

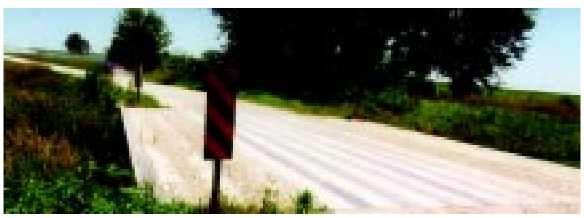


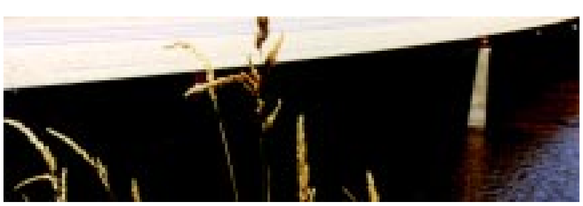


Low Water Stream Crossings in Iowa

A Selection and Design Guide

Sponsored by
Iowa Highway Research Board

Prepared by
Center for Transportation Research and Education, Iowa State University

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This selection and design guide is based on the results of *Low Water Stream Crossings: Design and Construction Recommendations,* a study sponsored by the Iowa Highway Research Board (TR-453) and conducted by R.A. Lohnes, R.R. Gu, T. McDonald, and M.K. Jha of Iowa State University. Additional information and references are available in that document.

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Low Water Stream Crossings in Iowa

A Selection and Design Guide

Introduction

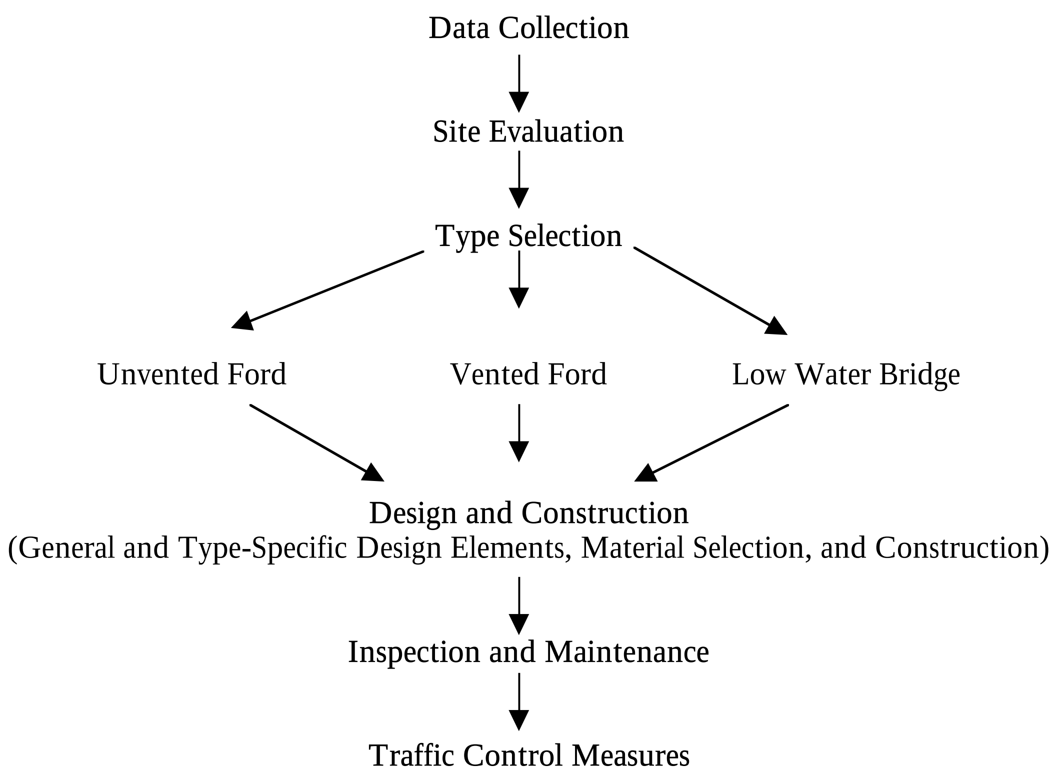
Most Iowa counties maintain low volume roads with at least one bridge or culvert that is structurally deficient or obsolete. In some counties the percentage of deficient drainage structures may be as high as 62%. Replacement with structures of similar size would require large capital expenditures that many counties cannot afford. Low water stream crossings (LWSCs) may be an acceptable low-cost alternative in some cases.

LWSCs are particularly suitable for low volume roads across streams where the normal volume of flow is relatively low. There are three common types of LWSCs:

1. unvented fords
2. vented fords
3. low water bridges

LWSC sites, types, and designs should be carefully selected since low water stream crossings will be flooded periodically, requiring the road to be temporarily closed to traffic.

This guide provides a simplified approach to LWSC selection and design. After weighing public opinion and considering potential liability, jurisdictions interested in low water stream crossings should follow these steps:



Data Collection

Certain information must be determined before any LWSC site, type, or design decisions are made. This data collection form may be photocopied and used to record the relevant data for specific LWSC site candidates.

Location of possible LWSC (name of roadway and name of stream or other identifying feature):

____

Type of Roadway

Roadway surface (check one):
☐ paved
☐ gravel or crushed stone
☐ dirt

Area service level (check one):
☐ Area Service A—maintained in conformity with applicable statues
☐ Area Service B—maintained at lower level with standards determined by county ordinance
☐ Area Service C—restricted access road maintained at minimum level as determined by county

Roadway Geometry

Roadway width: __________ feet

Existing approach grades (both): ______________ % Skewed approach: ☐ Yes ☐ No

Height of roadway above streambed: __________ feet

Use of Roadway

Average daily traffic (ADT): __________ vehicles/day

Roadway use (circle any that apply):
access to dwellings / field access / school access / postal route / recreation / other

Alternate access route available:
☐ Yes (additional travel time for alternate access route: __________ minutes or hours)
☐ No

Longest acceptable percentage of time per year for roadway to be out of service: _________ %

Type of Stream

Stream type at crossing (check one):

- ☐ perennial—water flows in well-defined channel at least 90% of the time
- ☐ intermittent—flow generally occurs only during the wet season (50% of the time or less)
- ☐ ephemeral—flow generally occurs for short time after extreme storms; channel is usually not well defined

Stream Channel Characteristics

Stream channel width, *w*: __________ feet

Stream channel depth: __________ feet

Longitudinal stream channel slope, *S*: __________ feet/foot

Bank slope (each side): ______________ feet/foot

Manning's Roughness Coefficient

Stream channel's Manning's roughness coefficient (*n*) from table: __________

Closest Description of Stream Channel	*n*
Regular section: some grass and weeds, little or no brush dense growth of weeds, depth of flow greater than weed height some weeds, light brush on banks some weeds, heavy brush on banks some weeds, dense willows on banks	 0.030–0.035 0.035–0.050 0.035–0.050 0.050–0.070 0.060–0.080
Regular section with trees in channel, branches submerged at high stage	Increase above values by 0.010–0.020
Irregular section with pools, slight channel meandering	Increase above values by 0.010–0.020

Drainage Area

Drainage area, *A* (obtained by measuring watershed area on USGS topographic map or by consulting published data): __________ miles^2

Daily Discharge

Average historical or estimated daily discharge at site: __________ feet^3/second

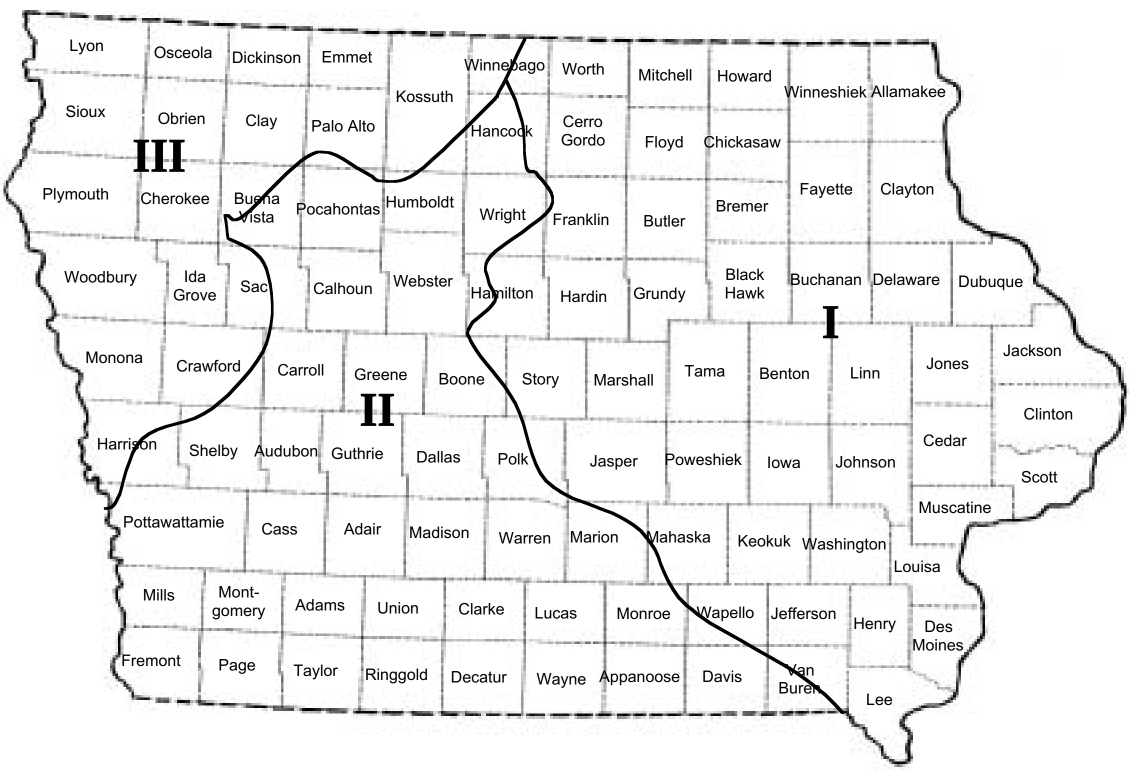
Design Discharge

Design discharge, Q_e: __________ feet^3/second

A suitable design discharge can be determined from historical daily discharges at sites where discharge data have been recorded or by using a design discharge calculation based on the site's location in one of three regions in Iowa. The equation is

$$Q_e = aA^b$$

where Q_e is the design discharge in feet^3/second and A is the drainage area is miles^2. Obtain the values for a and b from the appropriate region tables below, where e is the design exceedence probability (acceptable percentage of time per year for the road to be closed due to overtopping).



Regions I, II, and III

Region I Design Discharge

e	*a*	*b*
50%	0.17	1.05
25%	0.52	1.01
10%	1.37	0.98
5%	2.58	0.96
2%	6.78	0.90
1%	13.50	0.85

Region II Design Discharge

e	*a*	*b*
50%	0.06	1.09
25%	0.24	1.06
10%	0.91	1.00
5%	2.26	0.95
2%	6.78	0.90
1%	13.50	0.85

Region III Design Discharge

e	*a*	*b*
50%	0.015	1.24
25%	0.040	1.25
10%	0.150	1.19
5%	0.330	1.15
2%	1.230	1.06
1%	3.560	0.96

Site Evaluation

When considering whether a site is a good candidate for a LWSC, consider the criteria in the following table. These criteria are particularly applicable to unvented and vented fords; low water bridges may offer more flexibility.

Element	Criteria
Type of roadway	LWSCs are recommended only on Area Service B or C roadways: unpaved or primitive roads, field access roads, roads with no inhabitable dwellings or livestock operations, low traffic volume roads, and roads with alternate routes available during flooding.
Roadway geometry	Approaches should not be skewed. Approach grades should be less than 10%. Projected height between roadway approach and LWSC surface should be less than 12 feet.
Use of roadway	ADT of less than five vehicles is ideal. A LWSC should not be constructed on roads that provide critical travel routes or where a future increase in traffic is expected. Extra travel time for alternate access route should be less than one hour.
Type of stream	Ephemeral streams are the most preferable stream type. LWSCs are suited to perennial streams only in certain shallow, low velocity cases.
Stream channel characteristics	Stream channel should be stable with regard to both degradation and lateral migration. Average annual flooding is preferably less than two times per year, with less than 24 hours of traffic interruption per occurrence. Downstream slope should be 4:1 or flatter.
Cost	Cost comparison with bridge or culvert replacement should indicate considerable savings.

Type Selection

To select the most appropriate LWSC type—unvented ford, vented ford, or low water bridge—consider the following factors: classification and use of roadway, traffic volume and availability of alternate access route, stream flow velocity, projected depth of flow over LWSC structure, and cost.

Unvented Fords

Unvented fords are constructed of riprap, gabions, or portland cement concrete to provide a stream crossing without the use of pipes. Water will periodically flow over the crossing.

Unvented Ford

Unvented fords are best suited for ephemeral or intermittent streams (streams that are dry most of the year). Unvented fords may also be used across some shallow, low velocity perennial streams.

For safe passage, the maximum allowable depth of flow over a ford is 6 inches. The water depth can be determined either by site observation over a long period (at least a year or preferably five years) or by using the depth of flow calculations provided later. If the calculated depth of flow over an unvented ford on the channel bottom exceeds 6 inches, a raised unvented ford or a vented ford should be considered. Raising an unvented ford will usually reduce the overtop flow depth.

Unvented fords are the least costly of the three LWSC types.

Vented Fords

Vented fords use pipes under the crossing to accommodate low flows without overtopping the roadway. The pipes or culverts may be embedded in compacted earth fill, aggregate, riprap, gabions, or portland cement concrete. Higher stream flows will periodically pass over the crossing.

Vented Ford

Vented fords offer more flexibility and range of use than unvented fords. Vented fords should be considered where the normal depth of flow is calculated to exceed 6 inches over a raised unvented ford. Vented fords can usually be constructed for $15,000–$20,000.

Low Water Bridges

Low water bridges are flat-slab bridge decks constructed at about the elevation of the adjacent stream banks, with a smooth cross section designed to allow high water to flow over the bridge surface without damaging the structure.

Low Water Bridge

Low water bridges are the recommended LWSC choice where normal stream flows exceed the capacity of a vented ford or where the watershed has a high potential for debris that might clog the pipes of a vented ford. A low water bridge is also an appropriate alternative where the ADT exceeds five vehicles per day or where the road is relatively important, regardless of stream size.

A normal low water bridge may cost $40,000–$50,000 to construct.

Design and Construction

General Design Elements

General LWSC design elements are provided here. Recommendations specific to each of the different LWSC types follow.

Element	Criteria
Roadway approaches	Approach grades of less than 10%
Orientation of structure	Straight, avoid skew
Channel cross section	Do not alter if possible
Stream bank height	Less than 12 feet
Height of ford above streambed	Less than 4 feet
Overtopping flow depth for normal flow	Less than or equal to 6 inches

Unvented Ford Design

Unvented fords can be placed at the level of the streambed or the crossing elevation can be raised up to 4 feet above the channel.

Unvented Ford on Channel Bottom

To confirm that flow depth over an unvented ford on the channel bottom would not exceed the recommended maximum of 6 inches, use the following equation:

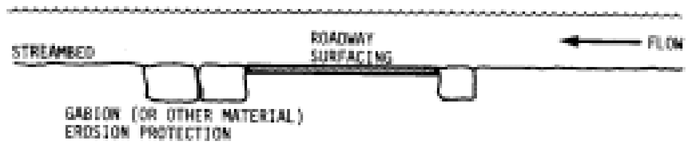
$$Q_e = \frac{1.486}{n} \frac{(wH)^{5/3}}{(w+2H)^{2/3}} S^{\frac{1}{2}}$$

where Q_e is the design discharge in feet^3/second, w is the channel width in feet, H is the depth of flow in feet, S is the channel slope in feet/foot, and n is Manning's roughness coefficient. Given Q_e, w, n, and S from data collection, the depth of flow, H, can be determined through trial and error. Start by assuming a best estimate value for H, or start with 6 inches (0.5 feet), and then adjust the value until the equation is balanced.

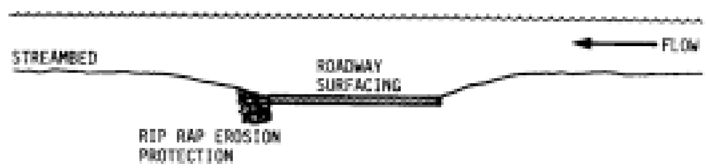
For very wide channels, where w/$H \geq 10$, the equation may be simplified to

$$H = \left(\frac{nQ_e}{1.486wS^{1/2}} \right)^{3/5}$$

Unvented fords on the channel bottom should be designed to best suit streambed conditions:



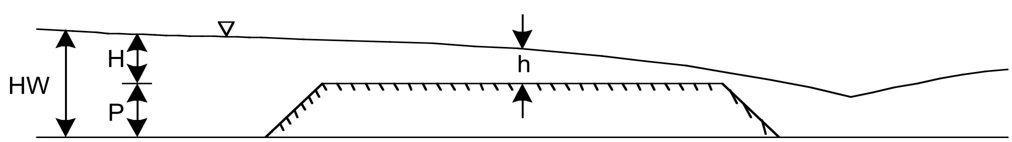
Unvented Ford on Channel Bottom when Streambed is Stable



Unvented Ford on Channel Bottom when Streambed is Erodible

Raised Unvented Ford

If the estimated flow depth over an unvented ford on the channel bottom exceeds 6 inches, a raised ford can be considered. In the following crossing profile of a raised unvented ford, *HW* is the depth of headwater, *P* is the height of the ford above channel bottom, *H* is the upstream head, and *h* is the water depth over the ford (use feet for all units).



Crossing Profile of a Raised Unvented Ford

The ford height, *P*, does not significantly affect the discharge-depth relationship, thus *P* is a flexible design parameter. However, the ford height should not exceed 4 feet to meet the Iowa Department of Natural Resources requirement for fish passage. A *P* value between 2 and 4 feet is recommended.

To confirm that the flow depth over a raised unvented ford will not exceed the recommended maximum of 6 inches, use the following equation:

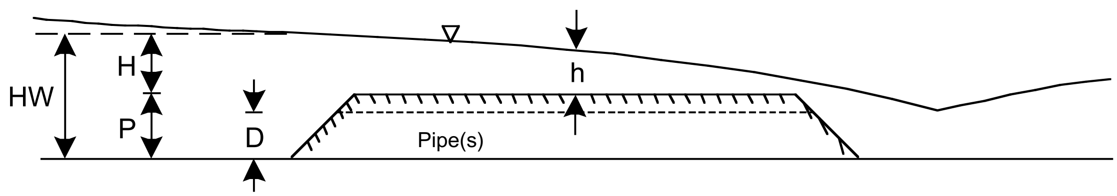
$$h = 0.233 \; Q_e^{0.599} L^{-0.493}$$

where h is the depth of flow over structure in feet, Q_e is the design discharge in feet^3/second, and L is the length of LWSC in feet.

Vented Ford Design

The design of a vented ford is similar to that of a culvert. Several of the tools available to assist with vented ford design are described in this section, including discharge equation derived design curves, existing hydraulic charts, and the CulvertMaster computer program. Gupta's culvert design procedures (*Hydrology and Hydraulic Systems*, Waveland Press, 2001) may also be of assistance.

In the following crossing profile of a typical vented ford, *HW* is the depth of headwater, *P* is the height of the ford above channel bottom, *H* is the upstream head, *h* is the water depth over the ford at the middle of the crossing, and *D* is the diameter of the pipe or the height of vent (use feet for all units).



Crossing Profile of a Vented Ford

Vent Discharge Capacity

First determine the structure's vent discharge capacity (Q_{vent}) using this equation:

$$Q_{vent} = Q_e - Q_{top}$$

where Q_e is the total design discharge from hydrological analysis and Q_{top} is the flow over the ford (all measured in feet^3/second).

Given that overtopping should not exceed 6 inches ($h \leq 0.5$ feet), flow over the ford can be calculated as follows:

$$Q_{top} = 3.538 \ L^{0.823}$$

where *L* is the length of the LWSC in feet.

Total Pipe Diameter

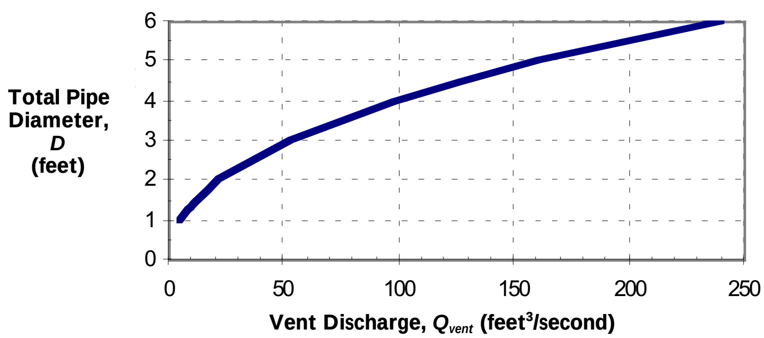
Determination of total pipe diameter in a vented ford design is a trial and error process. Generally in culvert design, it is first assumed that flow is governed by inlet control and then the design is checked for outlet control. In LWSC design, a vented ford is allowed to have an overtopping flow depth of 0.5 feet maximum and the inlet is submerged. When the inlet of a culvert is submerged, a larger pipe size is required under inlet control. Therefore, the design of a vented ford with a submerged entrance under inlet control does not need to be checked for outlet control.

Inlet control means that the discharge capacity is controlled at the entrance by headwater depth and entrance geometry, including barrel shape and cross-sectional area, and the type of inlet edges. Under the inlet control assumption, pipe barrel friction and other minor losses can be neglected. In an outlet control situation, barrel friction is the predominant head loss and tail water conditions have an important impact. The practical significance of inlet control is that the vent discharge capacity can be increased by improving the entrance conditions.

Once the structure's vent discharge capacity (Q_{vent}) is known, the corresponding pipe diameter (D) can be determined using one of the following design tools.

Discharge Equation Derived Design Curves. The appropriate pipe diameter can be obtained from design curves that plot diameter (D) against vent discharge capacity (Q_{vent}) (see Normann et al., *Hydraulic Design of Highway Culverts*, Federal Highway Administration, 1985).

As an example, for vented fords using corrugated metal pipes with a mitered entrance, barrel slope ≤ 0.02 feet/foot, and under inlet control, use the following design curve:



Design Curve for Mitered Entrance, Barrel Slope ≤ 0.02 feet/foot, and Inlet Control

For various other conditions with a submerged entrance under inlet control, similar design curves of total needed pipe diameter versus vent discharge can be calculated using this equation:

$$\frac{HW}{D} = c\left[\frac{Q_{vent}}{A_b D^{0.5}}\right]^2 + Y + f_s S_o$$

where HW is headwater depth in feet, D is the total pipe diameter in feet, Q_{vent} is the vent discharge capacity in feet^3/second, A_b is the full cross-sectional area of the pipe barrel in feet^2, c and Y are inlet constants, f_s is the slope correction factor of 0.7 for mitered inlets and -0.5 for other inlets, and S_o is the culvert barrel slope in feet/foot.

The headwater (HW) is equal to D plus pipe cover plus overtopping flow depth at the entrance (h). The area (A_b) of a circular pipe can be figured using the equation $A_b = \pi D^2/4$. The inlet constants c and Y are 0.75 and 0.0463, respectively, for corrugated metal pipe culverts with mitered entrance.

Hydraulic Charts. HEC-5 charts have been developed to aid with culvert size selection, and these charts may also be used for selecting vented ford pipe size. For a given headwater depth and design discharge, the appropriate vent diameter may be obtained from the corresponding chart. The charts are available in Herr and Bossy, *Hydraulic Charts for the Selection of Highway Culverts*, Federal Highway Administration, 1965, and Normann et al., *Hydraulic Design of Highway Culverts*, Federal Highway Administration, 1985.

CulvertMaster Computer Program. The CulvertMaster computer program developed by Haestad Methods (1999) provides quick culvert design calculations and detailed analyses. The CulvertMaster software can be purchased through the Internet at www.haestad.com.

Number of Pipes

A single pipe may be considered first. If the computed diameter is larger than the design height of the LWSC, multiple pipes may be used; determine the size of multiple pipes by simply dividing total design pipe diameter by number of pipes. Pipes should have a minimum diameter of 1 foot to limit clogging. Cover over the pipes should be a minimum of 1 foot.

Pipe Exit Flow Velocity

For scour control and channel protection, pipe exit flow velocity should not exceed 10 feet/second. Exit velocity can be computed by

$$V_e = Q_{vent}/(\pi D^2/4)$$

where V_e is pipe exit flow velocity in feet/second, Q_{vent} is vent discharge capacity in feet^3/second, and D is total pipe diameter in feet.

Ford Design Example

Data Collection

Factor	Value	Notes
Exceedence probability (e)	2%	Longest acceptable percentage of time for roadway to be out of service.
Stream channel width (w)	10 feet	
Stream channel slope (S)	0.0023 feet/foot	
Manning's roughness coefficient (n)	0.04	See table on page 4.
Drainage area (A)	10.60 miles^2	
Region (I, II, or III)	II	See map on page 5.

Design Discharge

Design discharge, Q_e, is calculated as follows:

$Q_e = aA^b$

A is the drainage area, 10.60 miles^2. The values for a and b are obtained from the Region II table on page 5 (exceedence probability, e = 2%): a = 6.78 and b = 0.90. Thus,

Q_e = 56.76 feet^3/second

Unvented Ford on Channel Bottom Design Calculation

Depth of flow, H, is calculated as follows:

$$Q_e = \frac{1.486}{n} \frac{(wH)^{5/3}}{(w+2H)^{2/3}} S^{\frac{1}{2}}$$

Q_e is the design discharge from above, 56.76 feet^3/second; w is the stream channel width, 10 feet; S is the stream channel slope, 0.0023 feet/foot; and n is Manning's roughness coefficient, 0.04.

The resulting depth of flow, H, is 2.0 feet, which is greater than the maximum of 6 inches (0.5 feet). Therefore, an unvented ford on the channel bottom is not an acceptable option here.

Raised Unvented Ford Design Calculation

Depth of flow over the structure, h, is calculated as follows:

$$h = 0.233 \;\; Q_e^{0.599} L^{-0.493}$$

Q_e is the design discharge from above, 56.76 feet^3/second; and L is the length of the LWSC, 10 feet.

The resulting depth of flow over the structure, h, is 0.84 feet, which is greater than the maximum of 6 inches (0.5 feet). Therefore, a raised unvented ford is not an acceptable option here.

Vented Ford Design Calculation

Flow over the ford, Q_{top}, is calculated as follows:

$$Q_{top} = 3.538 \;\; L^{0.823}$$

L is the length of the LWSC, 10 feet. Thus, Q_{top} is 23.54 feet^3/second.

Vent discharge capacity, Q_{vent}, is calculated as follows:

$$Q_{vent} = Q_e - Q_{top}$$

Q_e is the design discharge from above, 56.76 feet^3/second; and Q_{top} is the calculated flow over the ford, 23.54 feet^3/second. Thus, Q_{vent} is 33.22 feet^3/second.

The required total pipe size can be obtained from discharge equation derived design curves or existing hydraulic charts (see pages 12–13). Here we assume a design for corrugated metal pipe with inlet control and a mitered entrance. The recommended pipe diameter is 2.25 feet.

Pipe exit flow velocity, V_e, is calculated as follows:

$$V_e = Q_{vent}/(\pi D^2/4)$$

Q_{vent} is the calculated vent discharge capacity, 33.22 feet^3/second; and D is total pipe diameter, 2.25 feet. The resulting pipe exit flow velocity, 8.3 feet/second, is less than the maximum of 10 feet/second. Therefore, this vented ford design is an acceptable option here.

Unvented and Vented Ford Material Selection

The crossing may be constructed of compacted earth fill, riprap/crushed stone, gabions, portland cement concrete, or other suitable material.

Riprap/Crushed Stone

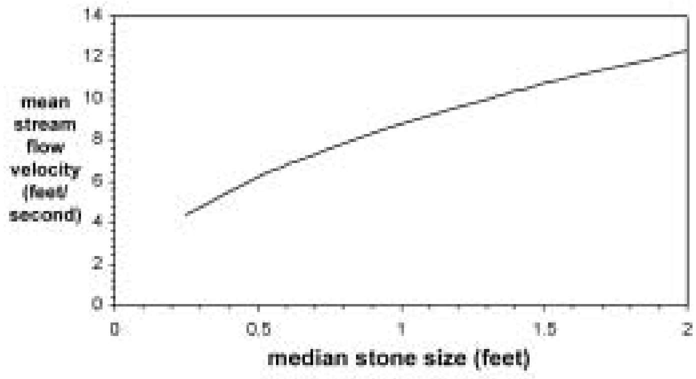
Dumped, hand-placed, or grouted riprap may be used to provide a protective lining on the streambed. Dumped riprap may be the best choice in terms of lower material costs, lower labor costs, and greater stability; however, stone size is also very important.

The recommended median stone size depends on the stream flow velocity (v) compared to the threshold velocity that would erode the material. The mean stream flow velocity can be calculated using this equation:

$$v = \frac{1.46}{n} R^{2/3} S^{1/2}$$

where v is the stream flow velocity in feet/second, n is Manning's roughness coefficient from data collection, R is the hydraulic radius in feet, and S is the slope of the streambed in feet/foot. For very wide channels, R = stream flow depth; otherwise, $R = a/p$ where a is the cross-sectional area of flow in feet^2 and p is the wetted perimeter of channel in feet.

Use the computed stream flow velocity to find the recommended median stone size in the following chart:



Recommended Crushed Stone Size

Block-shaped stones with sharp edges provide better interlocking and stability than elongated, smooth-edge stones. Stones with a length-to-width ratio less than 3/1 are preferred.

Gabions

Gabions are steel wire fabric baskets filled with stones, providing sufficient mass to resist displacement. Because gabions are flexible, they are not prone to settlement or undermining. Gabions fill up with silt quickly and thus facilitate the establishment of natural vegetation. Gabions are also 20%–30% less costly than concrete. However, gabion installation is labor intensive and a suitable filter material is required to prevent scouring of the underlying soil. Stone sizes should range between 4 and 8 inches.

Portland Cement Concrete

Portland cement concrete is the most durable ford material and requires the least maintenance. However, it is the most expensive initially and adequate protection for scour around the structure must be provided. In addition, sufficient thickness and/or reinforcement should be provided to reduce cracking and prevent differential settlement. Cast-in-place crossings are difficult to construct in flowing streams; precast panels, on the other hand, offer construction advantages. Precast panels may be placed directly on the streambed for unvented fords.

Precast Portland Cement Concrete Panel Recommendations

Element	Criteria
Panel thickness	8 inches
Usual length and width	6 feet by 16 feet
Reinforcement	#5 bars at 12-inch centers
Method of tying panels together	5/8 inch steel cable
Side gap fill	3 to 5 inch crushed stone

Unvented and Vented Ford Construction

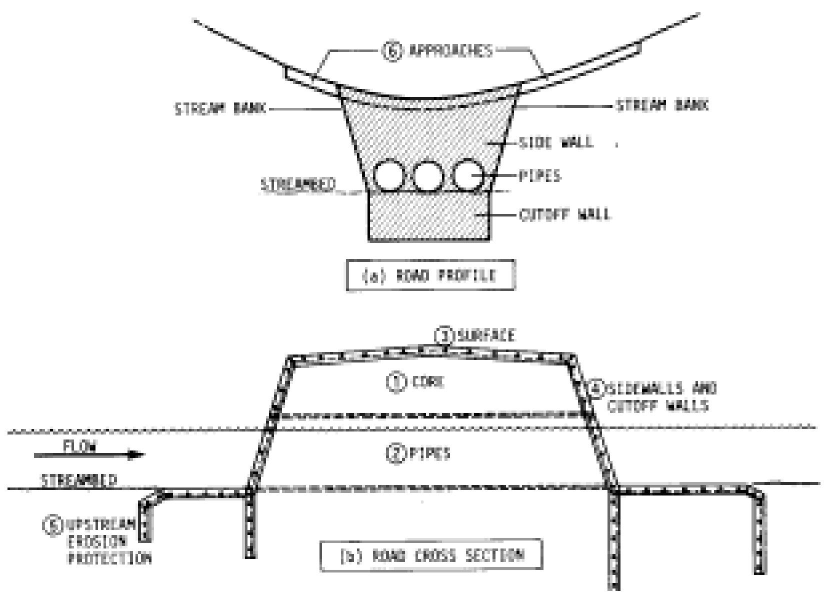
Streambed Preparation

In construction of unvented and vented fords, the streambed crossing base should be prepared by

- stabilizing the streambed with crushed stone, riprap, or rubble;
- removing silt and replacing with a suitable material; or
- compacting base and core to reduce future settlement.

Components of a Vented Ford

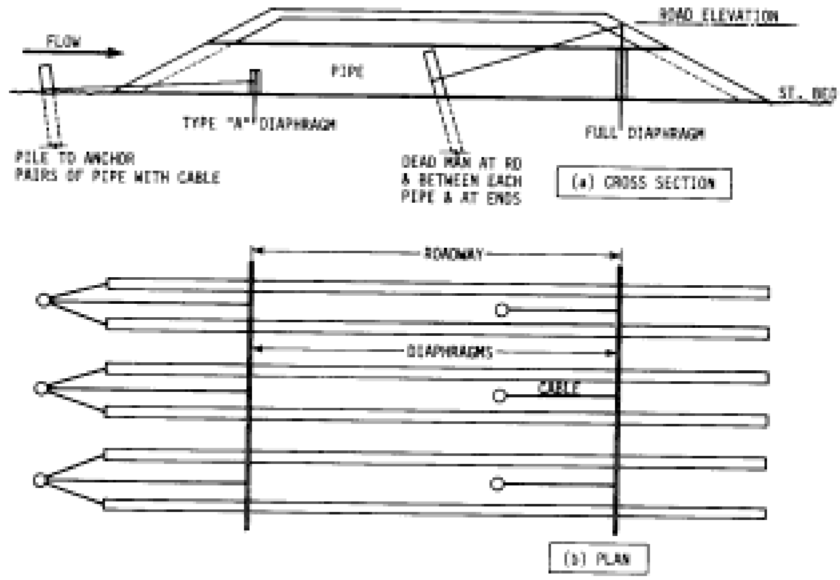
A typical vented ford has six primary components: core material, pipes, driving surface, sidewalls and cutoff walls, upstream and downstream erosion protection, and approaches.



Components of a Typical Vented Ford

Installation of Pipes (Vented Fords)

Corrugated metal, plastic, and precast concrete pipes are commonly used. For smoother hydraulic operation, and to reduce the potential of clogging, both ends (but particularly the inlet) should be beveled or mitered to fit the sidewall slope, or aprons can be added. Pipe(s) can also be offset from the center of the stream channel to reduce debris accumulation at the inlet. Diaphragms can be used to reduce seepage and piping. Some designs use one or more cables anchored to upstream piling and tied to the pipe or diaphragms to hold the pipe in place in case of washout of the core material (see figure on the following page). A 1-foot minimum depth of cover above pipes is recommended.



Cable Anchor Used to Secure Pipes

Driving Surface Considerations

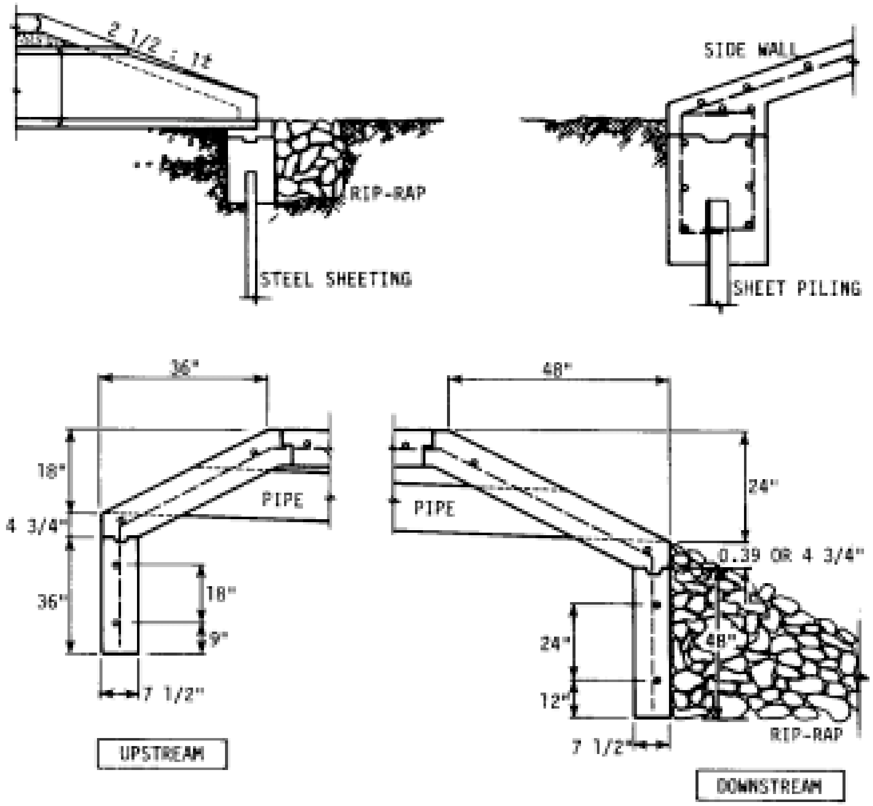
Surface material normally consists of crushed stone, rubble, or portland cement concrete. If concrete is used, a coarse texture will increase traction following overtopping and possible siltation on the surface. A crown will ensure cross drainage and avoid ponding on the surface. Non-rigid surfaces should have a steeper crown.

It may be a good idea to provide markers to help drivers identify the limits of the roadway when flooded, but if markers or other edge-identifying devices are used, care should be taken that the surface will drain completely after overtopping and that the surface is self-cleaning. Guard rails are not recommended to avoid catching debris during flooding. Any projection above the surface can collect debris, so roadway surfaces may require maintenance after overtopping.

Erosion Protection of Structure Side and Core Material

Sidewalls (ford foreslopes) are necessary to protect the edges of the structure and prevent erosion of the core material. Although 2:1 foreslopes can be used, a minimum slope of 4:1 is recommended for safety and to improve self-cleaning and flow in the pipes. A vertical sidewall is not recommended. If the sidewalls are constructed of concrete, joints should be sealed to reduce intrusion of stream flow. If riprap is used, the size should be selected and placed as a uniform mass and prevent subsequent abrasion of the core material. Geotextiles also may be used effectively.

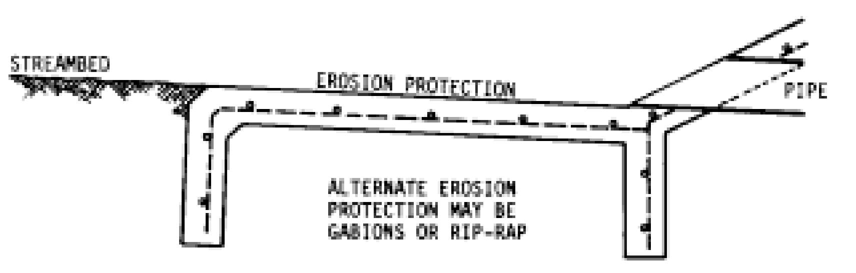
If the sidewalls cannot be tied into bedrock or a firm foundation of non-erodible material, cutoff walls may be necessary to protect against scouring. If cutoff walls are required, they should normally be used both upstream and downstream and can be constructed of concrete, rubble, or sheet piling. In all cases, placement of boulders, rubble, riprap, or gabions is recommended to protect the edge of the crossing.



Typical Sidewall and Cutoff Walls

Erosion Protection of Streambed

Streambed protection should be provided in erodible channels extending upstream and downstream. The protection may be constructed of concrete, riprap, gabions, or rubble. This practice will reduce the potential for turbulent flows to create scour pools, thus preventing undermining of the structure. In addition, vegetation can be established to help protect the stream bank.



Typical Erosion Protection of Streambed

Low Water Bridge Design

The two most common low water bridge design options are simple supported slab and beam-in-slab.

Simple Supported Slab Bridge

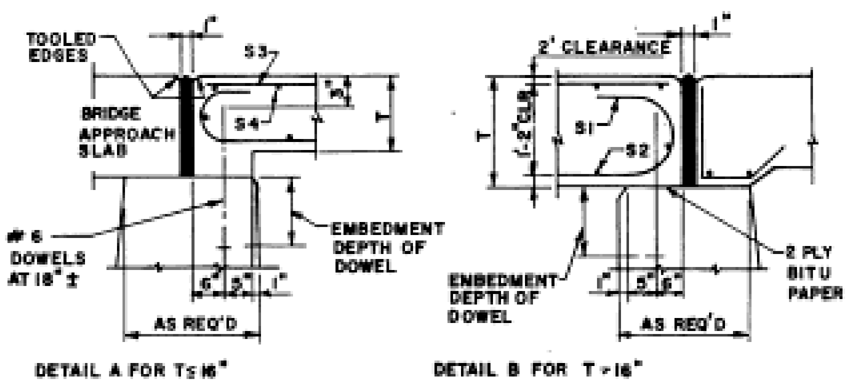
The simple supported slab design is limited to spans of 30 feet or less. The following table provides the recommended slab thickness for a given bridge span and corresponding configurations of the bottom bars S_1 and S_2 and top bars S_3 and S_4.

Slab Thickness and Reinforcement Bar Configuration

Bridge Span (feet)	Slab Thickness (inches)	Size and Spacing of Bottom Bars (inches)		Size and Spacing of Top Bars (inches)	
		S_1	S_2	S_3	S_4
10	11.0	#8 at 8.5	#6 at 12.0	#5 at 17.0	#4 at 12.0
12	12.0	#8 at 8.0	#6 at 12.0	#5 at 16.0	#4 at 12.0
14	12.5	#8 at 7.0	#6 at 12.0	#5 at 12.0	#4 at 12.0
16	13.5	#9 at 8.0	#6 at 12.0	#5 at 16.0	#4 at 12.0
18	14.5	#9 at 7.5	#6 at 12.0	#5 at 15.0	#4 at 12.0
20	15.0	#9 at 7.0	#6 at 12.0	#5 at 14.0	#4 at 12.0
22	16.0	#10 at 8.5	#7 at 15.0	#5 at 17.0	#4 at 15.0
24	17.0	#10 at 8.0	#7 at 15.0	#5 at 16.0	#4 at 15.0
26	18.0	#10 at 7.0	#7 at 15.0	#5 at 14.0	#4 at 15.0
28	19.5	#11 at 8.5	#7 at 15.0	#5 at 17.0	#4 at 15.0
30	21.0	#11 at 7.5	#7 at 15.0	#5 at 15.0	#4 at 15.0

From A. K. Motayed, F. M. Chang, and D. K. Mukherjee, *Design and Construction of Low Water Stream Crossings*, Report No. FHWA/RD-82/164, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 1982.

Detail A and Detail B below are design sketches for slab thicknesses less than or equal to 16 inches and more than 16 inches, respectively.

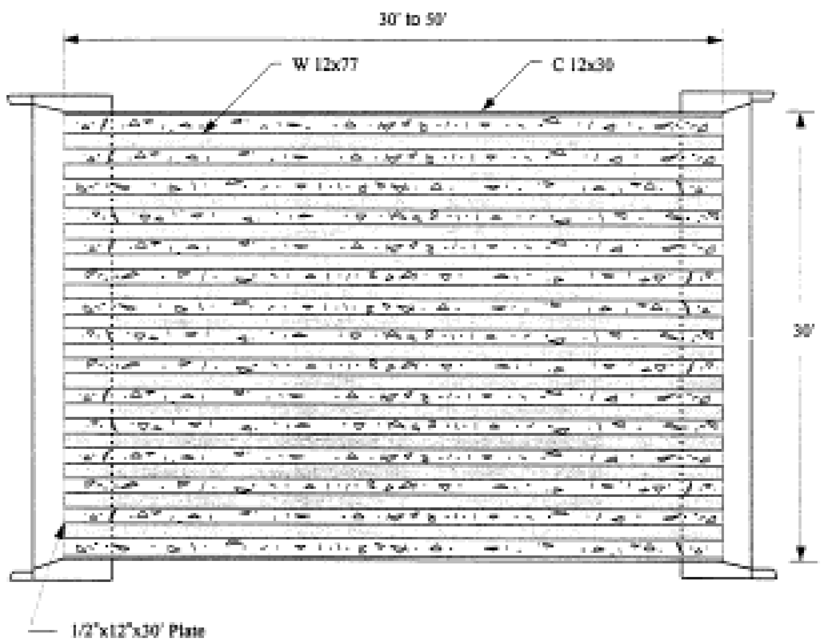


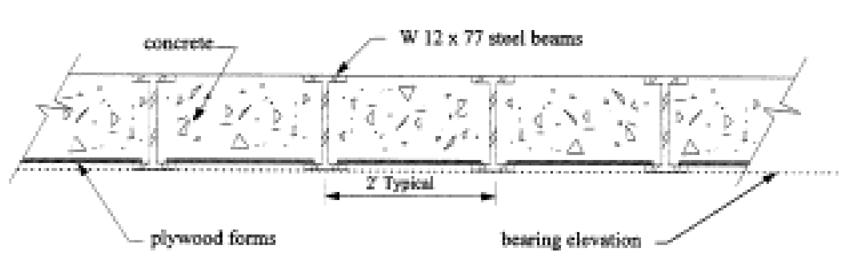
Slab Bridge Sections at Abutments

Beam-in-Slab Bridge

The beam-in-slab design can be used for spans between 20 and 50 feet. The following design guidance is taken from F.W. Klaiber et al., *Investigation of Two Bridge Alternatives for Low Volume Roads,* Iowa Department of Transportation, 1997.

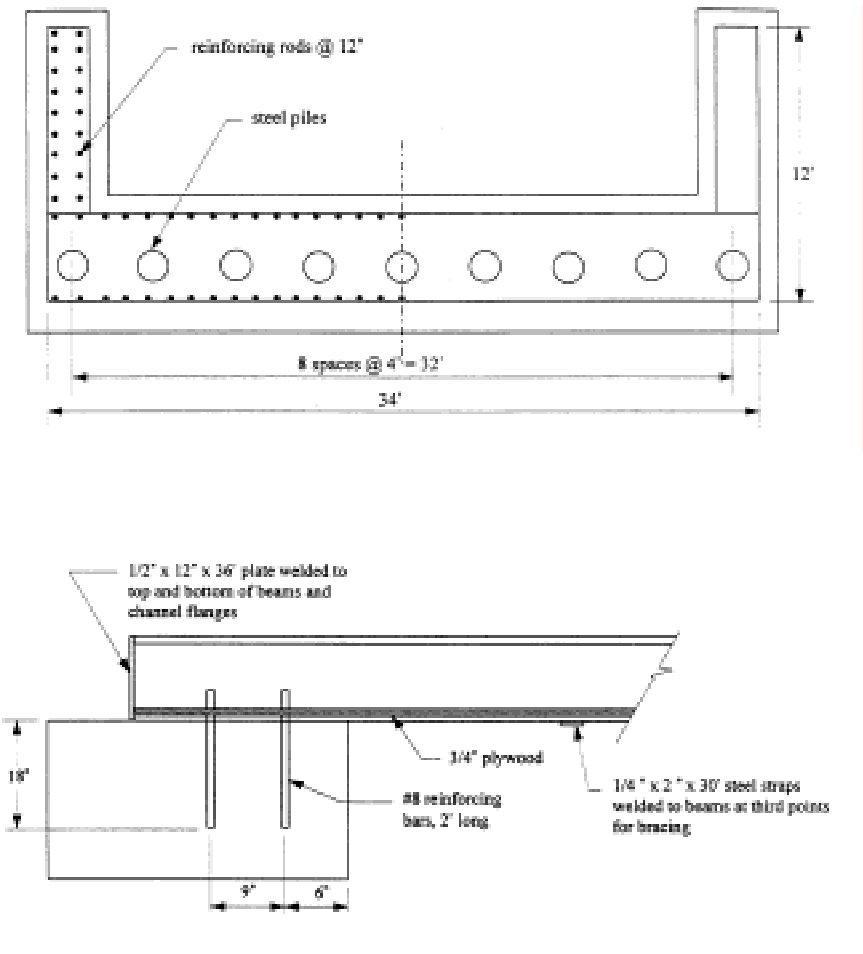
The beam-in-slab design consists of a series of W-shape steel beams generally W 12×79 spaced 2 feet center to center. The exterior beam can be either a channel section (generally C 12×30) of the same height as the W sections or another W section. A channel section provides some streamlining for water flow over the edge of the bridge. Plywood 5/8 or 3/4 inches thick is placed between the adjacent beams as a bottom form. The plywood is cut to a width of 18 inches so that concrete, when placed, is in contact with the surface of the bottom flange. After the formwork has deteriorated, bearing will still exist between the concrete and steel. Concrete is poured flush with the top flange of the beams. The width of the structure should be increased by 5 feet beyond the roadway on each side of structure to provide additional traffic space as a safety factor.





Beam-in-Slab Section

For abutments, generally nine steel piles are driven on 4-foot centers. As shown in the figure, wing walls of desired height are connected with reinforcement to each of the abutments. Reinforcing bars provide connection of the superstructure to the abutment.



Beam-in-Slab Abutment Details

Low Water Bridge Construction

Foundation

Footings only may be used when hard rock or non-erodible soil is at shallow depths. Piles should be used in all other situations.

Substructure

Piers should be well anchored to the foundation. The upstream edge of the pier should be rounded so accumulation of debris is minimized. To reduce the risk of overturning, the height of piers should be limited to approximately 10 feet. Piers and abutments require streamlining to reduce resistance to the stream flow. The abutment should not project excessively into the stream to avoid constricting the flow width and possible scouring. For some small bridges, various types of pilings have been used as piers to reduce construction costs. Piling is particularly suitable and economical for weak soil such as silt.

Superstructure

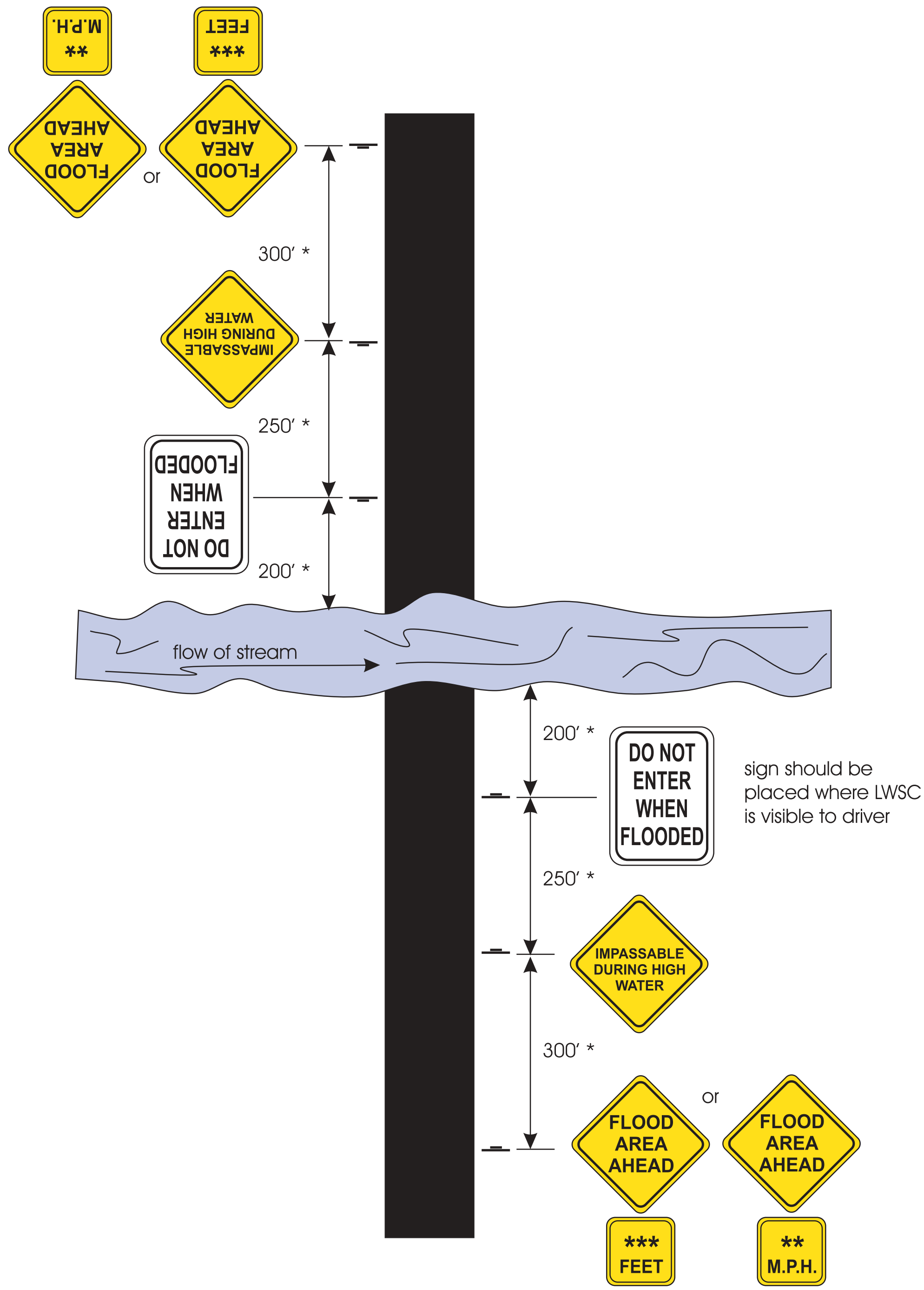
Reinforced concrete slabs with either steel or concrete beams may be used. Decks must be heavy to withstand drag, uplift, and lateral forces due to overflow and upstream water pressure. The deck slab should be well anchored to the substructure to prevent displacement by flood water. Upstream and downstream edges of the deck slab should be smoothly rounded to enhance the efficiency of flow over the slab during overtopping. There should be no projections above the deck that could catch debris.

Inspection and Maintenance

Like all other roadway features, LWSCs require periodic inspection and maintenance. Crossing approaches and surfaces should be bladed occasionally. Inspection, particularly after flooding, is recommended; removal of accumulated debris may be necessary.

Traffic Control Measures

Traffic control measures should be established and routinely inspected. The following illustration depicts a suggested layout for signing of a low water stream crossing in Iowa. The minimum sight distance for warning signs is 750 feet. Additional information can be obtained from the Center for Transportation Research and Education or the Iowa DOT Office of Local Systems.



* Nominal distance (other distance may be used if engineering study indicates).

Recommended Signing of a Low Water Stream Crossing

Legal Considerations

Local agencies may have concerns regarding potential liability exposure from the use of low water stream crossings. Some legal considerations are addressed here, along with a brief history of liability experience involving LWSCs in Iowa.

Section 309.79 of the Code of Iowa seems to imply that all bridges and culverts should comply with standards and specifications furnished to local agencies by the Iowa Department of Transportation. Section 309.74 of the Code of Iowa states that culverts shall allow a minimum clear roadway width of 20 feet and bridges a minimum width of 16 feet. LWSCs can easily be designed to conform with Section 309.74, but complying with Section 309.79 may be more difficult.

However, the Code of Iowa further allows considerable flexibility to boards of supervisors and county engineers in carrying out responsibilities for the secondary road system. Under Section 309.57, boards of supervisors have the authority to establish reduced maintenance levels for certain roads under their jurisdiction. Further, it has long been recognized that local agencies must prioritize available funding to best address the needs of public transportation. LWSCs designed, constructed, and maintained to reasonable guidelines would seem to meet these responsibilities.

In fact, with adequate traffic control, the potential for crashes and resultant tort claims may actually be decreased by LWSCs over deficient and obsolete bridges, as was concluded in an Iowa State University study (R.L. Carstens et al., *Liability and Traffic Control Considerations for Low Water Stream Crossings*, 1981).

In a recent survey of county engineers in Iowa (undertaken as part of *Low Water Stream Crossings*, TR-453, Iowa Highway Research Board, 2002), only three counties reported any tort claims relating to the more than 225 LWSCs in Iowa. Of these, two counties were found not at fault for crashes that occurred at existing crossings. The third claim concerned a right-of-way issue not directly related to the LWSC, and the county settled out of court. Based on this history, it would seem that potential liability from the use of LWSCs is not extensive in Iowa.

To minimize exposure to tort liability, local agencies using low water stream crossings should consider adopting reasonable selection and design criteria and certainly provide adequate warning of these structures to road users, as described in this guide.