Forest Practices Technical Note Number 5

Version 1.0

Determining the 50-Year Peak Flow and Stream Crossing Structure Size for New and Replacement Crossings

Effective May 10, 2002

Introduction

The objective of this note is to provide the essential information that will enable landowners and operators to install stream-crossing structures that will pass a 50-year peak flow. The guidelines described in this document supersede all past guidance documents for designing structures on state and private forestlands to pass a 50-year peak flow. Stream crossing structures are exposed to occasional peak flows that threaten to damage or wash out the structure. Costly repairs or replacements, disruptions to log hauling operations, and damage to fish habitat in downstream portions of the stream can occur when a peak flow exceeds the capacity of a stream crossing structure. The Forest Practices Act requires that stream crossing structures be adequately sized to handle a 50-year peak flow without backing up stream flow behind the road fill. This means that stream flow would reach the top of the culvert, or bottom of the bridge, once every 50 years on average. A variety of terms are used to refer to the peak flow having a 50-year recurrence interval. Sometimes it is called the "50-year peak flow" or "the 50-year storm." The use of the method described in this note will achieve compliance with the rules, while methods outside of this note may not comply with the rules and require further review by the ODF staff hydrologist.

This note begins with how to determine the 50-year peak flow at the proposed stream-crossing site, followed by how to determine the flow capacity of the structure being installed. There is a separate method for making this determination depending on whether a channel spanning structure (short or long-span bridge or open-bottomed arch) or a culvert is being installed, as well as whether or not the structure is on a fish-bearing stream (see Technical Note #4 for fish passage guidelines). The final section describes an optional alternative sizing method for stream-crossing structures in wide flood plains.

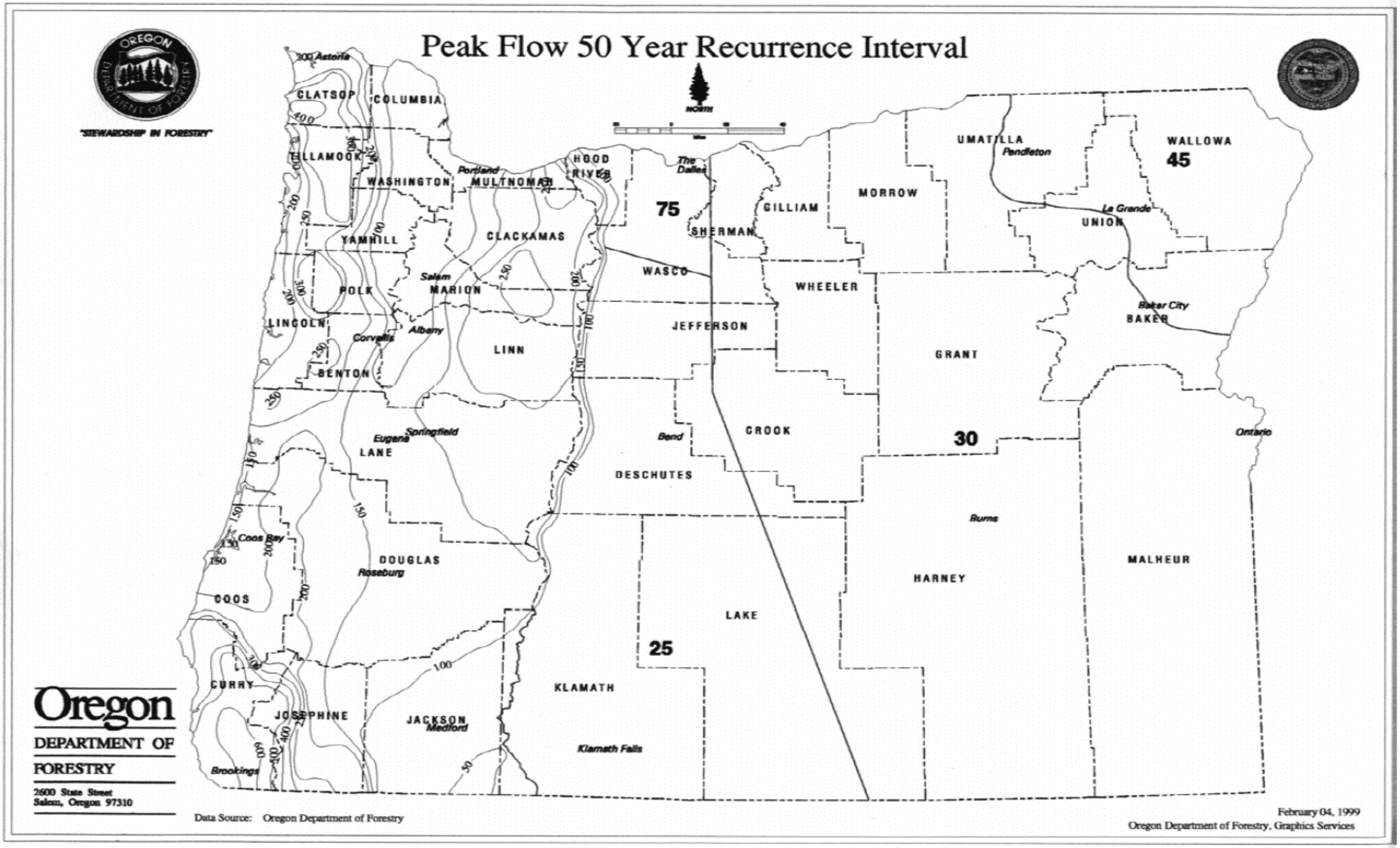
Determine the 50-year Peak Flow

Since few forest streams have long-term gaging stations, we usually do not know what the 50-year peak flow is at a proposed stream crossing. However, the 50-year peak flow can be estimated using information gathered from surrounding gaged streams. The Oregon Department of Forestry (ODF) analyzed all the available peak flow data for forest streams in Oregon and developed relationships that will allow you to estimate with some confidence the 50-year peak flow for a proposed culvert or bridge installation.

Information about 50-year peak flows throughout Oregon is displayed in Figure 1, a map titled "Peak Flows for Forest Streams" (a larger scale version of this map is available from ODF in

Salem). The values shown on the map indicate the 50-year peak flow in units of cubic feet per second (cfs) per square mile of drainage area.

For example, if a proposed culvert installation is at a location where the map shows the 50-year peak flow to be 200 cfs per square mile, and the drainage area upstream of the culvert installation is 0.7 square miles, then the culvert would need to be sized to handle a flow of 140 cfs (200 x 0.7 = 140).


Peak Flow 50 Year Recurrence Interval

"STEWARDSHIP IN FORESTRY"

Oregon
DEPARTMENT OF
FORESTRY
2600 State Street
Salem, Oregon 97310

Data Source: Oregon Department of Forestry

February 04, 1999
Oregon Department of Forestry, Graphics Services

Figure 1. 50-year peak flows for forest streams in the Oregon.

For eastern Oregon, the current procedure has divided the eastside into four general runoff regions as follows (Figure 1). The Eastern Cascade geographic region has two distinct areas. North of the Warm Springs Indian reservation the 50-year peak flow is 75 cfs per square mile and 25 cfs per square mile south of the reservation. The Blue Mountains geographic region also has two distinct areas. Northeast of Interstate 84 the 50-year peak flow is 45 cfs per square mile and elsewhere it is 30 cfs per square mile.

For western Oregon, 50-year peak flows are generally higher than on the eastside and can vary considerably over short distances (Figure 1). Lines are shown on the map indicating areas of common peak flow values, just as contour lines on a topographic map show areas of common elevation. In western Oregon, 50-year peak flow values vary from less than 50 cfs per square mile for an area east of Medford to 600 cfs per square mile for an area east of Brookings.

When determining the 50-year peak flow from the map and the location of a proposed culvert or bridge installation lies between two lines on the map, interpolate an appropriate value. For example, if the culvert location lies halfway between the 150 and 200 lines, then the appropriate value to use is 175 cfs per square mile [(150+200) / 2 = 175].

The drainage area upstream of a proposed culvert or bridge installation is an important piece of information to know when calculating the 50-year peak flow. Using a dot grid is a simple way to measure the drainage area, however there are other tools, such as a planimeter or digitizer. A topographic map should be used and the drainage boundary carefully identified as shown in Figure 2. Note that as you draw in the drainage boundary upstream of the proposed culvert location, the boundary is always at right angles to the elevation contours.

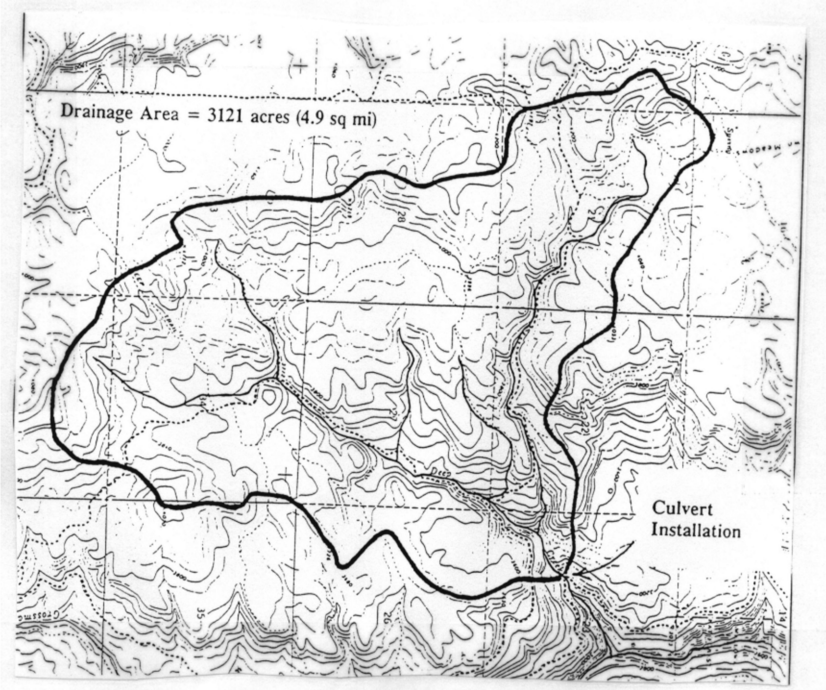


Figure 2. Example of the drainage area outlined upstream of a proposed culvert installation in far northeast Oregon. The drainage area is 4.9 square miles and the 50-year peak flow for this area is 45 cfs per square mile, so the culvert will have to be large enough to handle a flow of 220 cfs (45 x 4.9 = 220). Adapted from landowner reference manual.

A grid for use with 7.5-minute USGS maps (the map scale is 1:24000) is a relatively simple tool for determining the watershed area. First outline the drainage boundary and then place the grid over the area in a random orientation. Count the number of squares and fractions of squares that fall within the drainage boundary. Alternatively, you can count the number of grid intersections that fall within the drainage boundary. Multiply the number of squares or grid intersections by 0.036. This will give you the drainage area in square miles.

> *For example, if the number of squares counted within the drainage boundary was 46, then the drainage area would be 1.7 square miles [46 x 0.036 = 1.7].*

Determine the Flow Capacity of the Stream Crossing Structure

CHANNEL-SPANNING STRUCTURES

You need the following information to determine the appropriate dimensions for short and long-span bridges and open-bottom pipe arch structures capable of handling the 50-year peak flow:

- **Stream gradient**: The preferred method for determining stream gradient is to use the stream profile. The stream profile is the streambed elevation measured at a series of points up and down the stream about the road crossing. It can be measured using a hand level (or similar instrument that can be re-calibrated before each use) and stadia rod that will give a fixed elevation above the streambed. Often the existing stream profile immediately above and below the road crossing is artificial due to an existing culvert installation. Both scour at the outlet and deposition upstream of existing undersized culverts is common. Because of these types of problems, it is preferable to measure a long profile of the stream gradient between two points at least 100 feet upstream and downstream from the influence of the existing road/stream crossing.
- **A cross-sectional drawing of the bridge and stream channel**: The drawing must be drawn to scale (see Figure 3).

First, on the cross-sectional drawing of the channel and bridge design, draw a horizontal line 3 feet beneath the bridge's lower surface (Figure 3). This represents the water level during the 50-year peak flow. If feasible, it is recommended that three feet of clearance, or free board, be provided for to pass large wood and debris that is floating downstream.

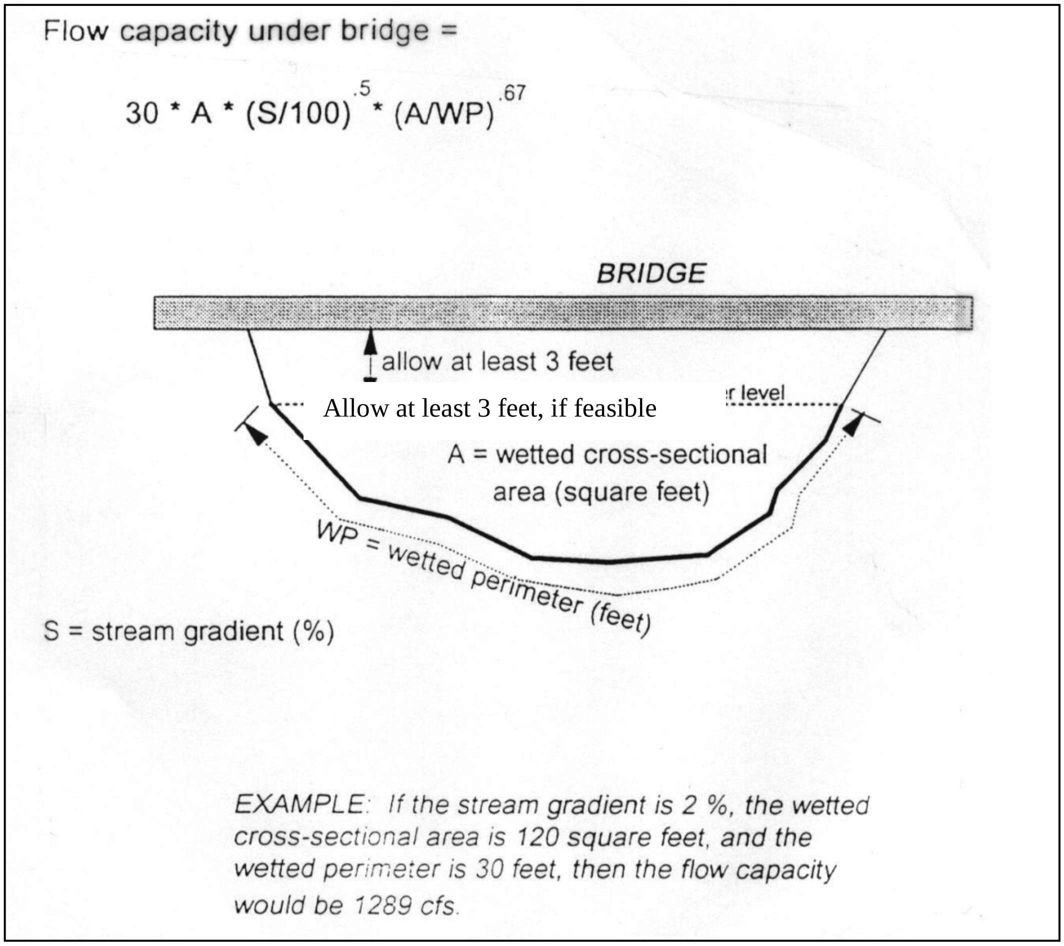
Next, measure the length of channel (in cross section) that would be wetted when the water is at a height three feet below the bottom of the bridge. This length is called the wetted perimeter. Write down what this length would be (in feet) in the field. Next, measure the cross-sectional area of water that would exist when the water is at a height three feet below the bottom of the bridge. This is called the wetted cross-sectional area. Write down what this area would be (in square feet) in the field. Finally, calculate the flow capacity of the bridge (in cubic feet per second) using the equation:

Equation 1:

$$\textbf{Flow capacity} = 30 \times A \times (S / 100)^{0.5} \times (A / WP)^{0.67}$$

where: A = *wetted cross-sectional area (square feet)*
S = *stream gradient (in percent, measured using a tripod level or similar device)*
WP = *wetted perimeter (feet)*

The bridge design is adequate if the flow capacity (derived by the equation) is greater than the 50-year peak flow determined for the site. If the flow capacity is less than the 50-year peak flow, raise the height of the bridge in the design until the 50-year peak flow capacity is met.



EXAMPLE: If the stream gradient is 2 %, the wetted cross-sectional area is 120 square feet, and the wetted perimeter is 30 feet, then the flow capacity would be 1289 cfs.

Figure 3: Cross-section drawing of a bridge and stream channel and the equation to calculate the flow capacity under the bridge. (Adapted from landowner reference manual).

CULVERTS

Type N & D streams

For non-embedded culverts installed on streams that are *not* fish-bearing, take the 50-year peak flow calculated above and use Table 1, or Equation 2 or 3 if the culvert size does not appear in Table 1, to determine the size with a flow capacity equal-to or greater-than the 50-year peak flow. The culvert size that corresponds to this flow is the minimum size needed.

Type F streams

Before determining if the culvert will pass the 50-year peak flow, the culvert type and size must first be chosen based on what is needed to provide fish passage (see Technical Note #4). Once you have determined the strategy and culvert size for meeting fish passage requirements, the *next* step is to check and see that it will also pass the 50-year peak flow. In order to evaluate the peak flow capacity for culvert installations designed to pass fish, the percent of rise/ diameter with culvert sinking must be taken into account when calculating flow capacity. For hydraulic designs (weir/baffles culverts), the height occupied by the weir/baffled culverts must be accounted for in a similar manner. The method for verifying the culvert capacity involves four steps:

Step #1: Potential flow capacity: Using Table 1, or equations 2 or 3, determine the potential flow capacity of the culvert *without* embedding.

Step #2: Resulting percent loss in flow capacity due to sinking: Calculate the percent of the rise/diameter *with* sinking and the corresponding percent-loss in flow capacity using Table 2 (columns A and B, or A and C)

Step #3: Effective flow capacity: Reduce value determined in step 1 by the percentage determined in step 2. This is the effective flow capacity after embedding.

Step #4: Compare to 50-year Flow: Compare the effective flow capacity to value to the 50-year peak flow value. If it exceeds the 50-year peak flow, no further changes are needed. If it is less-than this value, increase the size of the culvert accordingly.

Use Table 1, or Equation 2 or 3 if the culvert size does not appear in Table 1, to determine the potential flow capacity of the culvert size chosen in developing the fish passage design. Equation 1 and 2 are only valid for culverts up to about 10 feet in diameter or span. For larger culverts the potential flow capacity must be calculated individually, or obtained from the culvert manufacturer. Table 2 provides a comparison between the percent of the culvert height embedded and the corresponding loss in flow capacity[1].

It should be noted that the flow capacity of a culvert with almost any degree of slope is not dependent on its steepness. A culvert installed at a one-percent gradient has a capacity similar to one installed at an eight-percent gradient. The flow capacity for culverts placed in streams with a gradient less-than 1%, however, are outlet-controlled and generally have a lower flow capacity than what is calculated using Equation 1 or 2 and shown in Table 2. The degree to which it is reduced depends on the stream conditions at the outlet. In general, where an outlet-controlled crossing is constructed, the culvert should be oversized and/or an overflow dip should be constructed. Streams on forestlands with this low of a gradient are relatively rare, and thus will be dealt with on a case-by-case basis.

The following are two examples of how to go about ensuring that the culvert will pass the required 50-year peak flow. The first example uses a pipe-arch and the second example uses a round pipe.

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[1] Since flow capacity calculations are largely based on cross-sectional area, percent-changes in cross-sectional area can be assumed to result in the same percent-changes in flow capacity.

Example #1:

Lets say that you have a 3% gradient stream with an active channel width of 6.7 feet and a 50-year peak flow of 100 cfs. You have chosen the streambed simulation strategy (see Technical Note #4) and are using a pipe-arch that is 84”x 61” so that the effective width will be equal-to or greater-than the active channel width. It will also be sunken 18-inches into the streambed (sinking the pipe the greater of 20% of the culvert height or 18-inches).

Step 1: The 84” x 61” pipe-arch has a 170 cfs capacity (Table 1—or use Equation 3 if the size is not listed).

Step 2: 18”/61” = 30% of rise with embedding (Look up in Table 2, Column A). 30% of rise = 33% loss of flow capacity (Table 2, Column B).

Step 3: 33% loss of flow capacity means that the 84” x 61” pipe-arch will effectively have a 114cfs capacity (67% of 170 cfs).

Step 4: Effective capacity is greater-than the 50-year peak flow (114 cfs >100 cfs).

In this example, the pipe size chosen to ensure fish passage will result in passing 114 cfs, or 14 cfs more than needed to pass the 50-year peak flow. No further changes to the design are needed as both the fish passage and peak flow requirements will be met.

Example #2:

For the same crossing using a round culvert, the size chosen to ensure fish passage would be an 84-inch diameter pipe sunken 34” (considering active channel width and minimum sinking depth criteria). As a check to ensure that the effective width is equal-to or greater-than the active channel width, refer to Table 1, Column A and D. A 40% rise in diameter equates to an effective width of 98% of the diameter, or 6.9 feet (0.98 x 7’=6.9’). This is equal-to or greater-than the 6.7’ active-channel width, so the effective width criteria is met. Next, go through the same steps in the previous example:

Step 1: An 84-inch round pipe has a 262 cfs capacity (Table 1—or use Equation 2 if the size is not listed).

Step 2: 34”/84” = 40% of dia. with embedding (Look up in Table 2, Column A). 40% of dia. = 37% loss of flow capacity (Table 2, Column C).

Step 3: 37% loss of flow capacity means that the 84” round culvert will only be able to pass 165 cfs (63% of 262 cfs).

Step 4: Effective capacity is greater-than the 50-year peak flow (165 cfs >100 cfs).

In this example, the pipe size chosen to ensure fish passage will result in passing 165 cfs, or 65 cfs more than needed to pass the 50-year peak flow. No further changes to the design are needed as both the fish passage and 50-year peak flow requirements will be met.

Equation 2: For round culverts (<u>only accurate for diameters up to 10 feet</u>)

$$\text{Max Flow} = (0.0037) \times (\text{Diameter})^{2.52}$$

where: Max flow = maximum flow capacity of the culvert in cubic feet per second when H/D is 1.

Diameter is measured in inches.

Equation 3: For pipe arches (<u>only accurate for spans up to 10 feet</u>)

$$\text{Max Flow} = (0.0037) \times (\text{Rise} \times \text{Span})^{1.26}$$

where: Max flow = maximum flow capacity of the culvert in cubic feet per second when H/D is 1.

Rise and Span are measured in inches

Table 1. Flow capacities for round and pipe-arch culverts without embedding. The assumptions for this table are a projecting inlet and headwater depth equal to the diameter or height of the culvert (H/D = 1). This table is to be used for rough field estimates of flow capacities when scoping out various culvert sizes. For round culverts up to 10 feet and pipe arches up to 10 feet in span, see equations #2 and #3 for determining the flow capacity of a culvert size not included in this table. For culverts greater than 10 feet in diameter or span not included in this table, accurate flow capacity information will need to be acquired independently using information from the culvert manufacturer.

CIRCULAR CULVERTS		***PIPE-ARCH CULVERTS***	
DIAMETER (inches)	Maximum flow capacity (cfs)	**SPAN x RISE** (inches)	Maximum flow capacity (cfs)
24	11	24" x 18"	7
27	15	28" x 20"	9.5
30	20	35" x 24"	16
33	25	42" x 29"	26
36	30	49" x 33"	37
42	45	57" x 38"	54
48	65	64" x 43"	70
54	90	71" x 47"	90
60	110	73” x 55”	130
66	145	84" x 61"	170
72	180	98" x 69"	240
78	220	114" x 77"	330
84	260	*137" x 87"*	*460*
90	320	*154" x 100"*	*650*
96	380	*184" x 111"*	*910*
102	450	*199” x 121”*	*1100*
108	500		
114	580		
120	670		
126	*750*		
132	*860*		
138	*920*		
144	*1000*		

Table 2. Comparison of percent of culvert rise/diameter with embedding and corresponding cross-sectional area loss for round and pipe arch culverts. Also the effective width, in percent of diameter, with loss of area for round culverts.

A	B	C	D
Percent of rise/ diameter with embedding of culvert	% loss of flow capacity: **Pipe Arch Culvert**	% loss of flow capacity: **Round Culvert**	*Effective width (% of diameter) of **round culvert** with embedding*
10	8	5	*60*
15	14	9	*71*
20	20	14	*80*
25	26	20	*87*
30	33	25	*92*
35	39	31	*95*
40	45	37	*98*
45	51	44	*99*
50	57	50	*100*
55	63	56	
60	69	63	
65	74	69	
70	79	75	

Alternative Structure Sizing for Wide Flood Plains

Roads built across streams having wide flood plains are often less likely to cause damage to the stream over time if the road fill is designed with a reduced height. Less fill material in the flood plain means that less material is available to be delivered to the stream in case of a failure during an extreme flood event. In order to allow a low fill design, the rules give the operator the option to install a culvert or bridge with a lower flow capacity than would otherwise be required. Figure 4 illustrates the features of this optional design for wide flood plains.

A low fill design must contain the following elements to be approved:

- The crossing must be designed to provide fish passage (if the stream is a Type F).
- The flood plain of the stream should be at least five-times the width of the active channel.
- The culvert or bridge must be the same width as the active channel.
- An overflow depression must be constructed in the road fill at a location away from the crossing and at an elevation lower than the top of the culvert, or the bottom of the bridge.
- The road surface and downstream edge of the overflow depression must be armored with rock of sufficient size and depth to protect the fill from eroding when a flood flow occurs.

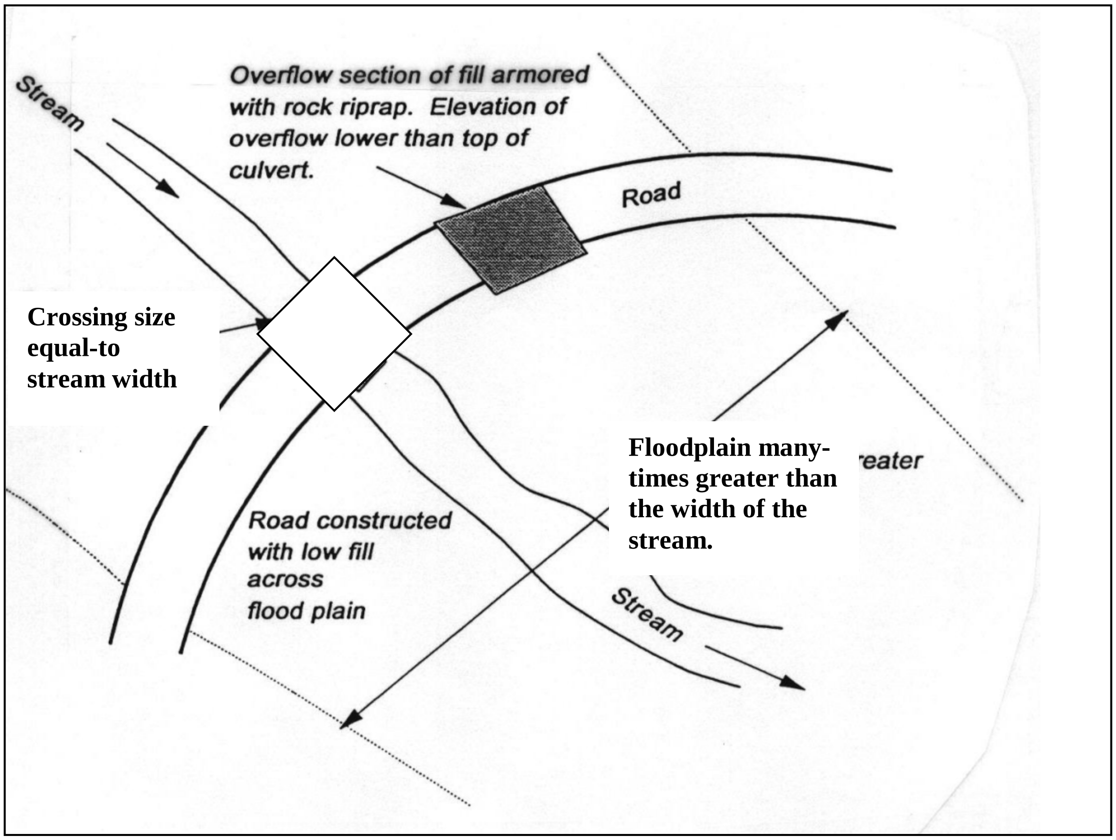

Figure 4. Features for the optional design of constructing a road with low fills and a culvert or bridge with less-than a 50-year peak flow capacity. (Adapted from landowner reference manual)

Sources of More Detailed Technical Information

Normann, M.N. and others. 1985. Hydraulic design of highway culverts. Report FHWA-IP-85-15. Federal Highway Administration.

Oregon Department of Transportation. (ODOT). 1990. Hydraulics manual. Oregon Department of Transportation Salem

Oregon Department of Forestry Field Offices

For more information about the Oregon Forest Practices Act or the Forest Practice Rules, please contact your local Oregon Department of Forestry office which can be found at http://www.oregon.gov/ODF/Working/Pages/FindAForester.aspx *or the headquarters office at 2600 State Street, Salem, Oregon 97310. 503-945-7200.*