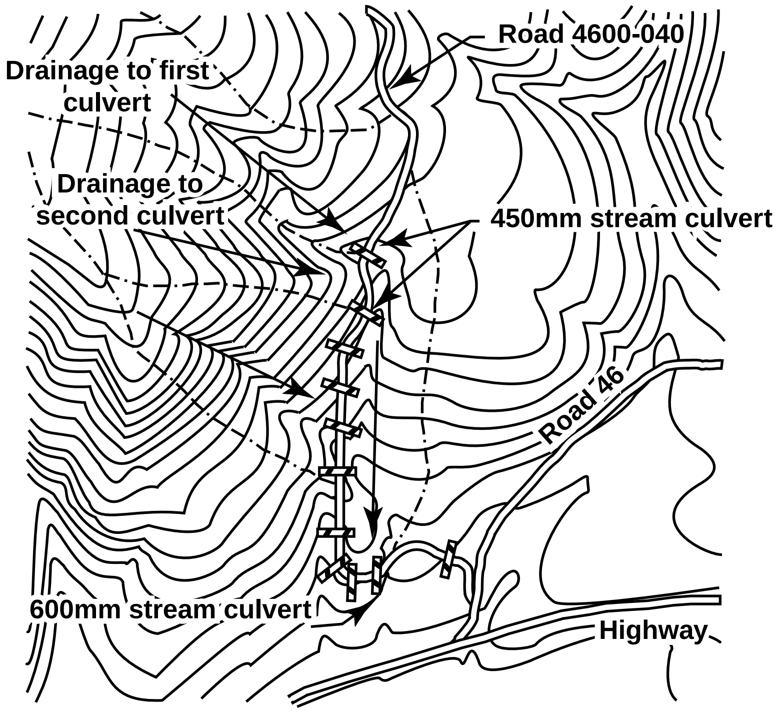

Figure 2—Breitenbush site map.

Figure 3—Severe gullying at Breitenbush flood-assessment site.

(stream) gradient. The upstream end of the culverts projected into widened inlet basins. Roadside ditches were open uphill and downhill to these inlet basins. Stream bedload accumulated at both of the culvert inlet basins, filling them until their inlets were buried. Storm flow was then diverted to the road ditch. The flow and stream sediment from the first culvert flowed down to the second culvert, where they combined and continued down the road ditch. The flow from the slope above the road and road surface drainage also accumulated in the ditch. The high volume and high-velocity flow—the road and ditch grade ranged from 8 to 11 percent—began eroding the road ditch to a depth limited only by bedrock lying from 0.5 to 3 meters below the originally constructed ditch bottom (Figure 3). At the entrances to ditch-relief culverts, either inlet basins were severely eroded or the entrances were plugged by sediment so that none of the culverts were transporting water across the road. The accumulated flow could not escape the ditch and continued down the road for 1.2 km (.75 mile).

Storm flow eventually eroded through softer road-fill material, forming a 1.3-m-deep gully. Debris was carried into a small, intermittent drainage where some of it was deposited. The remainder was carried further downhill into a larger stream drainage. This larger drainage crossed the road near the junction via the forest highway with a 900 mm (36 in.) culvert. The entrance basin to this crossing was filled by debris and the pipe entrance was buried. The stream flow overtopped the road and eroded through the fill approximately one meter down to bedrock, carrying the material 100 meters to the forest highway below. Debris deposited on the highway and the flow spread over the road surface and was dispersed into the forest below.

The dense, well-graded gravel road surface received little damage from surface runoff during the storm. Sediment and rock debris were scattered onto the road surface at some locations. A summary of drainage features and observations of what happened during and after storm events is shown in Table 2. Virtually all of the material that eroded and moved off site came from the unlined ditches and resulting gullying that occurred during the storm (Figure 3).

K-CREEK SITE

Damage at this site began at the 2.7-km stream crossing, where debris filled a stream crossing culvert inlet basin, plugging the 600-mm (24-in.) corrugated metal pipe and diverting the stream into the road ditch (Figure 4). As the road ditch was eroded, debris was scattered on the road surface in numerous places. Ditch relief culverts were plugged by coarse-grained sediment. A portion of the water was deflected off the road by this debris while the remainder flowed down the road ditch and traveled on the surface causing additional damage. Eventually the stream eroded through the road template creating a gully up to 3 m (9.8 ft) deep by 3 m (9.8 ft) wide (Figure 5). This gully followed the

Table 2—Cross drain culvert locations and characteristics on Breitenbush Road prior to April 1996 and after 1996 storm events.

Culvert	Distance to next culvert	Road grade	Drainage area	Condition after storm events	Apparent cause
	meters	*percent*	*hectares*		
450 mm relief culvert	232	12	27	open	
450 mm relief/stream culvert	137	12	21	plugged	bedload
450 mm relief/stream culvert	107	11	2	plugged	bedload
450 mm relief/stream culvert and slope drain	174	11	2	eroded around	large ditch flow
450 mm relief/stream culvert	137	9	2	plugged	sediment
450 mm relief culvert	265	9	2	open	ditch water eroded through fill before pipe
450 mm relief culvert	70	11	2	plugged	sediment
450 mm relief culvert	143	12	2	plugged	sediment
450 mm relief culvert	107	13	2	open	culvert inlet overtopped
600 mm stream culvert	183	13	70	plugged	stream bedload and ditch sediment
450 mm relief culvert	--	--	2	plugged	ditch sediment

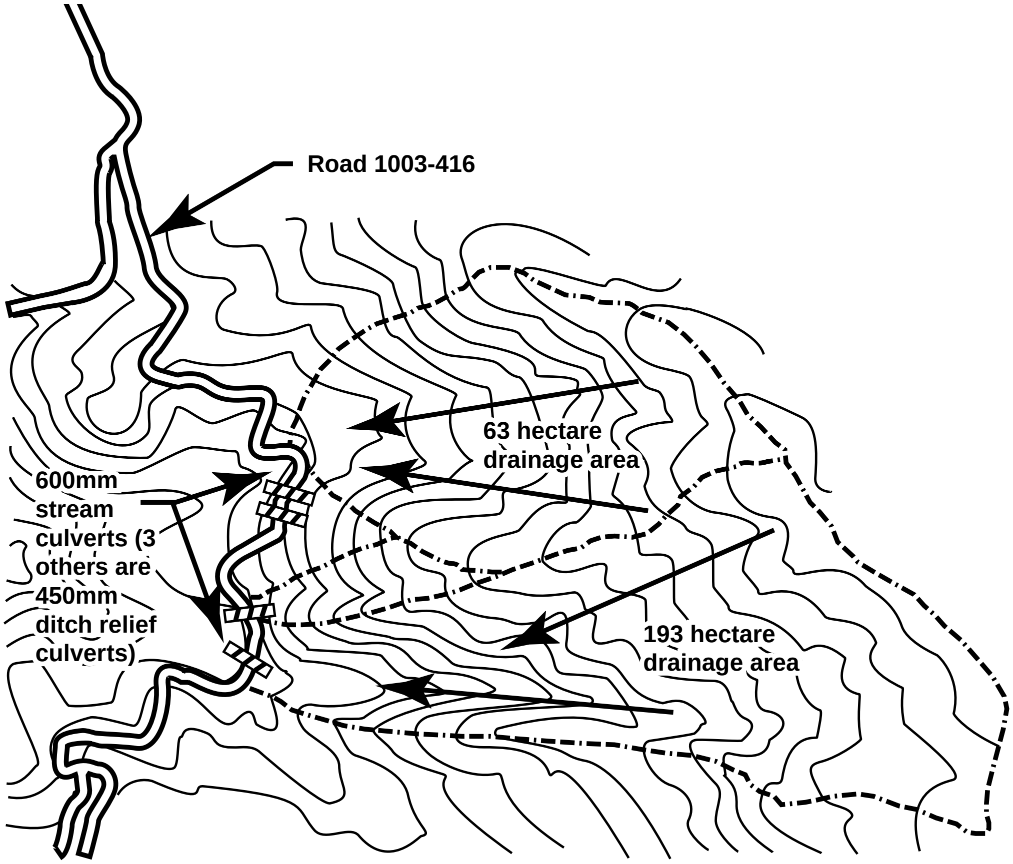

Figure 4—K-Creek site map.

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Figure 5—Severe gullying at K-Creek flood-assessment site.

road until it eroded through the fill, diverting the stream and depositing sediment in a broad, shallow basin adjacent to the road. The forest vegetation served as a buffer strip to help capture sediment before it reached stream channels. The basin allowed water to pool and drop suspended sediment. Location of cross drains and stream crossing culverts are shown in Table 3.

Debris generated from the diverted stream 0.5 km away was deposited in the inlet basin for a 600-mm (24-in.) diameter culvert near the bottom of the site (at location 3.2 km), plugging the inlet. The stream flow pooled and overtopped the road, eroding the fill and exposing the culverts. A summary of drainage features and observations of what happened during and after storm events at this site is shown in Table 3.

DEVIL'S CREEK SITE

This site involved the failure of a thin side cast road fill that scoured the soil off a drainage headwall on the hillside and deposited it on a lower segment of the road, within the lower segment of the drainage and within Devil's Creek (Figure 6). The failure was caused by water being diverted by a small cutslope slide (estimated volume was 5 cubic meters) that dammed a ditch, causing ditch water to run out onto the road surface, down wheel tracks and eventually over the fill slope edge of the road (Figure 7). The fill slope apparently failed as a result of saturation caused by rainfall combined with the overtopping ditch water eroding the toe of the fill. The failed fill slope became a fast-moving earth flow that combined with wet 1- to 5-meter-thick surface soil in the drainage headwall, gathering volume as it moved and not stopping until it encountered the road below. The debris then filled the inlet basin of the road culvert, covered the road with about 800 cubic meters of debris, and sent the bulk of the debris into the drainage channel below the road and into Devils Creek. The channel debris swept up a forest slope, knocking down trees and burying the channel. The drainage eventually eroded through the channel debris to reconnect with Devil's Creek. It was estimated that, of the approximately 4200 cubic meters that were eroded and subsequently slid from the site, about 25 percent was stopped by the road, with the remaining volume ending up within the stream bed below. The road fill was partially eroded, damaging the outlet end of two 750-mm (30-inch) diameter stream culverts located at the site. Apparently, one of the culverts had been damaged in the past by a debris slide, left in place, and replaced with a new culvert of the same size.

Subsequent maintenance at the site removed debris from the road surface, but did not re-establish flow into the cross drain. Instead, water flowed into the road ditch and continued about 70 meters down to the next culvert. The sediment carried by the diverted drainage eventually plugged the next culvert, then diverted over the road surface, eroding approximately 3,000 cubic meters of road fill. The fill material was deposited in a flattened area below the road and within a forested buffer strip area below. Very little road fill reached Devil's Creek drainage below. The road culvert was severely damaged and the road subgrade was destroyed.

Table 3—Cross drain culvert locations and characteristics on K-Creek road prior to April 1996 and after 1996 storm events.

Culvert	Distance to next culvert	Road grade	Drainage area	Condition after storm events	Apparent cause
	meters	*percent*	*hectares*		
600 mm stream and ditch relief culvert	85	9	63	plugged	stream debris and bedload, flow ran past here and into ditch
450 mm ditch relief culvert	43	8	3	plugged	bedload, ditch and gully sediment
450 mm ditch relief culvert	311	4	8	plugged	bedload, ditch and gully sediment
450 mm ditch relief culvert	7	4	2	plugged	bedload, ditch sediment
600 mm stream and ditch relief culvert	--	--	193	plugged	bedload, ditch and stream sediment, overtopped the road surface

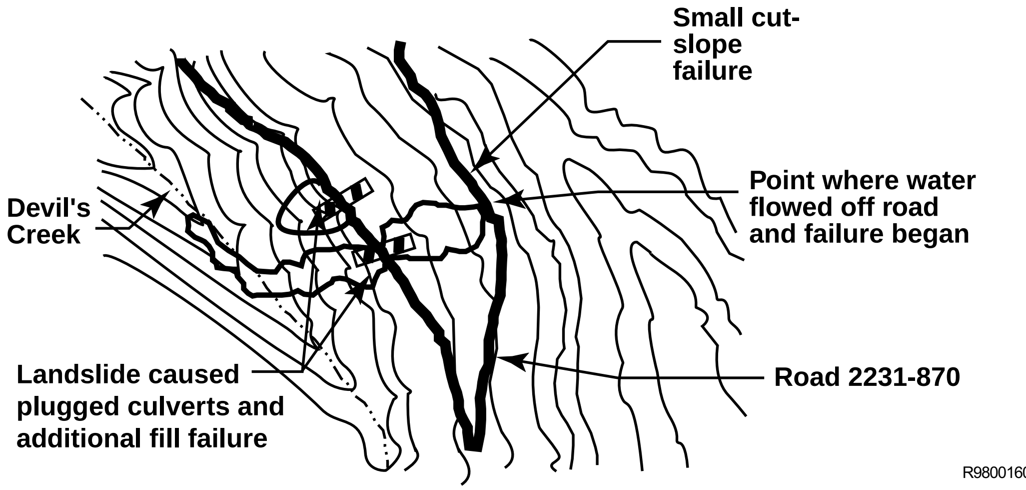

Figure 6—Devil's Creek site map.

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Figure 7—Initiation of debris slide at Devil's Creek flood-assessment site.

DISCUSSION

Plugged Stream Culverts

The site damage at the Breitenbush and K-Creek sites started from stream crossings that were overwhelmed with eroded bedload and debris, causing the crossings to become plugged. In general, a culvert stream crossing must meet hydraulic requirements and accommodate bedload and debris. This can be done by sizing the culvert to meet hydraulic requirements and then either increasing capacity to accommodate bedload and debris, or providing a means for accumulating this material at the inlet so that it can be removed by maintenance crews. It is preferable to provide means for the material to pass through the crossing. To pass bedload and debris, inlet basins should be narrow and straight, with the culvert and stream at the same grade. The culvert should be as large as possible, up to the stream channel width and depth. If this is not possible, a storage inlet basin should be considered. In locations where obstructed crossings carry a high risk of damage to downstream values, it is necessary to consider structures other than culvert crossings, such as low-water fords. Even when culvert crossings are used, an armored overtopping path for diverted flow should be considered.

For some cases, stream culvert crossings are needed where downstream values are at low risk, upstream geometry is broad and relatively flat, or the potential for debris and bedload flow at the crossing is determined to be small, and therefore that storage inlet basins will provide adequate protection from culvert plugging. In these cases, there must be reasonable assurance that inlet basins can be cleaned out on regular maintenance schedules. Because the size and quantity of bedload and woody debris that may impinge on stream crossings during storms is often not predictable, it is difficult to determine minimum standard dimensions for storage inlet basins, and often they are simply made as large as possible.

Small streams and drainages should be studied to determine drainage area and expected flow for storm events. Many small but recognizable drainages have enough volume to require culverts much larger than the 450-mm (18-in) diameter pipes that were prevalent at the three subject sites. For example, the small drainages at the top of the Breitenbush site have drainage areas of 32 hectares each. The size of a stream culvert capable of passing a 100-year storm flow of 1.11 cubic meters per second, with a headwater height equal to the culvert diameter at a gradient of 5 percent is 900 mm (36 in). The culverts installed were 450 mm (18 in) and thus substantially undersized for the stream's hydraulic requirements. Debris considerations would have indicated the need for an even larger culvert that could pass flood flows and debris at the same time. A more appropriate size would have been 1,200 mm (48 in). Another approach to consider in this case is a crossing design that allows water, debris, and bedload to flow over the top of the traveled-way surface.

Table 4—Comparison of the size of installed culverts with sizes calculated to meet 100-year flood discharge.

Road	Purpose	Existing Culvert Diameter	Culvert Diameter for Q_{100}
		millimeters	*millimeters*
Breitenbush	stream	450	900
Breitenbush	stream	450	900
Breitenbush	ditch relief	450	450
Breitenbush	ditch relief	450	450
Breitenbush	ditch relief	450	450
Breitenbush	ditch relief	450	450
Breitenbush	ditch relief	450	450
Breitenbush	ditch relief	450	450
Breitenbush	ditch relief	450	450
Breitenbush	stream	600	1350
Breitenbush	ditch relief	450	450
K-Creek	stream	600	1200
K-Creek	ditch relief	450	450
K-Creek	ditch relief	450	600
K-Creek	ditch relief	450	450
K-Creek	stream	600	1650

The stream crossing at the lowest elevation at Breitenbush was plugged from stream bedload and ditch sediment. The estimated peak 100-year flood discharge for this site was 3.45 cubic meters per second (Harris, et al. 1979). Based on accepted practice for calculating culvert size for a 5-percent culvert gradient, a 1,200-mm (48-in) diameter culvert would have been required to prevent overtopping the road surface, which was located only 1.5 meters (59 inches) above the existing 600-mm (24-in) culvert inlet bottom (Normann, et al. 1985). Therefore, this culvert was considerably undersized for its drainage. The culvert inlet was wide and shallow and heavily vegetated, which had the effect of slowing stream flows and causing debris to settle and accumulate at the culvert inlet.

Table 4 shows a comparison of a sample of the installed culverts with sizes calculated to meet 100-year flood discharge. It is likely that if the stream crossings had been sized to accommodate a 100-year storm flow, the larger culvert inlets would not have become plugged, and less water would have been diverted from upper stream crossings to lower crossings.

Table 5 shows other features that should be considered for incorporation into crossing culvert designs such as those at the three sites considered here.

Culvert Inlet Design

As discussed above, inlet design can have an effect on how bedload and debris behave at crossings. Inlets should be designed to direct water into culverts without slowing it down. Matching the culvert diameter to the cross-section area of the stream channel can minimize changes to flow velocity at the approach to the inlet. An inlet basin that is much larger than a culvert inlet allows settling and collection of material at the inlet during storms because it allows the water to slow down, reducing its transporting ability. The inlet area should be shaped to match the stream channel, or slowly tapered to the culvert diameter, to keep water velocity sufficient to help debris flow through the culvert.

Culvert Spacing

The cross drains at all three sites were not close enough to each other to carry the flow contributed by their respective drainage areas. For example, at Breitenbush, based on the average cross-drain drainage area of 16 hectares at this site, the diameter of a cross-drain culvert capable of passing a 100-year storm flow without overtopping the road surface would be 600 mm (24 in). By spacing cross drains closer together, the pipe diameter required to meet hydraulic requirements could be reduced to 450 mm (18 inches).

During the storm, even if debris had not plugged culvert inlets, cross drain culverts at Breitenbush and K-Creek would have overtopped the road because flow would have backed up and pooled at the inlet. The rise in water would redirect a portion of the flow across the road or down the ditch similar to what happened during the storm.

The average spacing of cross drains for Breitenbush, including stream-crossing culverts (which also function as ditch relief) is greater than 155 meters (see Table 2). If cross drains had been spaced according to published guides (Baeder and Christner 1981), spacing would have been between 25 and 60 meters, and the storm flow that each of the 450-mm (18-inch) culverts would have to have carried would have been reduced by 70 percent. Had they been installed at a minimum five percent gradient, they probably would not have been overtopped. Ditch erosion, gully formation, and culvert inlet plugging would likely have been reduced with closer spacing.

The cost for the additional 26 culverts needed to achieve an average cross-drain spacing of 42 meters would be about $19,500. The marginal cost for the

Table 5—Features to consider when designing small stream crossings, including ditch-relief culverts.

- Provide ditch dams to prevent stream flows from being diverted down the ditch during high flows.
- It is usually desirable to create an erosion-protected path to allow the flow from a plugged culvert to overtop the road and flow back into its channel rather than flowing down the road survace or ditch.
- At high-risk sites, an additional “overflow” culvert can be installed higher up in a fill to enable drainage to continue if a site is plugged.
- The steeper the culvert the greater energy it will have to carry debris through it. Stream-culvert gradients should not be less than the natural stream gradient.
- Construct inlet basins to allow easy transport of bedload and debris through the crossing.

larger-sized stream culverts would be approximately $4000. The combined total of $23,500 is 21 percent of the estimated $110,000 needed to restore the transportation function of the road.

Ditch Erosion

The soils at both Breitenbush and K Creek are easily eroded. Ditches would have benefited from either more frequent relief culverts or from erosion protection that could have been provided by grass or small riprap. Natural ditch vegetation was insufficient and natural armoring through erosion of fines, leaving coarse rock fragments for protection, did not occur at either site. The high-energy conditions and high-volume flow at the Breitenbush site produced very high erosional forces. It would be expensive and difficult to provide adequate protection for those conditions. At the K Creek site, the high-flow conditions were able to erode the unprotected ditch. In both cases, the road surfacing provided some protection from erosion and gully formation into the road. The key to preventing ditch erosion at these sites would appear to be in preventing plugging of stream culverts and diversion (see Table 5). Other important road-drainage features, such as closer spacing of cross drains could have reduced overall road damage since they would have provided additional places for diverted stream flow and drainage to escape. Ditch dams would have been helpful in getting ditch water into ditch relief culverts, especially at steeper grade sites.

Fill Failure

Damage to the Devil's Creek site resulted from a failed cut bank plugging a ditch. Wheel tracks carried the diverted water down the road until a surface depression was reached. The effect was to saturate a fill, which then initiated a slide at the toe of a slope. This small slide developed into a debris chute. The road is a full bench design that had a shallow layer of soil sidecast as waste during construction (a "sliver fill"). The sidecast soil lies on a thin mat of soil and organic matter (partially decomposed by now) such as stumps and brush. This created a zone of weakness that failed more readily than other soil in the area.

The topography and management regime below the road probably contributed to the failure. The area below the road was a 55 to 70 percent, ten-year-old, clear-cut unit. Typically, tree roots remaining in the soil in this type of area have significantly rotted, losing shear strength that helps hold soil on the slope. The absence of large trees also meant there was little to stop a slide once it became mobile. The underlying bedrock mostly parallel to the slope, acted as a slip zone for the soil. This situation suggests that maintenance personnel should carefully monitor roads in similar areas with steep, wet, relatively shallow soils with thin fills. Unstable fills should be pulled back before they can fail. Also, during full bench construction, efforts to pull back fill spilled over the side may eliminate potential failures.

The $5,000 to fix the upper road (clean ditch and ditch relief culvert) was small compared to the value of other resources that may could been damaged. In contrast to the other two sites, the role of the culvert/drainage design for this road was incidental to the initiation of the failure. The relatively small cut-slope failure that initiated this damage is an example of how seemingly isolated and innocuous events can trigger much more catastrophic results when "fail-safe" drainage designs are not used.

Traveled-way Surface and Ditch Shape

Traveled-way surface and ditch shape can play an important part in mitigating damage caused by floods of this magnitude. The Breitenbush and K-Creek sites both had crowned road surface shape. The advantage of this with respect to runoff is that the effective capacity of the inside ditch is increased somewhat because it includes the half of the road that is insloped. Half the surface water is directed to and over the outside shoulder of the road instead of along the direction of travel or to the inside ditch, as on an insloped road surface. While water tended to spread from the ditch over the road where the road grade flattened, dips in the road surface would have prevented excessive concentration of runoff and made the design more fail-safe by directing the water over and off the road at predetermined locations. Also, none of the three sites had ditches that incorporated ditch dams, which could have directed water into relief culverts, reducing the accumulation of ditch flow during moderate storms. At the Devil's Creek site, the upper road damage would probably have been prevented if the traveled-way surface had been insloped rather than crowned. With an insloped surface, all the surface water on the road is directed toward the cutslope, unless a slide covers the entire road. In this case, the diverted water would have flowed around the debris slide into wheel tracks and eventually run into the roadside ditch. In the case of the Devil's Creek site, however, the crowned surface caused the flow diverted by the cutslope slide to spill onto a fill slope that was not armored to prevent erosion, and that probably would have been susceptible to saturation (and failure) regardless of any measures that were taken.

Road-surfacing Materials

The properties of road-surfacing materials are often a factor in how well a road withstands severe flood events. The road segments considered at the three sites were all aggregate surfaced, but the surfacing on top (the most recently applied) was not capable of withstanding the velocity of the flows during these storm events. In several locations, older aggregate surfacing that became exposed only after the newer, top layer of surfacing was washed away, stayed intact. This older surfacing tended to have more fines, greater plasticity, was better consolidated, and was consequently able to hold up better to the flood flows. The newer surfacing had fewer fines and less plasticity. These differences could be a result of differences in the materials as they were initially installed, or of changes in characteristics that develop in any surfacing material as it becomes buried under newer material. Typically, surface material is subject to the de-consolidating influence of vehicle traffic and maintenance equipment, which tends to reduce the shear-resisting properties of any surfacing material. To protect the integrity of the road surface during storms (which may result in failed drainage systems), rock sources that produce well-graded material with adequate plasticity should be chosen. Management of the quantity and characteristics of vehicle traffic should also be considered. For example, reducing vehicle tire pressures has been shown to reduce the degradation of traveled-way surfaces.

CONCLUSIONS, SUMMARY AND RECOMMENDATIONS

Many lessons can be learned regarding forest roads from flood events such as those that occurred on the Detroit Ranger District during 1995 and 1996. While it is difficult to predict where damage will occur, risk can be assessed, and in these particular cases could have resulted in preventive measures that would have reduced damaging effects.

While it is not expected that all damage from intense storms will be avoided, damage can be minimized. The three sites featured in this report provided good examples of situations where relatively low-cost changes in drainage design and maintenance practices could pay large dividends in reducing flood-repair costs.

It is apparent from the study of these three sites that seemingly small details can lead to unexpectedly large and catastrophic failures. Some examples became apparent during the assessment of damage at the three sites that are the subject of this report:

1. Hydraulically undersized stream culverts

2. Hydraulically inadequate spacing of ditch relief culverts

3. Poor inlet/channel relationship, allowing debris and bedload to accumulate and plug culverts

4. Lack of fail-safe drainage features—ditch dams, rolled grade or drain dips, and inadequate maintenance frequency—allowing local failures to initiate damage affecting larger areas and impact higher-valued resources.

When the roads considered here were built (approximately 1960), it was assumed that adequate maintenance would be done. Regular, properly performed maintenance is designed to make sure that the small details such as road surface and ditch condition do not degrade to the point that catastrophic damage occurs during storm periods.

Planning for reconstruction, maintenance, or new road construction should include consideration of the risk and consequence of culvert failures, insurance measures where failures pose risk to resource values, and fail-safe road drainage design. Specifically, this means analyzing the potential for diversion of stream water to the road-drainage system; looking for and avoiding the possibility of progressive failure of down-grade culverts; planning for buffer strips; using appropriate surfacing and ditch materials; designing adequate culvert spacing; and considering local slope stability when specifying shape of the road surface.

On these sites, the planning for drainage should have included:

- A hydrologic and hydraulic analysis to design all stream crossings. This would have resulted in stream crossings that were more likely to provide the capacity to pass debris and bedload during storms.

- A cross-drain spacing analysis based on soil type, road grade, hydrologic input, and location of the road on the slope. This would have resulted in more frequent ditch relief culverts.

- Ditch erosion-control measures such as riprap or grass.

- Emergency overflow surface drain features at stream crossings to allow water to pass across the road near a stream crossing if the culvert becomes plugged. This might have included shaping the road grade, by using broad-based dips, and hardened surfaces at these points, or at least consideration of surface material that could better resist erosion.

The three flood-assessment sites considered for this report illustrate the need for planning and designing road-related drainage according to the following general guides:

1. Know the soil types of the subgrade, cut and fill slopes, and nearby areas, and use this information for planning drainage and erosion control measures.

2. Use cross-drain spacing guidelines that take into account the native, subgrade, traveled-way surface, and ditch surfacing materials.

3. Use hydrologic and hydraulic analyses to determine correct culvert sizes thereby preventing overtopping of a site. This should be done at all stream and drainage sites, even though they may appear very small. This analysis creates a lower limit for culvert sizing, sizing the culvert to match the dimensions of the stream channel. The recommended minimum-size culvert for any stream is 600 mm (24 in).

4. Consider the debris and bedload characteristics of the site and the associated drainage area and increase the size of culverts to enable the pipe to allow storm flows to pass when partially plugged.

5. Examine all stream crossings to determine the possible consequences of a large-storm event on stream bedload movement and debris potential. The cost of improved drainage can be much less than repairing the resulting damage to drainage facilities that are inadequate to handle storm events. Consider construction of a diversion-prevention dip to ensure overtopping flows are directed back into the channel (Copstead, et al. 1998, Furniss, et al. 1997).

UNIT CONVERSIONS

Multiply	by	To get
mm (millimeters)	0.0394	in. (inches)
cm (centimeters)	0.394	in. (inches)
m (meters)	39.4	in. (inches)
m (meters)	3.28	ft (feet)
hectares	2.47	ac (acres)
m^3 (cubic meters)	1.31	yd^3 (cubic yards)

CULVERT SIZE CONVERSIONS

Metric	English
450 mm	18 in.
600 mm	24 in.
750 mm	30 in.
900 mm	36 in.
1200 mm	48 in.
1500 mm	60 in.

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