Hydrology of Forest Roads in the Oregon Coast Range

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Abstract
The spacing of cross drain culverts on forest roads has historically been determined using soil type, road grade, and design rainfall intensities in combination with the experience of the forest engineer. Design criteria for culvert spacing has implicitly been to minimize ditch erosion. Contemporary issues, including the effects of forest roads on watershed hydrology and the occurrence of road-related landslides, indicate a need to incorporate the hydrology of roads into road drainage design. We measured ditch flow from ten road segments in the Oregon Coast Range, and two distinct hydrologic behaviors were observed. For one subset of road segments, ditch flow was continuous throughout the wet season (intermittent), and it increased in response to regional, wet mantle storms. For a second subset, ditch flow occurred only in response to periods of high intensity rainfall (ephemeral). We hypothesize that the source of ditch flow drives the hydrologic behavior of the runoff. Intermittent flow in road ditches appears to be the result of intercepted subsurface flow by the road cutbank, while ephemeral flow appears to be the result of runoff from the road surface. At this time it is not possible for us to predict the hydrologic behavior of a road segment based on physical characteristics. However, it is obvious that these different hydrologic behaviors have different inherent risks and, as such, merit appropriate design and management considerations.

Introduction
Guidelines for the design of forest road drainage in the Pacific Northwest were first published over forty years ago (Arnold 1957), and modified versions of these guidelines are still used widely today. They incorporate information on soil texture, road gradient, and rainfall intensity to determine adequate ditch-relief culvert spacing. The goal of Arnold’s (1957) guidelines was to minimize erosion from the road ditch, however concerns with watershed hydrology and accelerated erosion have changed the focus of the design of forest road systems.

Overland flow is rare in forests of the Pacific Northwest, so land managers’ attention was first directed to sediment-laden surface flow from roads and ditches. Researchers characterized road surface hydrology, developed sediment-discharge rating curves, and showed that sediment production was linked to geology and traffic level (Reid and Dunne 1984, Vincent 1985, Kahklen 1993, Luce and Black 1999, Kahklen 2001). Other studies have indicated that road-related landslides in steep, landslide-prone terrain can generate orders of magnitude more sediment than road surface runoff (Beschta 1978, Grant and Wolff 1991). Road cutslopes can intercept large volumes of subsurface flow and cause it to be concentrated by culverts. Thus road-related landslides and interception of subsurface flow have been a recent focus of hillslope hydrology research (Megehan 1972, Wemple 1998, McGee 2000).

Arnold (1957) used empirical data to make basic soil science useful to forest engineers. Since then, it has become clear that the hydrology of hillslopes and forest roads are linked but not well understood. There is a need to further incorporate hydrology into road management; nevertheless no method exists. The first step in developing such a method is to collect data on the hydrology of forest roads. Our objective for these studies was to classify road segments based on hydrologic considerations. Specifically, we wanted to determine how the hydrology of the road was affected when the road ditch carried intercepted subsurface flow, compared to when it carried only runoff from the road surface.

Methods
This paper combines results from two road research projects in the Oregon Coast Range. We primarily chose road segments that were located on sandstone geology, although some were located on intrusive igneous material. Road segment length ranged from 40m to 200m, and width ranged from 4m to 6m. Roads were crowned with inboard ditches. In the first project, we installed six trapezoidal flumes to measure ditch flow on six road segments. We paired each flume with a tipping bucket rain gauge, so ditch flow and rainfall were measured from October 1999 to July 2000.

In the second project, we studied five road segments from October 2000 to May 2002. At each road segment, we installed a vinyl fence into the road ditch, longitudinally dividing it into two separate ditches. One carried intercepted subsurface flow, while the second ditch carried road surface runoff. We then installed flumes to capture flow from each ditch. Therefore total runoff from the road ditch could be separated into known amounts of surface and intercepted subsurface runoff. Runoff hydrographs from the road surface could be described exactly and then compared to hydrographs derived from hillslope runoff.
Results
One storm from December 2002 is an example of how the double-flume sites responded to precipitation. One of the five double-flume sites intercepted subsurface flow from the hillslope, and a hydrograph from that site is shown in Figure 1. The other four double-flume sites had only runoff from the road surface, a hydrograph from one site is shown in Figure 2. In Figure 1, during a 35 hour storm, in which 98 mm of rain fell, 520 m$^3$ of intercepted hillslope water flowed down the road ditch, and the peak discharge was 3.5 l/s. Discharge increased gradually in response to the storm, and the ditch continued to flow after the storm ended (Figure 1). In fact, it flowed throughout the rainy season and behaved like an intermittent stream. Discharge in the other four ditches flowed only in response to high intensity pulses of rainfall (Figure 2). These ditches behaved like ephemeral streams and did not flow at all between storms. For the storm in Figure 2, 70 mm of rain fell in 47 hours. Yet only 0.2 m$^3$ of road surface water flowed down the ditch, and the peak discharge was 0.04 l/s.

Precipitation and runoff data for both research projects are shown in Figures 3 and 4. For the project with double flume road segments, the source of the ditch water was known and labeled as such. For these data, the road segment with intermittent flow had a peak discharge and flow volume that were two to three orders of magnitude greater than roads with ephemeral flow. When the data from the single flume road segments were plotted and labeled with the hypothesized flow pathway, they followed the same pattern as the double flume segments. Where we hypothesized that hydrologic behavior was governed by intercepted hillslope water, these data had similar peak discharges and flow volumes to the intermittent ditch in the second research project. Where we hypothesized that hydrologic behavior was governed by road surface runoff, these data had peak discharges and flow volumes similar to ephemeral ditches from the second research project (Figures 3 and 4).

Road segments can be stratified by hydrologic behavior based on runoff response factor. We described the hydrologic behavior of each segment in the first project as either intermittent or ephemeral, and then we used a response factor to hypothesize the source of road ditch flow (Table 1). The runoff response factor is the total volume of

![Figure 1](image1.png)  
**Figure 1.** Intermittent ditch flow (Q) hydrograph for a forest road segment in the Oregon Coast Range, December 2001. Segment length is 72m. Each point on the rainfall curve (P) represents a bucket tip in the rain gauge. Infrequent tips indicate low intensity rainfall. Frequent tips show up as a steep curve, indicating high intensity rainfall.

![Figure 2](image2.png)  
**Figure 2.** Ephemeral ditch flow (Q) hydrograph for a forest road segment in the Oregon Coast Range, December 2001. Segment length is 64m. Each point on the rainfall curve (P) represents a bucket tip in the rain gauge. Infrequent tips indicate low intensity rainfall. Frequent tips show up as a steep curve, indicating high intensity rainfall.
ditch flow per storm divided by the volume of rainfall that fell on the road surface, and it’s expressed as a percentage.

![Figure 3. Storm flow volumes for forest road ditches in the Oregon Coast Range. Axes are logarithmic scale. The solid circles and triangle are from water year 2002, while the open circles and crosses are water year 2000.](image)

It indicates what proportion of rainfall on the road surface actually flowed through the ditch as runoff. Roads with ephemeral flow had response factors of less than 100%. In other words, no more water flowed through the ditch than actually fell on the road surface. Roads with intermittent flow had response factors much greater than 100%. In other words, the source of ditch flow was more than just the road surface; it was the hillslope. Response factors for ephemeral ditches in the first project were less than 100%, similar to ditches with only surface runoff in the second project. Response factors for intermittent ditches in the first project were greater than 100%, similar to the ditch which carried intercepted subsurface flow in the second project.

**Table 1.** Response factor, expressed as percent, for ten forest road segments in the Oregon Coast Range. Number of segments per road type is given in parentheses.

<table>
<thead>
<tr>
<th>Runoff Type</th>
<th>Confirmed</th>
<th>Hypothesized</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ephemeral, Surface Flow</td>
<td>1 - 20 (4)</td>
<td>7 - 70 (4)</td>
</tr>
<tr>
<td>Intermittent, Subsurface Flow</td>
<td>1200 (2)</td>
<td>800 - 3700 (1)</td>
</tr>
</tbody>
</table>

**Discussion**

We identified two types of hydrologic behavior in these roads in the Oregon Coast Range. Some road segments exhibit intermittent hydrologic behavior. Water flows in the road ditch throughout the winter rainy season, and the ditch flow is governed by intercepted hillslope water. Other road segments exhibit ephemeral hydrologic behavior. Road ditch flow is governed by road surface runoff, which only occurs in direct response to high intensity rainfall. There are roads that fall in between these two extremes (Figures 3 and 4). They may take mostly road surface water, but they intercept hillslope water only during the wettest storms of the year.

In our study of ten road segments, those that exhibited ephemeral hydrologic behavior were most common (8 out of 10). Furthermore, this hydrologic behavior represents a lower risk of drainage failure for the road. Road segments that exhibited intermittent hydrologic behavior were less common (2 out of 10), and more likely, they represent a higher risk of drainage failure for the road. The data for these research projects has not all been analyzed, and more definitive results await that analysis. At this time, it is not possible for us to predict the hydrologic behavior that a road segment will exhibit without...
continuously monitoring the ditch flow. However, once identified, road segments that exhibit intermittent hydrologic behavior should require more attention and maintenance than road segments that exhibit ephemeral behavior.

Literature Cited


