LOW WATER CROSSINGS

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This paper provides a rationale for planning and constructing low water crossings on low volume roads. Fords, fords with culverts and crossings on low structures are described. Examples are given of good and poor designs using different types of materials and involving a variety of environmental considerations. Examples come from National Forests in Minnesota, Missouri, West Virginia and New Hampshire.

Definitions

Low water crossings are road-stream crossings designed to allow flooding approximately once a year. This contrasts with the more conventional stream crossings designed for 25-50 year floods. Low water crossings include the following, as shown in Figure 1:

1. Fords (or dips) - - Formed by lowering the road grade to the streambed level from bank to bank. Commonly used across dry drainages or where the day-to-day stream flow is low.
2. Vented fords (or dips with culverts) - - Formed by partially lowering the road grade for floods and providing culverts to handle the day-to-day flow. Commonly used where day-to-day flow exceeds a fordable depth.
3. Low Water Bridges - - Formed by partially lowering the road grade for flooding and providing a bridge type structure to handle day-to-day flow that can not be handled by culverts.

It is reasonable to drive even a modern car through 10-15 cm (4"-6") of water. Single use access roads, such as those for logging or recreation, rarely need 100% access. Often the activity itself may not be feasible because of the same heavy rain which closed the road. Scattered farm residences usually can operate adequately with occasional road closures. Often there may be alternate but longer access routes available when high water temporarily closes one crossing.

Most reference books on highway engineering (1, 2, 3, 4, 5, 6) stress the higher standard stream crossings designed to pass 25-50 year floods. A few texts (7, 8) do make brief reference to low water crossings as economical alternatives for low volume roads, but they provide few details. T.R. Agg referred to fords in his 1929 edition of "Construction of Roads and Pavements" (9), but the reference was dropped in his 1940 edition.

The only details on low water crossings that we found were given by A.D. Leydecker (10), and Sharma and Sharma (11). Leydecker describes the use of gabions in constructing a ford. Sharma and Sharma describe both a rubble and concrete ford, and a dip with culvert.

Location and Design Considerations

Raised road grades and constricted drainage waterways can cause flooding in broad, flat stream valleys. These flood plains often include valuable crops as well as residences. The low water crossing permits a large, natural waterway which minimizes the flooding of adjacent lands. High approaches to flood-free crossings may be expensive and aesthetically undesirable. Occasionally, structures that have adequate clearance to pass floods have low approach roads. Since access can be restricted when approach roads become flooded, it makes little sense to overbuild a structure to insure access. A low approach road which ramps up and over a high stream crossing also presents an undesirable hump or roller coaster appearance and ride.

In mountainous terrain, streams on alluvial fans often appear to be running on top of the ridge. These streams have widely varying, rapidly changing flows and very unstable channels. Stream crossings built to handle peak flows can be large and may also appear humped. Floods backed up by the constricted waterway often jump around the ends of such structures causing washouts or even running down the road. Maintenance to keep a mountain stream in its channel can be very expensive or even impossible. Low water crossings in these cases offer a low investment in a high risk situation and minimize the chances of causing a channel change.

Figure 1: Types of Low Water Crossings.

(a) Ford (or dip) on the Mark Twain N.F., Missouri

(b) Vented ford (or dip with culvert) on the White Mountain N.F., New Hampshire.

(c) Low water bridge on the Monongahela N.F., West Virginia

Swampy areas have weak foundation conditions, making high approach embankments and large structures particularly expensive and impractical.

In arid or semi-arid regions, drainages carry little or no water except during sudden, severe storms. Structures adequate to carry these large, infrequent floods may be prohibitively expensive. In mountainous areas, peak flows are often short lived because of the mountain-caused squalls, small drainage areas and steep stream gradients. In northern climates, floods are often associated with spring runoff, while flows may be low and steady during the remainder of the year. In nearly all areas, small drainages can be found that run only a small volume of water even during heavy rains.

Economics provide the common denominator for comparing alternatives, whether low crossings are considered because of limited access needs, environmental concerns, terrain conditions, foundation conditions, or climates. The savings in construction cost and materials, property damage, and maintenance for low water crossings can be significant. Decreased environmental and aesthetic impacts are significant although difficult to assess economically.

A suggested criteria for access (11) is closure one to three days at a time, totaling not more than 15 days a year. The designer, of course, has the flexibility to vary these criteria for each specific situation. We typically design low water crossings for the maximum annual storm.

The exposure of a low water structure to the full impact of overflowing water is possibly the most important design consideration. Erosion downstream and around the ends of the structure cause the major maintenance problems and even failures. Debris carried by the stream, such as ice or logs, contribute to these erosion problems. Cutoff walls and riprap usually are not carried far enough along the roadway to protect against high water. While the waterways of low water crossings may only be designed for annual storms, the structure itself may necessarily be designed to resist washout from the 25-50 year storm.

Fords

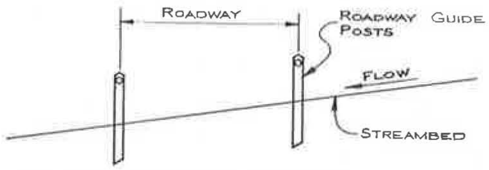
In their simplest form, fords consist of an unsurface stream crossing on the natural bed of the stream or drainage. More commonly, the stream bed is leveled for the width of the roadway as shown in Figures 2 and 3. Leveling may be accomplished by placing a row of boulders along the downstream roadway edge and filling behind the boulders with gravel. A more reliable design may utilize gabions along the downstream edge. Low water crossings are usually upgraded as their use increases.

Once the stream gradient has been changed, as with boulders or gabions, downstream erosion usually accelerates. Unless the crossing is on bedrock or large boulders, or the stream gradient is zero for some distance downstream, a plunge pool develops just below the crossing. As this plunge pool grows, it may undermine the roadway support, creating maintenance problems. Adequate embedment of the boulders or gabions and additional boulders for stream energy dissipation are important.

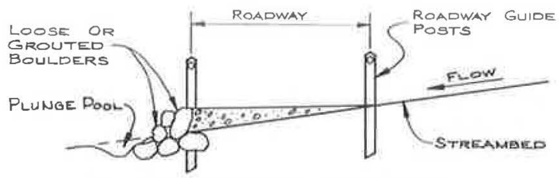
Fords may be surfaced with concrete, asphalt or gabions. The surfacing protects the crossing from erosion, and provides the driver a stable, tractive surface.

Figure 2: Examples of unsurfaced fords (no scale).

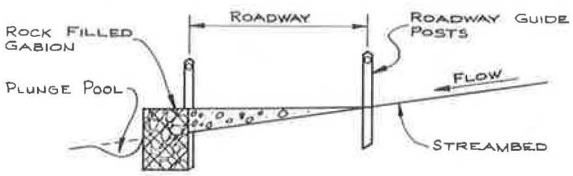
(a) Ford on natural streambed.



(b) Ford with downstream boulders.



(c) Ford with downstream gabion (10).



Reinforced concrete provides the strength adequate to carry traffic over weak stream beds. Concrete fords such as shown in Figure 3(c), built 20-30 years ago, have given maintenance-free service. On the other hand, concrete has a high initial construction cost and erosion through cracks in the concrete can cause settlement and further deterioration.

Asphalt surface treatments are usually adequate to protect the driving surface. However, where used for erosion protection along the downstream edge of the roadway, a 10-15 cm (4-6 in.) layer of asphalt and aggregate must be used.

Gabion surfaced fords provide the flexibility and erosion resistance characteristic of gabion structures. Traffic may eventually break down wires on the surface, but the side baskets continue to hold the crossing together.

Vented Fords

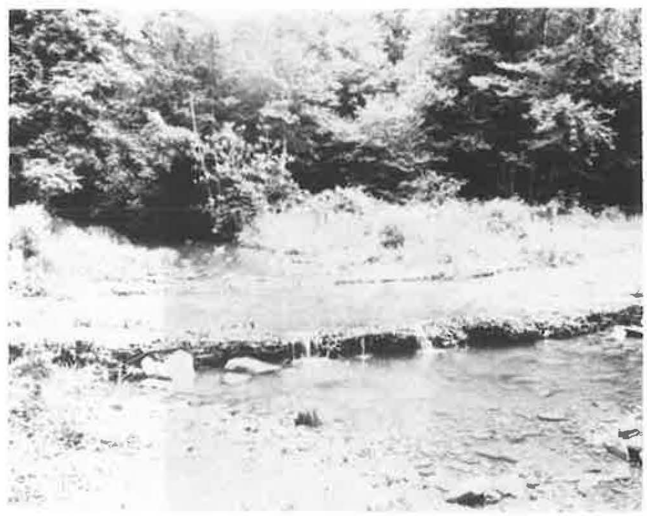
Vented fords, or dips with culverts, create a very significant velocity barrier with severe erosion potential.

When maintenance crews upgrade fords to small vented fords without benefit of a design, problems often develop. Materials usually include hot or cold mixed asphalt and concrete grouted rubble stone. Experience with these smaller vented fords has resulted in development of the typical sections shown in Figure 4. The sloped culvert entrance and sloped embankment catch less debris and clean themselves during high water. The sloped culvert entrance, particularly the formed metal entrance section, also improves the culvert capacity. A splash apron along the downstream

Figure 3: Examples of fords.

(a) Gravel ford on the Mark Twain N.F., Missouri.

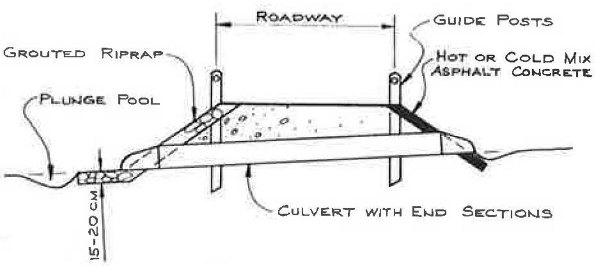
(b) Gabion ford on the Monongahela N.F., West Virginia.



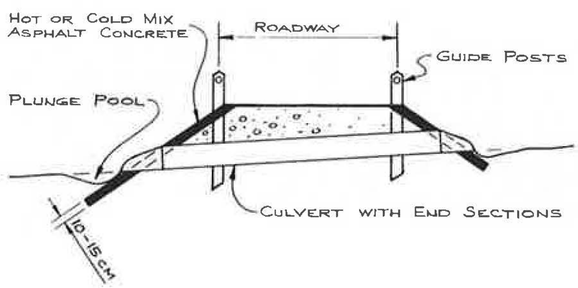
(c) Concrete paved ford on the Mark Twain N.F., Missouri.

Figure 4: Small vented ford sections (no scale).

(a) Grouted riprap and asphalt section.



(b) All asphalt cover.



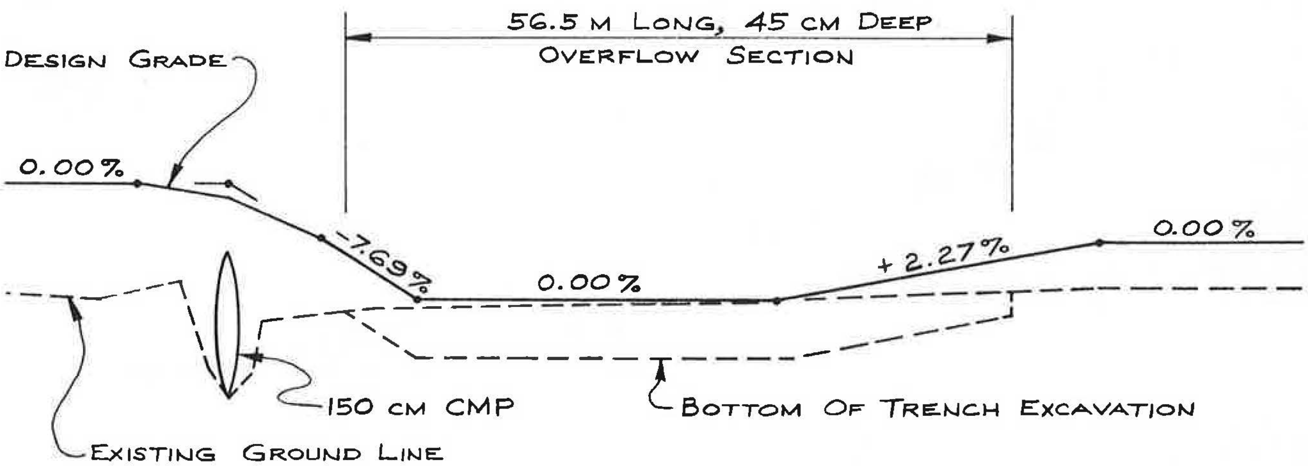
edge of the crossing will move the plunge pool further downstream, preventing undermining of the roadway and culverts. However, where only asphalt contains the road section, Figure 4(b), a cutoff wall should be used rather than a splash apron. The weaker asphalt aprons break off and deteriorate, quickly becoming a maintenance problem.

Figure 5 shows a variation of a vented ford in which a dipped overflow section was offset from the culvert. The single 150 cm (5 ft.) CMP and 56.5 m (185 ft.) dipped section was designed as an economic alternative to the five CMP's that would have been necessary to provide for a 25 year design period. Woven plastic filter fabric and rock were used for erosion protection of the overflow section and the roadway surface was given a single asphalt treatment.

Larger vented fords may be cast-in-place concrete structures encasing culverts, as in Figure 6. These structures have been designed both with and without wheel guards. Experience has shown that sloping the traffic face of the wheel guards, particularly on the down stream edge, reduces the collection of ice and debris during the overflow periods (Figure 6(c)). The surface slabs on these type structures must be well anchored to prevent uplift and displacement during high flows.

Figure 5: Culvert with offset overflow section, Chippewa N.F., Minnesota (no scale).

(a) Road centerline profile.



(b) Cross section through overflow.

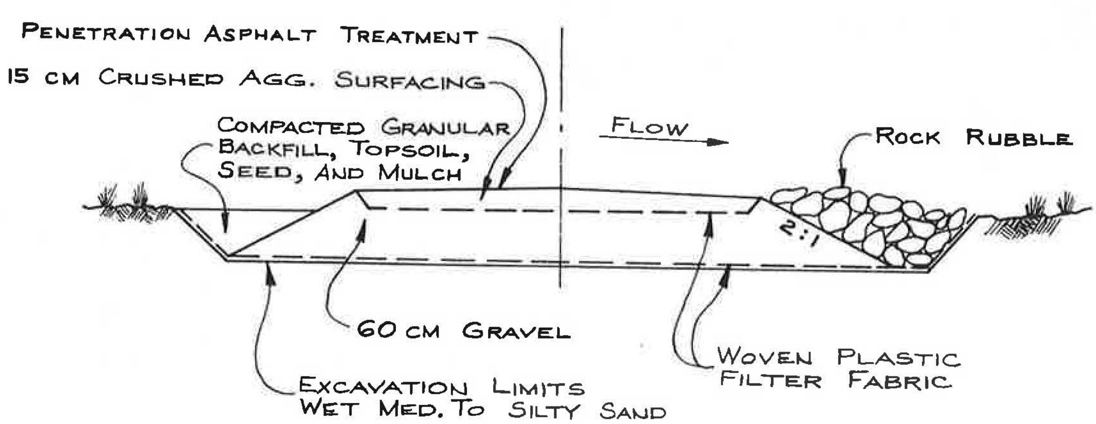
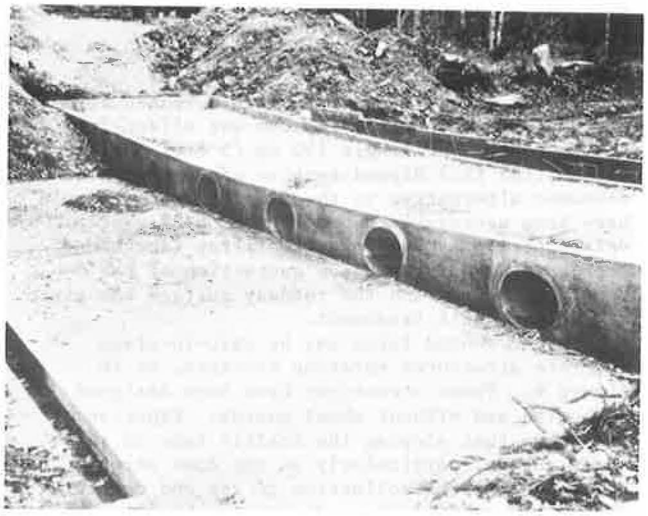


Figure 6: Examples of concrete vented fords on the Monongahela N.F., West Virginia.

(a) Vented ford under construction.



(b) Completed vented ford.

(c) Overflowing vented ford.

Figure 7: Examples of Low Water bridges.

(a) Low water bridge on the Mark Twain N.F., Missouri.

(b) Low water bridge overflowing on the Monongahela N.F., West Virginia

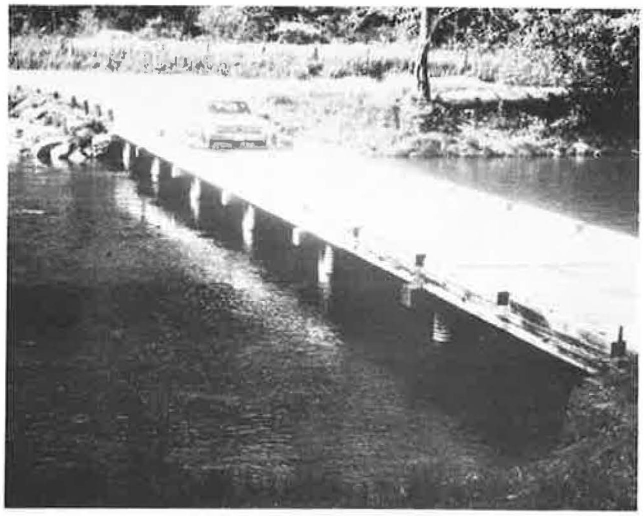
Low Water Bridges

Figures 1(c), 7 and 8 show examples of low water bridges constructed of concrete and concrete with wood decks. These structures can include 10-45 m (30 - 150 ft.) crossings, and spans of 5-10 m (14-30 ft.). Cutoff walls and/or riprap should be carried above the 50 year storm level where practical. Where this may be impractical due to the low approaches to the crossings, cutoff walls should be carried around the ends of the structures to protect the structure itself.

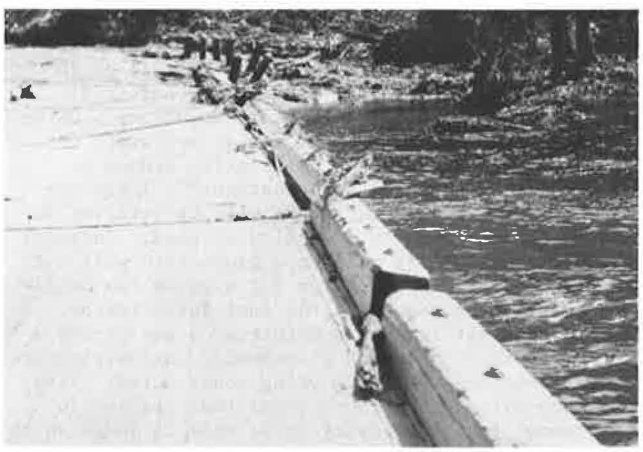
The low water bridge shown in Figure 8 was designed with pier footings to be buried 100 cm (3 ft.) into the river bottom. Built in 1966, the footings were embedded only 30 cm (1 ft.) into the stream bed. The structure performed well until the winter of 1976-77, when an ice flow caught on

Figure 8: Low water bridge on the Monongahela N.F., West Virginia.

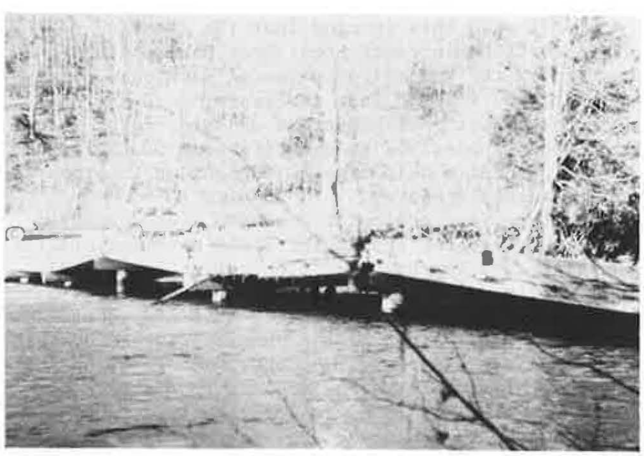
(a) Structure shortly after construction in 1966.



(b) Downstream wheelguard caught and held ice flow during the winter of 1976-77.



(c) Displacement caused by ice flow, water pressure and erosion.



the downstream wheelguard. The excessive forces and current lifted and tilted most of the pier footings. Figure 8(c) shows the structure with as much as two feet vertical displacement.

Had the footings been buried the designed depth, damage would most likely not have occurred. Also, sloped wheelguards may not have caught the ice flow. The gabion protected approaches suffered significant erosion. However, without the gabions, the approaches would certainly have been completely lost. A new all-concrete replacement low water crossing has been designed.

Summary

Low water crossings have proven adequate and economical under a variety of environmental and terrain conditions. While difficult at first for some designers and planners to accept, the advantages of low water crossings can be seen, particularly for low volume roads.

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