Low-water crossing designs have multiplied as structures were adapted to meet site-specific conditions, cost feasibility, available materials, and resource issues. This section summarizes the most common low-water crossing types, along with some of their advantages, disadvantages, construction details, and other factors unique to each type of structure.

5.1 At-Grade Rock Fords

Unimproved at-grade fords are crossings where vehicles simply drive across the channel without the benefits of hardening or grading. The ideal site for an unimproved ford is one with rocky, hard substrate (fig. 5.1) or bedrock. Even where the channel bottom is hard, the streambanks can be soft and erodible. In such cases, traffic generally causes the stream to widen as the banks break down and wash away. This problem can be fixed by "improving" the ford—removing soft soils and replacing them with select coarse rock.

Figure 5.1—Unimproved rock ford on the East Fork San Gabriel River, Angeles National Forest, California.

Improved at-grade rock fords are typically the least expensive and easiest ford to construct. They work best on ephemeral channels and on low-velocity streams, where the armoring rock will not be moved by the current. They should be kept "at-grade" (close to the natural stream channel bottom elevation) to minimize channel changes or fish barriers (fig. 5.2). The rock surface should be coarse to minimize water velocity acceleration across the ford and to resist movement of the rock.

Where existing or imported rock is too coarse (greater than 3 to 4 inches), it is commonly in-filled (choked) with finer (1½- to 2-inch) graded aggregate to facilitate traffic, because very coarse, loose rock is difficult to drive through. The finer material will need periodic replacement after high flows (case studies 1 and 2).

Improved rock fords are usually constructed by overexcavating the roadway area 6 to 8 inches deep and backfilling the excavation with well-graded coarse rock back to the natural stream channel level. Coarse rock size should be selected to resist movement at maximum flow velocities, and mixed with finer material for trafficability. Often two separate layers of rock are needed to satisfy both concerns. The downstream outlet area of the ford may be stabilized with moderately large riprap. A naturally coarse rocky stream channel bottom or a smooth bedrock area is ideal and requires no overexcavation.

Figure 5.2—At-grade improved rock ford, Plumas National Forest.

Simple at-grade rock fords have occasionally been improved by armoring with grouted rock, masonry, or a layer of asphalt concrete. Although this material can make an erosion-resistant driving surface, keying in the material around the edge of the structure is important. Asphalt layers are relatively thin and lightweight, and can float off the site due to uplift forces during high flows. The driving surface should be kept as rough as possible to minimize flow acceleration. At-grade structures that simulate the natural channel shape will best maintain channel processes and minimize aggradation or degradation problems.

At-grade rock fords, as well as improved fords with a variety of armored surfaces are ideal for semiarid and desert environments where flow fluctuations are extreme and floods may carry large amounts of debris.

5.2 Concrete-Slab Fords

Although concrete-slab fords are relatively simple and very durable, they are expensive compared to simple rock fords. The structure can be at-grade with the stream channel bottom, or raised to minimize the depth of water driven through. Concrete slabs are some of the best structures in many applications (if kept at-grade) because of their durability and minimal effect on the stream system. If raised, however, they dam the channel and cause aggradation upstream, and degradation or scour problems along the downstream edge. Virtually all slab fords are at least slightly elevated above the stream bottom. Because they are located right where most bedload transport occurs—on the channel bottom—they tend to trap bedload upstream. If the slab is high enough, the accumulated bedload may fill the channel, destabilizing the banks. If the channel is not well-entrenched, this process may cause it to shift location or braid.

Concrete slabs can withstand a large amount of debris or sediment overtopping the structure without damage (fig. 5.3). They are relatively common on flashy desert streams, even streams large enough to provide at least intermittent fish habitat. Except when backwatered, they commonly create fish passage problems because of the increased flow velocity and shallow flow across the smooth concrete slab (case study 8). Roughening the slab with embedded boulders or a rough concrete finish may help promote passage, but will not solve the problem completely. Elevated slabs or flat slabs in a steep channel with a water drop along the downstream edge require more downstream scour protection and often create a jump barrier.

Carefully designed slots formed into a slab and positioned parallel to flow will concentrate low flows and can facilitate small fish passage (case study 9). The concrete planks in figure 5.4 are bolted to a 5-foot-wide concrete slab set in the middle of the 8-foot-wide channel. The slab has a 9½-inch-wide by 10½-inch-high slot cast in the center, which successfully provides passage for trout at low flows (Panter, personal communicaton).

Concrete slab fords usually consist of a simple "at or near grade" reinforced concrete slab 6 to 8 inches thick, with upstream and downstream cutoff walls several feet deep for scour protection. The slab usually has a 2- to 4-percent minimum downstream cross-slope (maximum 8 to 10 percent). Ideally, the cross-slope matches the natural channel gradient. Although a nearly flat cross-slope helps minimize velocity acceleration, it may create a waterfall at its outlet in a steep channel (see case study 8). Such a waterfall is detrimental to fish passage and can create scour problems. As flows deepen over the slab during high

flows, the flow velocity is less affected by the slab and its slope. A flat slab may also tend to accumulate sediment during periods of low flow.

Holes may be needed through a large concrete slab to minimize uplift pressure and keep the slab from floating away. Alternatively, a thick, heavy slab, as well as the use of cutoff walls, can prevent uplift. Uplift forces should be examined during the design of the structure.

Figure 5.3—Old concrete slab ford with grout apron, Ashdale Administrative Site, Tonto National Forest. (case study 8)

Figure 5.4—The Thomas Creek 198 ford, Fremont National Forest. A slot in the concrete slab between the planks provides low-flow passage for trout.

5.3 Precast Concrete Planks

Precast concrete planks also are used in at-grade fords to provide a concrete-hardened driving surface. The structure typically consists of individual 12-inch by 12-inch by 16- to 20-foot long, steel reinforced, precast concrete "planks" or logs, bolted together with iron flanges to hold their spacing (McNemar 1983). The planks are placed upon a prepared, graded rocky surface. The outlet may be armored with riprap to protect against the increased flow velocities across the planks and through the small channels between the planks (case study 5). The structure acts like a vented ford (with small vents) at low flow, with a dry driving surface and with flow going between the planks (fig. 5.4).

Figure 5.5—Concrete plank ford at edge of the North Fork Clearwater River, Clearwater National Forest, Idaho.

The bed for the planks is prepared by smoothing the subgrade and channel bottom, placing a thin layer (a few inches) of gravel or fine rocky bedding material, and laying the planks in place. In very rocky or boulder-lined channels, some rock will have to be overexcavated and backfilled with small rock to form a smooth base for the planks. Although enough small rock to form a smooth bed for the planks is necessary, the fine bedding material may be susceptible to scour and movement. Damage observed to precast concrete plank structures has come from scour of the bedding material beneath the planks causing movement and deformation of the structures (case study 5). This problem can be minimized with a thin,

well-compacted rocky base, and geotextile placed between the rocky bed and the planks. Where feasible, a solid concrete slab is generally preferable and more durable.

This structure is not recommended for fish passage. Although the 6-inch-wide channels between the concrete planks may provide partial passage, they tend to fill up with gravel and rock, limiting passage. Best passage is attained when the entire structure is submerged.

The Black Canyon ford on the Clearwater National Forest (case study 10) uses steel-reinforced, precast 8- by 15-inch-wide by 14-foot-long planks, placed 1 to 2 inches apart at the toe of a debris avalanche chute. They are set on a very rocky foundation with gravel cushion. Fish passage is not an issue at this site. To minimize cost, the planks were cast offsite by forest crews.

Compared to concrete slabs, advantages of precast planks include minimizing onsite construction time, avoiding working with fresh concrete in the stream environment, reducing the quantity and cost of both concrete and formwork, and providing small channels for aquatic organism passage. Disadvantages include the relatively small, independent planks that can move individually and are subject to scour between them. This type of structure is particularly unsuitable for channels with fine-grained alluvial materials readily susceptible to scour.

5.4 Cable Concrete Blocks

Cable concrete blocks, or articulating concrete block fords, are made of 1-foot-square concrete blocks held together with a light cable. The concrete-block mats come in dimensions of 4- to 8-foot-wide by 8- to 16-foot-long sheets. Block thickness varies from 2.5 to 8 inches. The mats are placed upon a shaped, compacted subgrade, at or near the stream channel bottom elevation, but overexcavated to accommodate the thickness of the concrete blocks. Some blocks come with a geotextile backing. Otherwise, a layer of geotextile should be placed upon the prepared subgrade before placement of the cable concrete block mats (fig. 5.6). Gravel may be placed into the voids between the blocks to produce a smoother driving surface immediately, or they can be left to fill naturally.

For scour protection, one row of the blocks (approximately 1-foot wide) is buried at least 6 inches into the stream channel completely around the perimeter of the concrete-block mat. Additional depth or other scour

protection, such as riprap, may be needed along the downstream edge of the structure. The mats can be anchored in place simply with rebar and cable clamps, or with soil or rock anchors in a dynamic environment.

Figure 5.6—Cable concrete block ford, Bighorn National Forest, Wyoming. Note that mat should extend higher to protect the crossing adequately.

Having a smooth, uniform, compact bed underneath the blocks is critical. Because each block is independent, it can settle, rotate, or tilt if the foundation material settles or if there are boulders just beneath the blocks. In addition to producing a nonuniform driving surface, irregular blocks can also become snagged on bumpers or trailer hitches and possibly be pulled out of place if the vertical curve of the driving surface is not sufficiently smooth. In addition, the cable connecting the blocks can get caught and either be pulled out of the blocks or break and lose its anchorage.

Because each mat is large, heavy, and flexible, the Bighorn National Forest fabricated a rigid lifting bar made of small steel I-beams welded to size to handle the mats (Golden, personal communication). A backhoe with chains can pick up the mats and lifting bar, and move them to the site. The lifting bar can then be fitted onto the backhoe for lowering the mats into position. Adjoining mats are held in place by cable clamps which join the cables from both mats. See also case study 6, figure A30.

5.5 Geocell Fords

Geocells, or plastic cellular confinement structures, have been used on some very low-use roads to confine fine gravel and rock, forming a stable driving surface with the confined material (Pence 1987). The geocells are made of an expandable high-density polyethylene plastic (HDPE) with 6- to 8-inch-diameter cells and a thickness of 2, 3, 4, 6, or 8 inches. The expanded sheets are 8-feet wide by 16- to 20-feet long but can be cut to size easily. Geoweb geocells have been the most common material used to date, and they can be purchased solid or with perforations (holes) in the cells for drainage.

The site should be dewatered to facilitate construction and minimize site sediment production. Then, the roadbed is excavated to the depth of the geocells plus cover, and prepared by removing boulders, filling voids with gravel, leveling, and compacting the base of the crossing (fig. 5.7). The first step in installing the mat is to place the geotextile layer on the base. Second, the geocells are expanded in place across the area on top of the geotextile, and staked down. Third, the geocells are backfilled with 1½- to 4-inch-minus gravel or smaller crushed rock by dumping the material directly into the expanded cells. Finally, the geocells are covered with a 4- to 6-inch-thick layer of a relatively coarse aggregate (a thicker layer of aggregate can be used if more structural support is needed). Ideally, all materials should be well-graded, angular, and relatively free of fines to minimize sediment in the creek. The top of the cells, plus some cover rock, should be at the level of the natural stream channel bottom (case study 7).

Figure 5.7—Geoweb installation on the South Fork Tongue River, Bighorn National Forest, Wyoming. Note exposure of geoweb due to traffic and water flow.

Geocell fords appear best suited for crossings in a relatively "low energy" environment with relatively flat stream gradients, low channel velocities and debris loads, and minimal scour potential. Although the geocell itself is not particularly strong, the composite structure gains its strength by confining the aggregate. Because vehicles should not drive directly on the geocell mat, a minimal aggregate cover thickness of at least 2 inches is recommended. Edges of the structure can be overexcavated and bent down (keyed) into the streambanks and streambottom, roughly twice the cell depth. The edges can also be anchored and protected by placing riprap on the backfilled cells along the streambank or along the downstream edge of the structure. To minimize settlement in soft, fine streambank soils, either overexcavate the fine material and backfill with aggregate, or compact it to create a firm foundation.

The collapsed geocell sheets come in bundles approximately 11 feet long and 5 inches thick. Although the geocells are easy and quick to expand and fill after their bedding is prepared, they can be easily overstretched if their dimensions are not carefully checked (overstretched cells lose some of their capacity). Once the geocells are properly cut to size, expanded, and laid out, they can be staked in place with 3-foot-long rebar bent into a hook-shaped stake. If work is done in the stream current (note: this is not recommended), only short sections of geocell should be filled at a time. If the relatively fine cover material is washed off during a flood or by traffic, it will need periodic replacement. This low-water crossing is best suited for light traffic such as local administrative traffic or access into campgrounds. Tire action and fast water flow can remove the gravel cover and expose the geoweb (figs. 5.7 and 5.8).

Figure 5.8—Geoweb exposed by tire action on road approaches, Ashley National Forest, Utah.

5.6 Porous, Large Rockfill Fords

Porous, large rockfill fords are raised rockfills built to be overtopped by high flows or debris flows (fig. 5.9; see also fig A111). They are used in steep topography and in deep, incised channels where a crossing requires a high fill for good road alignment. Initially, they are porous so some water passes through the fill, but with time, they usually "silt in," becoming impermeable and allowing flows to go over the top of the structure. They are, therefore, best suited for headwater areas where streamflows are relatively low, but carry considerable debris.

Figure 5.9—Dooley rockfill ford under construction, Plumas National Forest, California.

Rock size is usually determined by the largest materials available, and the rockfill should be constructed of angular, well-graded material. Class 3 to Class 5 riprap (15- to 27-inch size) may be specified in this application. The fill height (depth) will be determined by both (a) the channel's depth and slope and (b) the roadway elevation needed to produce a suitable road grade or vertical curve. In steep topography or steep channel gradients, the rockfill may be 5 to 15 feet high (case study 3). Because it essentially dams the channel, this rockfill does not allow for fish passage and prevents the passage of fish and possibly other aquatic species. The face of the fill should be U-shaped in plan view to keep water and debris in the middle of the channel, and prevent erosion along the structure's margins where the rockfill contacts native soil (fig. 5.10). This shape will also help prevent bank scour immediately downstream of the structure.

SAMPLE NOTES:

1. Dip shall drain to center of Rolling Dip and outside edge of Road.

2. Larger rock shall be placed towards the bottom of the slopes.

3. Class III rock, plus aggregate surfacing, shall be placed on Roadway, and Class V & VII rock on slopes.

4. Riprapped bottom of slopes shall be as wide, or wider, than the floodplain area.

5. Pipe Capacity shall be for a Q_2 to a Q_{25} flow (Low to High Standard Road). Entire Ford shall pass a Q_{100} flow.

6. In new FP-03 Specifications, Old Class III = Class 2; Old Class V = Class 3; Old Class VII = Class 4 Riprap.

PROFILE VIEW

ROCKFILL FORD (WITHOUT PIPE) FOR DEBRIS-PRONE HEADWATER CHANNELS

PLAN VIEW

PROFILE VIEW

VENTED ROCKFILL FORD WITH PIPES, (USED ESPECIALLY TO RETRO-FIT UNDERSIZED CULVERTS OR PREVENT STREAM DIVERSION)

CROSS-SECTION AT CULVERT

Adapted from Region One, Idaho Panhandle National Forest

TYPICAL ROCK FORD OPTIONS
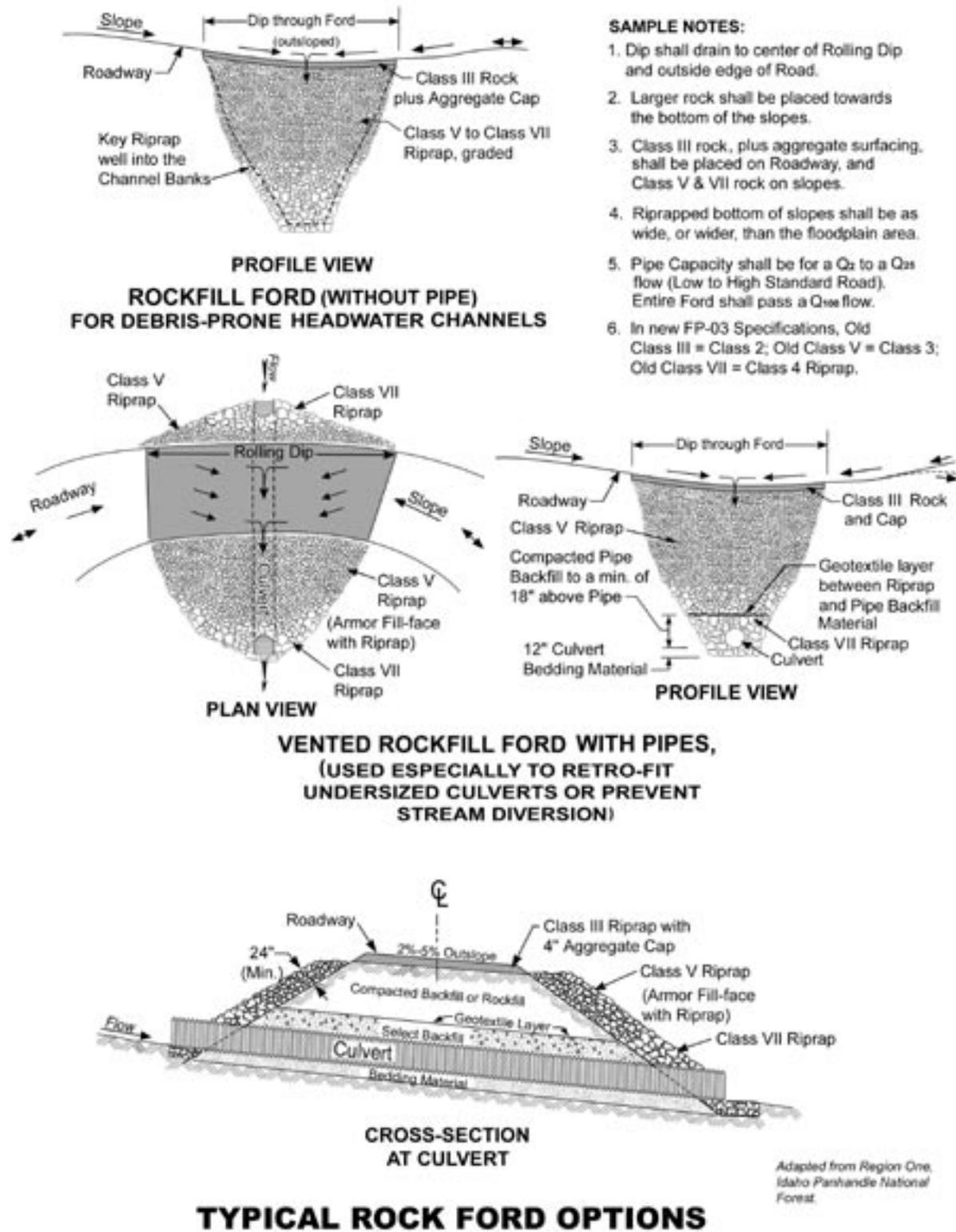
Figure 5.10—Sketches of various types of rockfill fords with design details.

A rockfill ford may also be constructed with a pipe or pipes, producing a vented rockfill ford. Vented rockfill fords are sometimes used where an existing conventional culvert pipe is undersized and protection is needed in the event of overtopping (case study 3, figures A14 and A15). Like all crossings with diversion potential, vented rockfill fords require a dip over the pipe to ensure overtopping flows stay within their own creek boundaries (fig. 5.10). These structures are created by forming a dip in the roadway over or near the culvert, and armoring the fillslopes with riprap. Ideally, rock is placed upon a geotextile filter in a layer 1 to 2 feet thick.

5.7 Gabion and Jersey Barrier Sill Fords

Gabions, jersey barriers (sometimes called K-rail), other concrete walls, or even logs have been used in relatively low-gradient channels (up to 10-percent slopes) to hold the road prism in place (case study 4) (Leydecker, 1973) To ensure the gabions or jersey barriers do not move, it is common to partially bury them forming a sill on the road's downstream edge. Frequently, the actual roadway platform is then made of local rocky channel material, placed with a 3- to 5-percent outslope across the road and the sill. The barriers should be placed to form a gentle U-shaped weir across the channel (the U faces downstream) to concentrate flow midchannel. The structure usually creates a low waterfall below the crossing, so the structure may be a barrier to fish and other aquatic species. Therefore, this structure should not be used in channels where AOP is needed (fig. 5.11).

Figure 5.11—Gabion ford, Tonto National Forest, Arizona.

Because of the waterfall created by the structure, some downstream protection—such as additional gabion baskets, **Reno mattresses**, or coarse riprap—may be needed along its downstream edge for scour protection. The sill structures also should be keyed into the natural streambank to prevent end scour. Fine roadway material may need to be replaced periodically but the basic structure should be heavy enough to resist movement and damage. Logs have been used successfully in small streams with low-flow velocities and relatively flat gradients.

If Jersey barriers are set too high, the crossing may be too flat and sediment may deposit on the road during high flows. The waterfall over the downstream edge of the ford will also promote toe scour, and the barriers may be pushed over by the lateral pressure of the road fill (fig. 5.12). Ideally, Jersey barriers should be set into the stream channel at roughly half their height to prevent them from overturning or sliding downstream. Actual grade and height of the sill will depend on the channel gradient and other conditions.

Figure 5.12—Jersey barriers used for a temporary ford after the Ojai wildfire in 2004, Los Padres National Forest, California.

Gabions are typically set on the channel grade or are embedded several inches into the stream channel bottom. Actual elevation will depend on scour considerations and the design elevation of the roadway. Gabion sills can be capped with asphalt across the driving surface. Although

these structures can work for low-velocity environments, there are sites where the asphalt layer was damaged or floated off the gabions. Gabion structures may also be so porous they take the flow through the structure rather than over it. In time, the structure may silt in, but until then, water going through the baskets can cause piping or scour under or behind the structure. The best way to prevent piping and scour problems is by wrapping the gabion with a filter such as a geotextile, and compacting material firmly around and behind the gabions.

5.8 Vented Fords with Small Single or Multiple Culverts

Many raised vented fords with multiple, small diameter culverts (vents) were built from the 1960s to the 1980s throughout the National Forest System. Culvert pipes were set near the streambed level, and the crossing was backfilled with compacted material. In most cases, at least a foot of cover was placed over the culverts. The embankment material was then protected against overtopping with riprap, gabions, or concrete. Single, double, or multiple culverts were used.

Vented fords enable low flows to go through the pipes, therefore preventing most vehicles from driving through the water and maintaining water quality. The structure can be relatively low profile, or the embankment can be relatively high. If the ford surface is 3 feet or higher during overtopping, the flow drop on the downstream side of the structure will generally cause scour. Scour protection on the downstream edge is critical, both because of the water drop at high flows and because of the accelerated stream velocities exiting through the culverts. Downstream scour protection has been achieved with vertical cutoff walls, gabions, riprap, or simple plunge pools.

The major disadvantage of this structure is that it typically has a low VAR and acts as a dam across the channel at high flows (case study 11). The damming effect causes upstream backwater and aggradation (fig. 5.13a) and sometimes downstream degradation and scour. Both processes contribute to channel instability and high maintenance costs. Pipes in these structures often plug with debris and usually require, at the least, cleaning in the inlet area after a major storm event (fig. 5.13b). In addition, these structures often prevent fish passage where culvert outlet velocities are high, where flow depth is very shallow in the pipes, or where there is a drop at the culvert outlet. Low water velocities and backwater through the culvert can allow for some fish passage.

Figure 5.13a—Murdock vented ford, Plumas National Forest, California looking upstream (note excavated sediment upstream of ford).

Figure 5.13b—Murdock ford, looking downstream at inlets partially plugged with woody debris after a high flow.

Conventional culvert installations are sometimes converted to vented fords by constructing a dip over or near the culvert and hardening the fill to sustain overflow. This might be done, for example, where a wildfire or

a landslide occurred in the watershed, making the existing capacity of the culvert inadequate for expected flows. In some cases, an existing pipe may simply be undersized and require additional protection. The downstream face of the fill usually needs to be armored and its toe protected against scour. This type of "retrofit structure," similar to rockfill fords discussed in section 5.6, can offer inexpensive protection against a total pipe failure in many settings.

5.9 Vented Ford with Concrete Box Culverts

Vented fords are often constructed with raised platforms and box culverts to pass low to moderate flows (fig. 5.14). Vehicles are kept out of the water at all times except during high flows. Although these structures are similar to vented fords with culvert pipes, they commonly have a larger waterway open area across the channel, or a high VAR. They also tend to be shorter in the along-stream direction than crossings with pipes. They readily pass small debris through the structure but can still plug with large woody debris in a major storm event. The box structures are typically structural concrete and may have either a solid bottom or vertical walls set upon spread footings, with a natural channel bottom. The roadway surface may be solid reinforced concrete, or it may consist of metal grating, such as cattleguard material, which can be removed to clean debris from the structure. Typically, these structures are relatively expensive, but they can perform very well, minimize traffic delays, and maximize channel function and aquatic organism passage (case studies 13, 14, 15, 16, 18, and 19).

Figure 5.14—Long Creek embedded concrete box high-VAR ford constructed in 2005, Ouachita National Forest, Arkansas.

The number of box openings depends upon the design flows and the width of the channel. To minimize channel constriction, the flow area should include the majority of the channel cross section. Depending on the extent to which flow area is constricted during bankfull or higher flows, the structure will cause sediment deposition, usually in the outer boxes (see case study 19). Ultimately, the sediment may need to be cleaned out to avoid backwatering and flow acceleration in the remaining open boxes.

If a continuous streambed is maintained through the structure, this is one of the best for maintaining channel function. Where foundation conditions are good enough to construct an open-bottom box with a natural stream channel bottom, the structure is ideal for fish and aquatic organism passage. If a full concrete box is built, the box bottom can be embedded 1 to 2 feet below natural stream channel bottom elevation and filled with streambed material. Low gradient channels with mobile bed material may need at least a 2-foot embedment. Steeper channels where streambed materials are coarser and less mobile may need minimal embedment, although 1 foot is a reasonable minimum value.

The embedded box can be backfilled to the channel level with rocky material, or left to fill naturally with stream substrate. Angle iron bed material retention sills have been built into conventional culvert structures to help retain materials, particularly on steep channels. Cutoff walls several feet deep should be added along the downstream embedded box edge for scour protection.

Except where the crossing is backwatered, if the bottom of the box is not embedded, water flowing over the smooth concrete floor will be faster and shallower than in the natural channel, impeding fish passage. On the Ouachita National Forest (case study 14), boulders were set into the concrete to roughen the surface and provide some fish habitat. Alternatively, to concentrate low streamflows and promote low-flow fish passage, small channels have been formed into the bottom of the concrete box, or a slight V shape has been built into the base. These measures may help downstream fish passage at very low flows (case study 13).

These relatively large, high-VAR structures also are used on steep channels prone to debris torrents. The large openings can pass a large amount of water (thus minimizing traffic delays). Debris rides over the top, and the road can be easily reopened by pushing remaining debris off the structure (case study 16).

Concrete boxes have also been used successfully as grade control structures. In case study 15, a bridge was considered, but the vented ford was less expensive and it offered a solid structure capable of preventing further headcutting. Although such structures are massive and relatively expensive, they can be significantly cheaper than a longspan bridge. Because this structure maintains a large elevation drop across the crossing, a fish ladder or other measure is needed for fish passage.

Because the structure driving surface is typically elevated at least several feet higher than the vent or above the natural channel elevation, some curbing is desirable or may be required for traffic safety.

5.10 Vented Fords with Large Open-Bottom Arch Culverts

This vented ford is desirable because it offers some of the economic advantages of culverts with the broad-span advantages of a bridge. The structure usually has a high VAR and can or should span the entire drainage, preferably to the bankfull width. Ideally, the structure is a bottomless arch with spread footings parallel to the stream channel, minimizing disturbance to the middle of the stream channel and preserving the natural substrate. This structure is ideal for "stream simulation," where the natural channel width and bottom material are preserved (fig. 5.15).

Figure 5.15—Metal bottomless arch high-VAR ford, San Bernardino National Forest, California.

Alternatively, a large arch pipe can be used. The pipe is buried several feet below the natural stream channel bottom and in-filled with streambed material. The arch pipe has to be oversized to account for the flow capacity lost in burial.

The disadvantage of this structure is the pipe may be relatively high, so maintaining the dip through the crossing can be difficult. Low profile pipe shapes available today can minimize this problem. Moreover, scour protection against overflow conditions must be well-selected. Ideally, the roadway driving surface and fillslopes will be concrete-armored or formed out of structural concrete. Usually large arch pipe culverts are not used in low-water crossing structures, but they can be made to work in some stream channels.

5.11 Low-Water Bridges

In this publication, we define low-water bridges as structures supported by piers or spread footings with a natural stream channel bottom. They can look quite similar to embedded box-culvert fords, but are commonly longer and have no floor. Low-water bridges have a raised superstructure over a natural stream channel bottom, a total span of more than 20 feet, and are designed to sustain overtopping (Brink 1974 and 2000). Generally, they have the highest VAR of any of the low-water crossing structures. To function as "low-water" bridges, the structures need to be above bankfull elevation to pass flow most of the time, yet be low enough to be overtopped by larger floods (Webb 1994) (fig. 5.16).

Figure 5.16—Capps low-water bridge, Eldorado National Forest, California.

Low-Water Crossings

Although low-water bridges are usually the most expensive low-water crossing structures, they can maintain the best channel function and have the least adverse effect on fish and other aquatic organisms. The structures also can be very useful for other wildlife species passage along the riparian corridor, particularly if the bridge span is considerably wider than the low-flow channel. This structure is also very useful in broad flat rivers where considerable base flow exists but peak flows and/or debris loads are extreme. Although the structure may be relatively expensive, it can still be much less expensive than a longspan conventional bridge high enough to pass all the flow during an extreme high-flow event (case studies 20 and 21).

Because the structure is periodically inundated and may trap debris, particularly large limbs and rootwads, the abutment and girders or slabs must all be well-connected and anchored to resist the lateral forces of the flow and debris. Anchorage may include heavy concrete abutments or piers, or cables anchored to deadmen buried in the streambanks. Protection against local scour around the abutments or any midchannel piers is also usually needed.

In some broad channels, conventional or low-water bridges may be used in conjunction with other unvented or vented fords, accommodating main channel flows, overflow channel flow, and a large amount of debris passing through the system during flood flows (Eriksson 1984).

Traffic safety, which is critical with an elevated structure, may be difficult to achieve on low-water bridges because normal bridge railings cannot be used. With an elevated platform—usually at least several feet high—the structure needs railings or curbs to keep traffic safely on the deck. The taller the railings, the safer the traffic conditions will be. Because a ford is periodically overtopped, the structure needs as low a profile as possible since any railing acts as a trash rack, trapping debris. The best compromise appears to be using high curbs, 6 to 12 inches high for wood structures, or 15 inches high for concrete structures (FSH 7709.56b). In addition, object markers and warning signs placed well before drivers reach the active channel can improve traffic safety. Remember the FSM requires any bridge structure, including low-water bridges, be designed by a licensed engineer and reviewed by the regional Director of Engineering. Warrants must be developed evaluating the safety of the structure.