Low-Water Crossing Structure Selection Process

When deciding whether to use a low-water crossing and which low-water crossing type to select, it is important to evaluate the following: the site, costs, streamflow patterns, channel characteristics, and aquatic organism passage (AOP) needs. The various factors can be complicated and interrelated, but the selection process is simplified by a two-step process. First, evaluate whether a low-water crossing structure is appropriate and preferable to a culvert or bridge. Second, decide on the appropriate type of low-water crossing based upon the site characteristics and AOP needs. Each decision can be reached by considering these basic questions:

Questions To Consider in Choosing Whether To Use a Culvert, Bridge, or Low-Water Crossing

- Is the road a noncritical route or is there alternative access to the area?
- Is the traffic use low and are occasional traffic delays acceptable?
- Is the channel ephemeral or does it have relatively low baseflow?
- Does the watershed have large flow fluctuations or a "flashy" response?
- Does the channel carry a large amount of debris?
- Is the channel unentrenched to moderately entrenched (broad and shallow)?
- Is a low-water crossing the most cost effective or inexpensive structure?

If the answer to most or all of these questions is **YES**, then the site is likely a good candidate for a ford or low-water crossing.

Questions To Consider in Choosing The Type of Low-Water Crossing

- Does the stream have low or zero baseflow and "flashy" high flows?

If **YES**, first consider a simple (at-grade), unimproved ford.

- Are the channel bottom and streambank materials soft or erodable?

If **YES**, consider an improved ford with a hardened driving surface.

- Is AOP or maintaining stream function an important issue at this crossing?

If **YES**, consider (1) an unimproved ford with a natural bottom; (2) an improved at-grade ford with a roughened driving surface, (3) a low-water bridge, or (4) a high-VAR ford.

- Is driving through water frequently prohibited or are long traffic delays unacceptable?

If **YES**, consider only the vented structures and low-water bridges with an elevated driving surface.

- Is the channel incised or entrenched?

If **YES**, consider a vented structure with boxes that match the channel's shape.

- Is the channel very broad or does it carry a considerable baseflow with high peak flows?

If **YES**, consider a relatively long span low-water bridge.

- Does the channel carry a lot of large woody debris?

If **YES**, consider an unimproved or improved unvented ford.

- Does the drainage pass periodic debris torrents through an incised channel?

If **YES**, consider rock-fill fords. Alternatively, massive concrete vented fords have been used with trash racks to pass the debris over the structure.

- Is a barrier needed to exclude exotic species?

If **YES**, consider an improved, unvented ford with a raised platform or a raised vented ford with a perched outlet (consider, however, potential adverse channel effects).

- Is a grade control structure needed?

If **YES** to promote aggradation, first consider an improved unvented ford with a raised platform (a low dam). A vented ford with perched vents may also work.

If **YES** to stop headcutting, consider using a structure with a solid, stable bottom and downstream cutoff wall.

Chapter 3—Selecting the Best Structure for the Site

This chapter will help determine (a) whether an overtoppable structure is appropriate at a given site and, if so, (b) which type is most appropriate.

First determine whether a low-water crossing should be considered at all. Section 3.1 outlines considerations that help distinguish sites conducive to low-water crossings from those where an overtoppable structure would be undesirable. If conditions are conducive to a low-water crossing, then consider what *type* of low-water crossing structure would best achieve the multiple objectives of resource protection, traffic access, and safety (section 3.2).

3.1 Is a Low-Water Crossing Appropriate?

More recent confirmation of the ongoing risks of low-water crossings can be found at http://www.floodsafety.com, managed by the nonprofit Flood Safety Education Project.

Low-water crossings have substantial limitations and are most suited for roads with low traffic volumes, and trails. The foremost constraint is public safety. According to a review of National Weather Service reports from 1969 to 1981 (French et al. 1983), nearly half the flood-related deaths in the United States each year were occurring in vehicles. Many of these deaths occurred when people drove into flooded crossings. Drivers may underestimate how fast small streams can rise in some parts of the country during a flood, and they may ignore the possibility the crossing has already eroded. Even 2 feet of water can float and wash away an ordinary car or truck (fig. 3.1).

Low-water crossings—especially vented fords—can also pose significant hazards for boaters and other users who might accidentally approach too closely (Robertson, personal communication). During higher flows, floating objects can be trapped and pinned against the structure by the force of the water. When flows increase such that they submerge a culvert, powerful whirlpools can form that can suck objects on the surface into the culvert opening. For these reasons, vented fords and low-water bridges may not be appropriate on streams that are used for recreation during moderate-to-high flows.

Another safety concern is winter ice on the roadway, a condition hazardous even to slow-moving traffic and especially likely on fords at the low point of the dip. Low-water crossings with steep approaches, particularly unvented fords, may not be good choices for icy roads in winter. Table 3.1 lists the traffic and environmental conditions most and least conducive to selecting a low-water crossing structure.

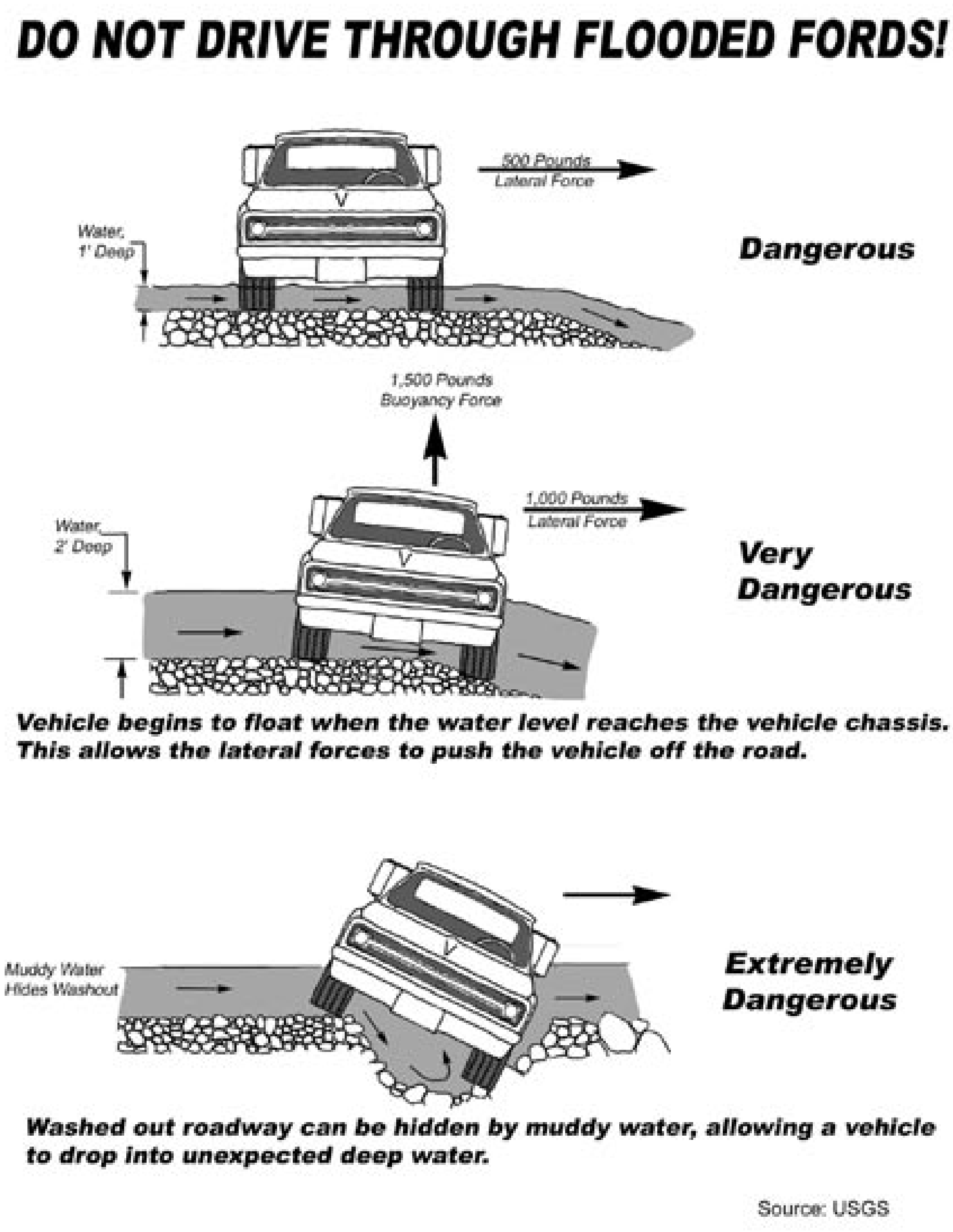

Figure 3.1—Do not drive through floodwaters. Redrawn from USGS Fact Sheet 024-00, March 2000.

Table 3.1—General selection factors for low-water crossings

	Most conducive	Least conducive
Access priority	Low	High
Alternative route	Available	Not available
Traffic speed	Low	High
Average daily traffic	Low	High
Flow variability	High	Low
High-flow duration	Short (hours)	Long (days)
High-flow frequency	Seldom (rare closure)	Often (frequent closure)
Debris loading	High	Low
Channel entrenchment	Shallow	Deep

Access priority/ alternative route

Low-water crossings are not appropriate on roads that access essential public facilities or that serve as the only public route to an area. Many States restrict construction of low-water crossings on school bus routes and on roads required for national defense. Typically, low-water crossings are not desirable for accessing an area with permanent residences. Even alternate routes to isolated towns may qualify as priority access.

Traffic speed

Low-water crossings are most suited for rural roads with low-to-moderate traffic speeds. Unimproved fords may only be driven over at low speeds, less than 10 to 20 miles per hour. Vented fords with a broad, smooth dip and gentle transitions may be suitable for speeds up to 20 to 40 miles per hour. If high-speed traffic is anticipated, then low-water crossings are likely unsuitable for that road.

Average daily traffic during season of use

The lower the traffic volume on a road, the more suitable a low-water crossing is likely to be. With only a few vehicles per day, the consequences of periodic delays are minimal. With increasing traffic volume, the impacts of periodic or occasional delays become more important. Many times, short access roads (i.e., less than half mile of road) see little traffic, making a low-water crossing a desirable option.

Flow variability

Low-water crossings are commonly used in areas with highly variable flows, such as desert streams subject to flash floods and thunderstorm-prone areas. High, short-duration peaks followed by long intervals of very low or no flow are most conducive to low-water crossings as long as traffic interruptions during floods are tolerable. Because standard crossings need to be very large to convey such high flows together with their debris loads, they may not be economically feasible for many low-volume roads. Streams with highly variable flows may also be less stable than streams in which steady baseflows support vigorous riparian vegetation. Putting a large expensive structure on a channel that may shift within the structure's lifetime is even less desirable. Chapter 4, section 4.5 contains information about hydrologic data useful for evaluating flow variability.

High-flow duration

The duration of an overtopping flow controls how long a crossing will be closed. Although weather patterns are the greatest influence (e.g., intense summer short-duration storms), watershed attributes also play a large role. Characteristics of 'flashy' watersheds (where flows rise and fall rapidly) can include the following:

- Steep, short drainage basin (high basin relief).
- Small basin area.
- High drainage density (miles stream/basin area).
- Thin and/or impermeable soils.
- Little or no flood plain.
- Low vegetative cover.

High-flow frequency

The peak-flow frequency during the season that the road or trail is used is another variable affecting the probability of traffic interruptions and safety problems. Look for long-term stream gauge records. Alternatively, road maintenance records, local newspaper archives, or interviews with area residents can indicate the historical frequency of and damage sustained from large runoff events and flooding.

Debris loading

Channels in areas prone to landslides and/or debris flows may be good candidates for low-profile crossings that allow debris to pass over the road.

Channel entrenchment

Channels deeply incised below the adjacent ground surface and channels closely bounded by steep slopes (**confined**) are generally difficult locations for low-water crossings (fig. 2.1). In both cases, the soil disturbance necessary to construct approaches creates the potential for sediment to impair water quality and aquatic habitat. Although some low-water crossings are successful in such locations (case study 6), mitigating potential erosion problems requires special measures, such as paving the approaches and rocking the ditches. Shallow channels on wide flood plains may be good candidates for low-profile crossing structures because the road approaches do not need to ramp up to cross a high culvert or bridge.

Table 3.2 provides more quantitative—although still subjective—selection criteria from a survey of transportation engineers from several different states (Motayed 1982). Although these numbers may not be applicable to all USDA Forest Service locations, they are a starting point for forests to develop their own criteria.

Table 3.2—Quantitative selection criteria for low-water crossings (Motayed et al. 1982).

Criteria	Most favorable for LWC	Least favorable for LWC
Average daily traffic (ADT)	Fewer than 5 vehicles	200 vehicles
Average annual flooding	Less than 2 times	10 times
Average duration of traffic interruption per occurrence	Less than 24 hours	3 days
Extra travel time for alternate route	Less than 1 hour	2 hours
Possibility of danger to human life	Less than 1 in 1 billion (with excellent warning systems)	1 in 100,000
Property damage, dollars	None	1 million
Frequency of use as an emergency route	None	Occasional-frequent

3.2 What Type of Low-Water Crossing Best Fits the Site?

If site and traffic conditions are conducive for a low-water crossing, decide what structure type is best suited to the specific field situation. Table 3.3 lists key site, road management, resource protection, and recreational use factors affecting the choice of structure type. It points out pros and cons of each general structure type for each factor. Keep in mind, however, functionality depends strongly on specific features designed to tailor the structure to the individual site. Chapter 4 contains information on these design considerations.

Low-VAR fords are undesirable in virtually all situations. Table 3.3 mentions them only to warn practitioners about specific effects they can have (see sidebar low-VAR fords).

Why are low-VAR fords not recommended?

In very stable streams, low-VAR fords may not have severe detrimental effects on channel stability. It is common, however, to see at least a fair amount of channel instability associated with these structures. When flow begins to exceed the vents' capacity, low-VAR fords begin to function like low dams. They backwater flow upstream of the structure, and where the stream is carrying a substantial bed sediment load, deposition reduces channel capacity and elevates the streambed. This frequently leads to bank erosion and channel widening. Sometimes, the aggraded stream may also shift its location across the valley floor when it seeks lower ground or a steeper grade (fig. 3.2). In channels that are already laterally unstable, low-VAR structures exacerbate the tendency for bank erosion and channel shift.

Compared to high-VAR fords, these dam-like structures overtop relatively frequently, so scour protection is critical to avoid bed erosion downstream. Even with adequate scour protection, streambed composition can become coarser when the fines are winnowed away, which happens in channels downstream of dams that impound sediment. Also, depending on how well the ford matches channel shape, the backwatered pool upstream may flow out around the structure's edges. When flow reenters the channel downstream, it can erode both the flood plain and streambanks.

Because the vents or pipes in low-VAR fords are small compared to the stream, they plug easily and tend to require frequent maintenance. They are also hazards to swimmers and boaters. In addition to being small, they may or may not be installed at stream grade and they are usually at least partial barriers to AOP.

For all these reasons, the authors' recommend high-VAR fords be used when a vented ford is desired. Low-VAR fords are not included in table 3.3, which deals with considerations for selecting the type of structure best suited to a site.

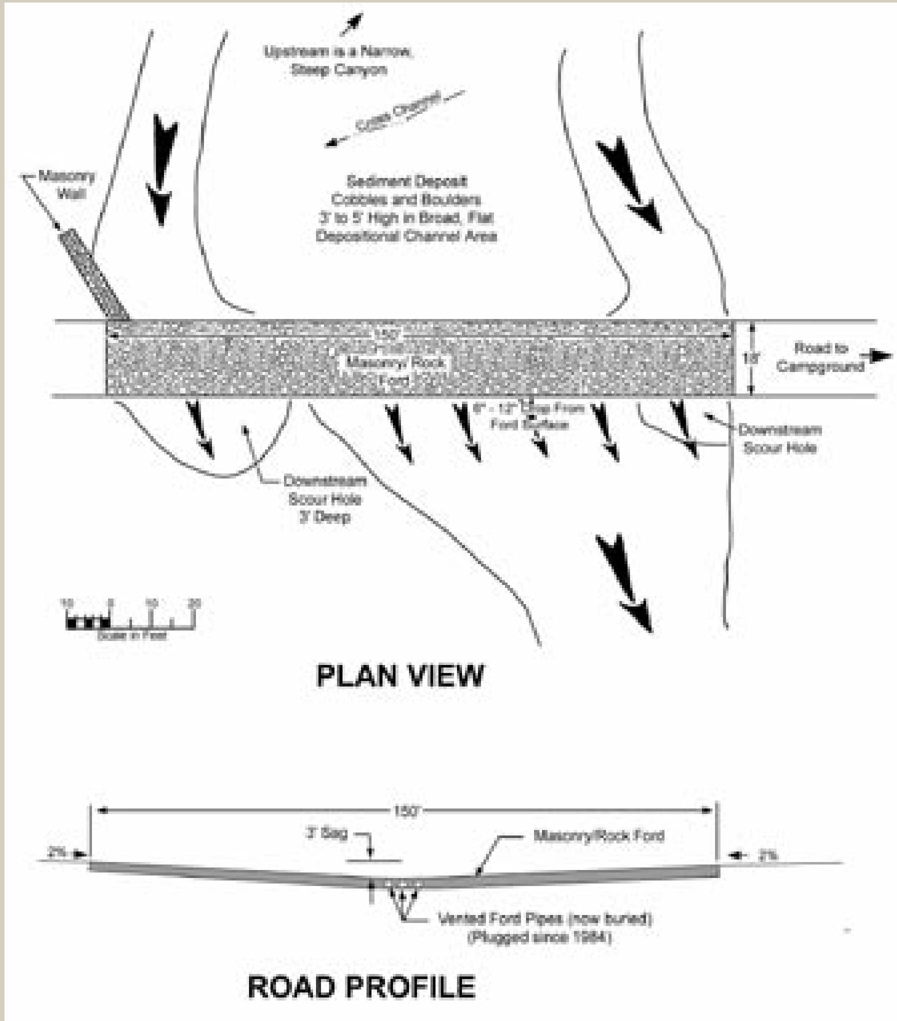

Figure 3.2—Sediment deposition and channel widening caused by the “damming” effect of a low-VAR ford.

Table 3.3 occasionally makes reference to Rosgen’s channel types. For reference, appendix C includes two figures illustrating the classification system. Readers unfamiliar with this classification system should refer to either Rosgen’s paper (Rosgen 1994) or book (Rosgen 1996).

Table 3.3—Considerations for low-water crossing structure type selection.

Type of Factor	Factor	Unvented Fords	Vented Fords (High-VAR)	Low-Water Bridges
Site	**Baseflow** Baseflow is the component of streamflow derived from ground water. It is relatively constant. Flood flows, which are derived from surface or near-surface runoff, vary much more than baseflow. Ephemeral stream channels are above the ground water table, and therefore have no baseflow. Intermittent channels intercept ground water only when the water table is high after a runoff event. Perennial channel beds are below the ground water table year round. Normal low flows are generally baseflows.	Appropriate for ephemeral streams and intermittent streams where the road is closed during the flow season. Where baseflows are high and steady, vehicles must drive through water that will probably be a habitat for aquatic species. In some parts of the country, unvented fords are still common on perennial streams where traffic volumes are low, but they are likely causing at least some damage to aquatic organisms and their habitats.	Appropriate for intermittent and perennial streams. Consider the need to provide aquatic organism passage.	Appropriate for all flow regimes.
	High-flow duration during season of use See discussion in section 3.1	Most useful where high flows are short (so that traffic is only briefly interrupted). Commonly used in flashy desert streams.	These structures usually convey a relatively large volume of flow under the deck, so they are useful where high flows last longer. Where the structure will be submerged for long periods of time, an alternate route should be available	
	Woody debris and ice blockage hazard Structures designed for overtopping reduce the risk of crossing failure and stream diversion where ice or debris may plug culverts. See case studies 16, 17, 18, 19.	The open cross section presents least risk of debris- or ice-blockage. Traction can be a severe problem for winter traffic when the ford surface is icy.	Consider high-VAR fords where ice or debris may plug a culvert. However, even fords with large openings can plug and be maintenance headaches if the channel carries a lot of large woody debris and tree trunks. Can be designed with removable driving surface (e.g., cattleguards) for easy clean-out. Removable metal grates, can be more slippery than gravel or paved surfaces when icy.	Consider low-water bridges where debris loads are very high and traffic volume does not justify construction of a bridge high enough to avoid debris jams. The hazard of debris- or ice-jamming is higher than for ordinary bridges because of the lower clearance. Traction issues are similar to those encountered with conventional bridges.

Table 3.3—Considerations for low-water crossing structure type selection—*continued*

Type of Factor	Factor	Unvented Fords	Vented Fords (High-VAR)	Low-Water Bridges
Site	**Slightly entrenched** (Rosgen E, DA, stable C) See case studies 18, 19, 20. Overbank flood plain flows are fairly frequent on these streams, and can be of long duration. Road approaches are often raised above the flood plain surface, backwatering overbank flows upstream of the road, and altering scour and deposition processes that maintain flood plain habitats and ground water tables. Unentrenched channels in wide flood plains are often highly sinuous and may shift their location on the flood plain over time.	Appropriate where channel width is much greater than depth, so that a ford matching channel shape has a vertical curve adequate for passage of the design vehicle. Many channels in wide flood plains have steep, densely vegetated streambanks (even though they may be low). Approaches to unvented fords cut through the banks and widen the high-flow cross section, inducing sediment deposition. Additionally, many meadow soils are soft and compressible, qualities that contribute to this problem if approaches are not adequately reinforced or hardened (case study 7).	Good options if potential problems with outflanking during high flows can be avoided. Overbank flows that go around the structure can cause bed and bank erosion downstream. Road approaches should be kept low across the flood plain, or should span it to avoid interrupting flood flows and sediment and debris transport on the flood plain. (See case study 20 for an example of a very low profile low-water bridge in a flat E channel in Florida.) Even stable meandering streams experience meander shift. At bends, erosion on the outer bank and deposition on the inner bank cause the channel to change location over time. This process often modifies the channel's angle of approach to a crossing. An acute angle of approach can cause sediment and debris deposition above the structure. Culverts can plug and bank erosion can become severe. Designers should consider spanning the entire meander belt (the zone of active meander shift), or they might plan for regular monitoring and maintenance.	
	Moderately entrenched (Rosgen B) See case studies 4, 8, 12, 17.	Because these streams have relatively mild approach grades and are moderately wide relative to their depth, unvented fords can be appropriate.	Good options. Bank erosion is less of an issue than for slightly entrenched streams because the channel is more constrained and less able to shift location.	
	Entrenched (Rosgen F, A, G) See case studies 3, 5, 6, 16. Entrenched channels are either incised between high banks or are closely bounded by valley walls. Approaches to the low-water crossing have to slope steeply into the channel, creating the risk of sediment introduction from road surface and ditch. Be careful to carry channel protection from scour high enough in these channels, since the water surface does not spread very much (but rises vertically) as flow increases.	Generally not appropriate at deeply entrenched channels where the approaches require cutting through the adjacent slopes to achieve a drivable grade. Approaches may also require extraordinary stabilization measures, such as paving and rocking ditches. There may be no room for ditch relief or a sediment trap. If aquatic organism passage is not an issue, rockfill fords (e.g., case study 3) can be appropriate in entrenched channels.	Application limited to small entrenched channels where the driving platform can be raised high enough to have a suitable road alignment and entail minimal earthwork. Useful in steep channels that are subject to frequent debris flows (case study 16). Successful vented fords are large concrete structures that allow debris to ride over the driving surface and have removable tops for cleaning out trapped debris.	Suitable for spanning small channels. A bridge crossing a wide entrenched channel would likely be a standard high-clearance structure.

Table 3.3—Considerations for low-water crossing structure type selection—*continued*

Type of Factor	Factor	Unvented Fords	Vented Fords (High-VAR)	Low-Water Bridges
Site	**Laterally unstable** (especially Rosgen D, unstable C) In depositional channels such as braided or alluvial fan channels, or in streams undergoing rapid bank erosion, the channel may shift abruptly or progressively. If at all possible, avoid locating a crossing in such a spot. If you cannot avoid it, then low-profile or flood plain-spanning structures are less likely to obstruct flow and exacerbate lateral shift. Laterally unstable channels frequently have high sediment loads. If a crossing structure obstructs sediment transport—especially if it plugs—it can induce even more channel erosion. See case studies 2, 21.	Unimproved at-grade rock or native material fords are the cheapest and easiest structures to replace when the channel shifts location, and are common in desert braided stream environments. Improved fords in these environments are usually paved or concrete dips. Where the approach roadfill concentrates dispersed floodplain flows through the ford, the added erosive power puts the channel downstream of the road at risk of local degradation.	Generally would not be used because of the risk that the channel would move away from the structure. If used, VAR should be high and road approaches should be low to minimize obstruction of flow and sediment transport.	Bridges are less likely than other crossing structures to exacerbate channel shifting by obstructing flow or sediment transport. Nonetheless, the potential for the channel to shift and isolate the bridge should be considered. A long structure may be needed to span the flood plain.
	Vertically unstable (aggrading or incising) If at all possible, avoid crossing any unstable stream. In aggrading channels at valley margins or on alluvial fans, obstructing sediment transport can lead to plugging or channel shift. An incising channel can cause any crossing structure with a floor to become perched, thereby either undermining the structure or causing the structure to become a grade control (i.e., a structure that controls upstream channel elevation and grade). If a grade control is desired, predict the depth of future downcutting and provide downstream cutoff walls to protect the structure (section 4.7).	In an aggrading reach, unvented fords have the benefit of not plugging, and they have no roadfill to fail in a flood event. Given the potential for lateral shift in this setting, consider using an unimproved ford to minimize the investment in the structure. In a degrading reach, like other crossing structures, unvented fords may be undermined when an advancing headcut reaches them. If the structure is well protected from undermining, it will inadvertently become a grade control, preventing the headcut from migrating upstream. See case study 9.	Appropriate at depositional sites such as where a tributary enters the valley floor (case study 13). Use removable tops to facilitate debris removal. Can be designed to function as grade controls in incising channels (case study 15).	Considerations for aggrading channel sites are the same as for laterally unstable channels; i.e., the channel may shift away from the bridge. For incising channels, the risk of scour undermining the piers would be a major site limitation. Designers can minimize this risk by avoiding mid-channel piers and using long spans to keep abutments out of the channel.

Table 3.3—Considerations for low-water crossing structure type selection—*continued*

Type of Factor	Factor	Unvented Fords	Vented Fords (High-VAR)	Low-Water Bridges
Road Management	**Acceptable traffic delay** Acceptable depends on traffic volume, traffic type, and the availability of alternative routes. Where no traffic counts exist, maintenance level can be used as a rough surrogate for traffic volume and type for the purpose of selecting the appropriate structure type. Actual delay times depend on the flood frequencies and runoff patterns of the watershed (section 4.5).	Usually limited to those locations where delays may occur without endangering the public. The lower the traffic volume and the shorter the high flow duration, the more likely a ford is acceptable.	Appropriate for higher traffic volume roads (roughly **maintenance level** 2-3 roads). Flows pass through the vents most of the time, minimizing safety hazards and traffic delays.	Because bridges usually provide the most open area under the deck, they are appropriate for higher traffic volume roads and where traffic interruption is least acceptable (roughly, maintenance level 2-4).
	Vehicle type Ground clearance affects the depth of water a vehicle can be driven through. Wheel-base length affects the allowable vertical curve through a crossing.	Unimproved fords may be appropriate for roads that are closed or managed for high-clearance vehicles or off-highway vehicles only (trails and maintenance level 1 and 2 roads). If the channel is narrow and deep, an unvented ford may have a sharp vertical curve that can snag trailer hitches and cause long wheel-base vehicles to drag.	Raised driving platforms generally minimize the depth of water driven through and flatten out the roadway sag "vertical curve." Feasibility for various vehicle types depends on approach grades and the resulting vertical curve.	Low water bridges accommodate the widest range of vehicle types. Weight limitations may be a design consideration.
	Traction Wet or icy surfaces are a safety hazard.	Traction can be a severe problem for winter traffic when the surface is icy.	Some vented fords have removable metal grates, which can be more slippery than gravel or paved surfaces.	Traction issues are the same as those encountered with conventional bridges.
	Maintenance access and commitment All structures require inspecting and sometimes cleaning, maintenance or repairs after high flows.	A good choice on closed roads where access for inspection and maintenance will be difficult. They usually require minimal maintenance, depending on the structure type and the quality of its installation. Maintenance needs typically arise after a flood; they include removing sediment and debris, regrading approaches, and replacing surfacing materials.	Vented fords in streams that carry large woody debris often require cleaning and can be a maintenance headache. Removable tops are good design features for streams with large debris loads. The tops can be removed before a large storm or a seasonal road closure.	Generally the only maintenance required is after large floods, when debris trapped on the structure needs to be removed and any channel or bank erosion around the structure is repaired.

Table 3.3—Considerations for low-water crossing structure type selection—*continued*

Type of Factor	Factor	Unvented Fords	Vented Fords (High-VAR)	Low-Water Bridges
Economic	**Cost** Costs associated with crossing structures include installation, maintenance, replacement, and (sometimes) road user costs. Total life-cycle costs also include the damage to stream channels, flood plains, and aquatic habitats caused by obstruction of natural transport processes or by structure failure.	Generally cost much less to install than other structures (Warhol 1994) and, when properly constructed, they require little maintenance. Construction and maintenance costs may be higher where special efforts for water quality or habitat concerns are necessary; in such cases, another structure type may be preferable anyway (see appendix D).	High-VAR fords are likely to have installation costs similar to those of ordinary culverts. Since vented fords are designed to sustain overtopping flows, replacement costs should be lower, especially where plugging makes ordinary culvert failures frequent.	Likely to be somewhat cheaper than standard bridges, because they do not need to be as high above the water surface. Although the risk of debris blockage is higher for low-water bridges, they are not likely to fail because of it. Costs associated with maintenance may be higher in areas with large debris loads. In broad, valleys where debris plugging could cause channel shift away from the bridge in a major flood, channel rehabilitation could add to the lifetime cost.
Resource Protection	**Aquatic Organism Passage** Unobstructed passage for all aquatic animals is presumed to exist when the streambed is continuous throughout the crossing. When channel width, depth, and structure (e.g., steps, pools, riffles) in the crossing are similar to those of the natural channel, the crossing should be nearly indiscernible to aquatic species. Designing for swimmable velocities and depths at selected flows can also allow some fish passage (see section 4.3).	Due to the potential for habitat disturbance, fish injury, and the water quality impacts of vehicles passing through water, unvented fords are not generally recommended for locations with fish passage concerns. However, fords may be a good choice where • traffic volume is low • aquatic habitat is limited • aquatic habitat is poor quality • the channel is prone to shifting In such cases, the resource or access benefits might not justify the cost of a culvert or bridge that would provide better fish passage. Good design is critical for fords where aquatic organism passage is desired (see section 4.3) Most fords provide at least partial passage when they are backwatered or submerged.	Can provide passage by matching channel width and maintaining streambed continuity through the structure (case studies 17, 18, 19). Usually, these structures are box culverts that allow the crossing structure to be short in the along-stream direction. Some concrete fords include a slot to concentrate low flows and provide partial fish passage (case studies 9, 12). This type of ford should generally be a last resort in most fish-bearing streams; it is unlikely to provide more than partial passage for a target species and may provide no passage at all for other aquatic species.	Assuming they are wide enough, low-water bridges are a good structure type because the streambed remains continuous through the crossing.

Table 3.3—Considerations for low-water crossing structure type selection—*continued*

Type of Factor	Factor	Unvented Fords	Vented Fords (High-VAR)	Low-Water Bridges
Resource Protection	**Water quality** (See also appendix D: Low-water crossing effects on water quality.) The importance of protecting water quality at a site affects the choice of structure type because structure type determines how frequently vehicles drive through water, and the feasibility of diverting sediment-laden road surface runoff before it reaches the stream. Depending on the State and the project, one or more permits may be required before undertaking construction in a stream channel.	Construction may affect water quality temporarily depending on site stability, excavation requirements, and flows during construction. Traffic through water is most likely to deliver pollutants to waterways and cause some channel erosion, although significant effects have not been demonstrated. Because they directly connect some portion of the road to the stream, unvented fords have the highest potential for sediment delivery of any structure type. However, since there is no fill to fail, they do not produce the large volumes of sediment that culvert plugging sometimes produces during catastrophic floods.	Construction can affect water quality temporarily if excavation and fill are not isolated from flowing water. Traffic over these structures is likely to have little or no effect on water quality, especially if best management practices are implemented to isolate road surface runoff from the stream.	
	Noxious weeds Vehicles may carry invasive aquatic and other weeds (seeds and plant parts) and deliver them to waterways.	Most likely to permit weed introduction to new waterways.	Where the driving surface has gaps (e.g., cattle guards), weed seeds could fall off vehicles into the channel. No information about how significant this risk is was found.	
Recreation	**Hazards for recreational users** Any in-stream structure influences water velocity and direction in ways that may create risks for swimmers or boaters, especially at high flows.	Depending on depth of flow, floaters might scrape the ford surface. If the ford is elevated above the stream bottom, the hydraulic jump that forms downstream during overtopping flow can constitute a risk to boaters and swimmers.	At high flows, as the rising water surface nears the roadbed, boats can be trapped against the structure. When flow overtops a culvert opening, rafts and swimmers can be sucked underwater. Section 4.9 includes design ideas for minimizing these risks.	