



## **Low Volume Roads**

### **Chapter 8 – Culverts**

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2 PDH Credits



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# Low-Volume Roads Engineering

## Best Management Practices Field Guide

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## Chapter 8

# Culvert Use, Installation, and Sizing

*"Ensure that culverts are adequately sized or have overflow protection."*

**C**ULVERTS ARE commonly used both as cross-drains for ditch relief and to pass water under a road at natural drainage and stream crossings. In either case, they need to be properly sized and installed, and protected from erosion and scour (*Photo 8.1*). Natural drainages need to have pipes large enough to pass the expected flow plus extra capacity to pass debris without plugging (*Photo 8.2*). Fish passage may also be a design consideration. Discharge (design flow) will depend on the watershed drainage area, runoff characteristics, design rainfall intensity, and return period (frequency) of the design storm. Culvert design typically uses a minimum storm event of 20 years, and may design for as much as a 100-year event (*Photo 8.3*), depending on local regulations and the sensitivity of the site (such as with endangered species).

For small watersheds (up to 120 hectares) pipe size can

be estimated using *Table 8.1* (if better local data is not available). For larger drainages, specific site hydrologic and hydraulic analyses should be done. These analyses must consider the watershed and channel characteristics, high water levels, local rainfall data, and other available flow information (see Chapter 5, Chapter 6, and Chapter 7- Natural Stream Crossings).



**Photo 8.1** Protect the outlet of culverts against erosion. Graded riprap is common for this purpose.



**Photo 8.2** A culvert failure caused by insufficient flow capacity or inadequate pipe size to pass the debris (boulders) moving through the drainage.

Culverts are made of concrete or metal (corrugated steel or aluminum), and plastic pipe is occasionally used, as well as wood and masonry. The type of material used depends on cost and availability of the materials. However, corrugated metal pipe (CMP) and concrete pipe are generally more durable than plastic pipe. The shape of the culvert, such as a round pipe, pipe arch, structural arch, or box, depends on the site, the needed span, and the allowable height of soil cover. The key factors in culvert selection are that the culvert has adequate flow capacity, fits the site, and that the installation is cost-effective.

Cross-drain culvert installation options and details for ditch relief are seen in *Figure 8.1*, as well as *Figures 7.6* and *7.7*. The cross-drain pipe should ideally be placed at the bottom of the fill, the inlet should be protected with a drop inlet

structure or catch basin, and the outlet area should be protected against scour.

Culvert installation and alignment factors for drainage crossings are shown in *Figures 8.2, 8.3, 8.4, and 8.5*. Important installation details include:

minimizing channel modifications; avoiding constriction of the bankfull flow channel width; maintaining the natural grade and alignment; using quality, well compacted bedding and backfill material; and using inlet, outlet, and streambank protection measures (*Photo 8.4*). Trash racks (*Figure 8.6*) are often desirable in channels with significant amounts of debris to prevent pipe plugging (*Photo 8.5*).

Bedding and backfill material for culverts is commonly specified as “select granular material” or “select mineral soil”. Actually, most soils are satisfactory if they are free of excessive moisture, muck, lumps of frozen soil, roots, highly plastic clay, or rock larger than 7.5 cm. Bedding material beneath the pipe should not have rocks larger than 3.8 cm. Clay soil can be used if it is carefully compacted at a uniform, near-optimum moisture content. **Ideal**



**Photo 8.3** Install masonry/concrete box or metal culverts with a large enough size (capacity) to safely pass the anticipated design flow (typically a 20- to 50-year recurrence event), based upon hydrological analysis. Use headwalls and wingwalls whenever possible.



**backfill material is a moist, well-graded granular or sandy gravel soil with up to 10 percent fines and free of rocks.** The material should be well compacted, at least as dense as the adjacent ground, and preferably at a density of 90-95% of the AASHTO T-99 maximum density. It should be placed in 15cm thick layers (lifts). A dense, uniform backfill is important to structurally support the lateral pressure from the pipe, particularly with plastic pipes.

Uniform fine sand and silt soils can be problematic when used for culvert bedding or backfill material. These fine, non-cohesive soils are very susceptible to scour and piping from moving water (*Photo 8.6*). Thus their use is

discouraged. If used, they should be very well compacted against the pipe. Ideally, a clay plug or anti-seepage collar, made of metal, concrete, or even geotextile, should be placed around the culvert pipe to force any water channel to flow in a longer path through the soil. Concrete headwalls also deter piping.

Because of changing climatic conditions, debris and bedload in channels, changing land use patterns, and uncertainties in hydrologic estimates, culvert size and capacity should be conservative, and should be oversized rather than undersized. Ideally, a culvert will be of a size as wide as the natural channel to avoid channel constriction.

Channel protection, riprap, overflow dips, headwalls, and trash racks can all help mitigate culvert problems, but none are as good as an adequately sized and well placed pipe. An oversized culvert, designed to avoid pipe repairs or failure as well as prevent environmental damage, can be very cost-effective in the long run. Also, the addition of concrete or masonry headwalls helps reduce the likelihood of pipe plugging and failure.

Pipe size, as a function of anticipated design flow (capacity) and headwater depth, can easily be determined using the Nomograms presented in *Figures 8.7a, 8.7b, and 8.7c*. These figures apply to commonly used culverts of round corrugated metal pipe,

Table 8.1

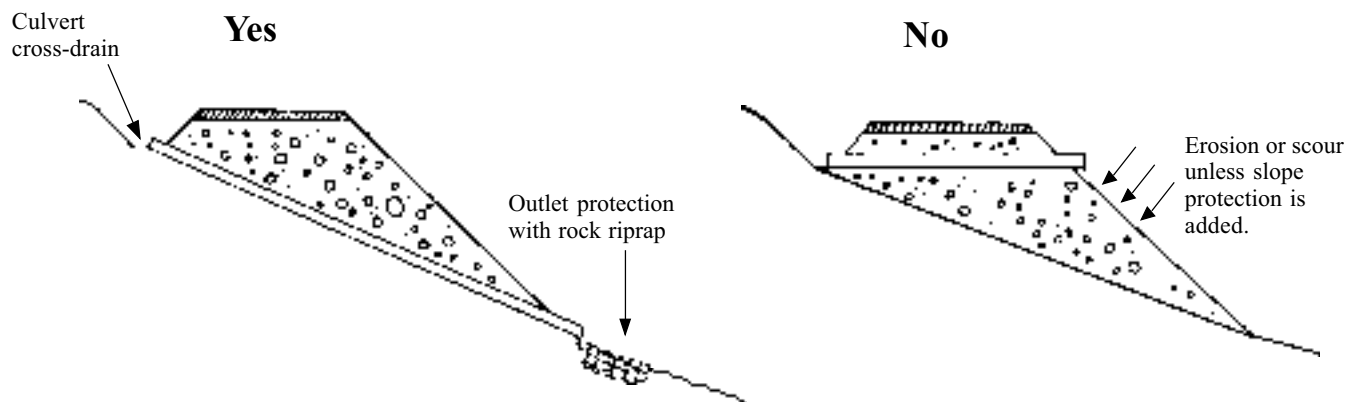
DRAINAGE STRUCTURE SIZING				
Drainage Area (Hectares)	Size of Drainage Structure			
	Steep Slopes		Gentle Slopes	
	Logged, Light Vegetation		Unlogged, Heavy Vegetation	
	C 0.7		C 0.2	
	Round Pipe (in)	Area (m <sup>2</sup> )	Round Pipe (in)	Area (m <sup>2</sup> )
0-4	30"	0.46	18"	0.17
4-8	42"	0.89	24"	0.29
8-15	48"	1.17	30"	0.46
15-30	72"	2.61	42"	0.89
30-50	84"	3.58	48"	1.17
50-80	96"	4.67	60"	1.82
80-120			72"	2.61
120-180			84"	3.58

Notes: If pipe size is not available, use the **next larger** pipe size for the given drainage area. For intermediate terrain, interpolate between pipe sizes.

-Pipe size is based upon the Rational Formula and Culvert Capacity curves. Assumes a rainfall intensity of 75 mm/hr. (3"/hr) to 100 mm/hr (4"/hr). Values of "C" are the Runoff Coefficients for the terrain.

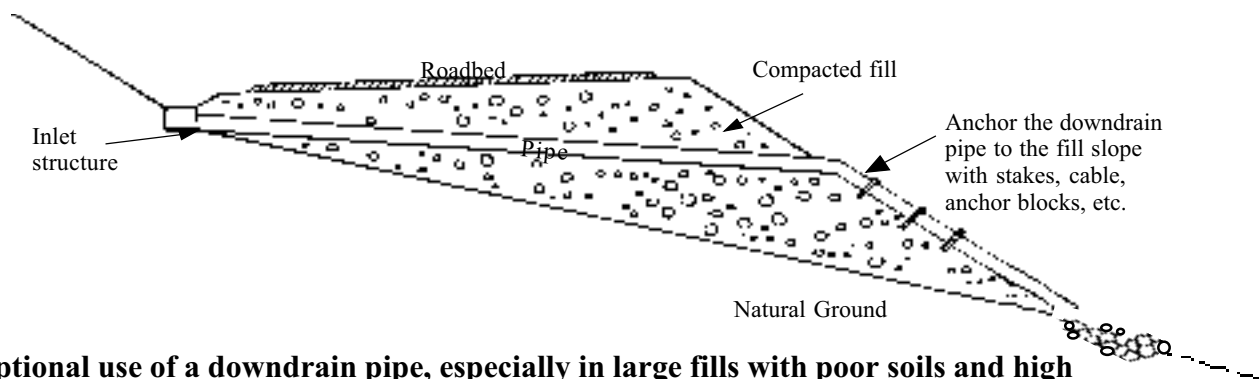
-For tropical regions with frequent high intensity rainfall (over 250 mm/hr or 10"/hr), these drainage areas for each pipe size should be reduced at least in half.

**Figure 8.1** Culvert cross-drain installation options in a fill.



**The outlet of the pipe should extend beyond the toe of the fill and should never be discharged on the fill slope without erosion protection.**

### Optional



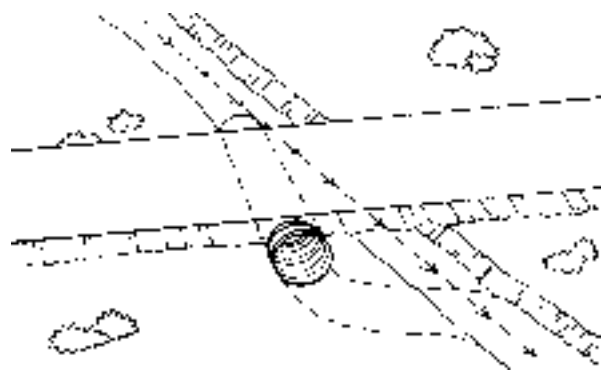
**Optional use of a downdrain pipe, especially in large fills with poor soils and high rainfall areas, where fill settlement may require culvert repairs.**

round concrete pipe, and concrete boxes. Each of these figures applies to pipes with inlet control, where there is no constraint on the downstream elevation of the water exiting the structure. Ideally, the inlet water elevation (headwater depth) should not greatly exceed the height or diameter of the structure in order to prevent saturation of the fill and minimize the likelihood of the pipe plugging from floating debris. More detailed information is found in FHWA Manual HDS-5, Hydraulic Design of Highway Culverts, 1998)

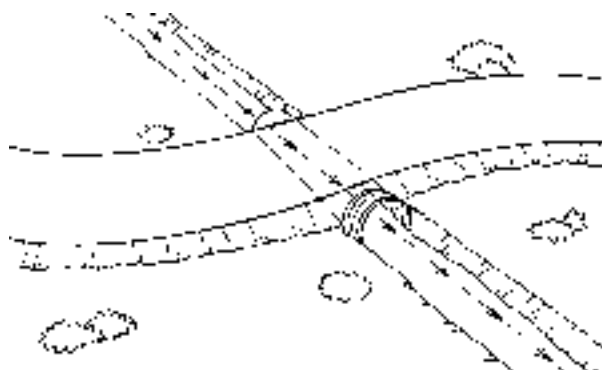


**Photo 8.4** A structural plate arch pipe culvert with stream bank protection using large rock riprap placed upon a geotextile filter layer.

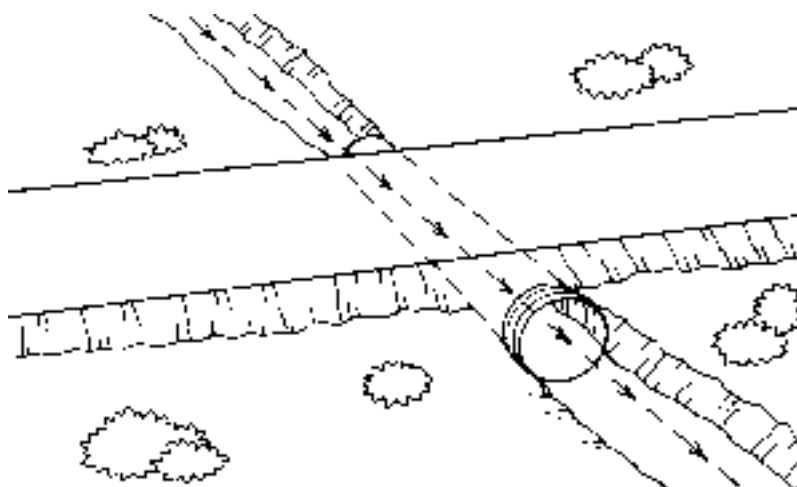
**Figure 8.2** Culvert alignment and installation detail (continued on next page).



**Poor** – Requires a stream channel modification.

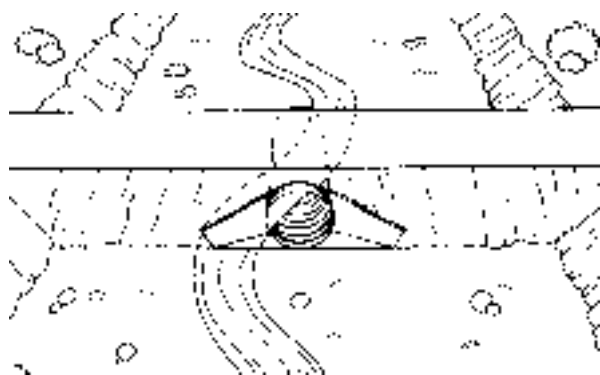


**Adequate** – No channel modifications but requires a curve in the road.

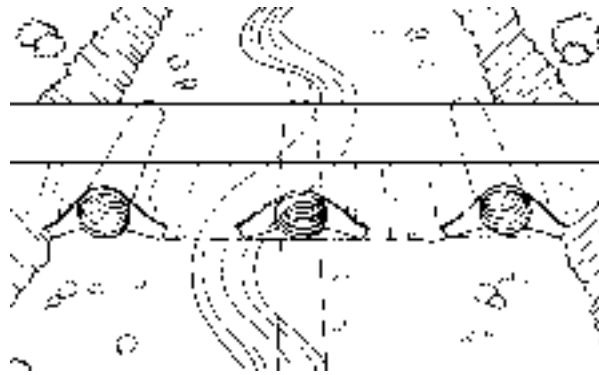


**Best** – No channel modification, and the road is perpendicular to the culvert without a curve in the road alignment.

**a. Culvert alignment options.**



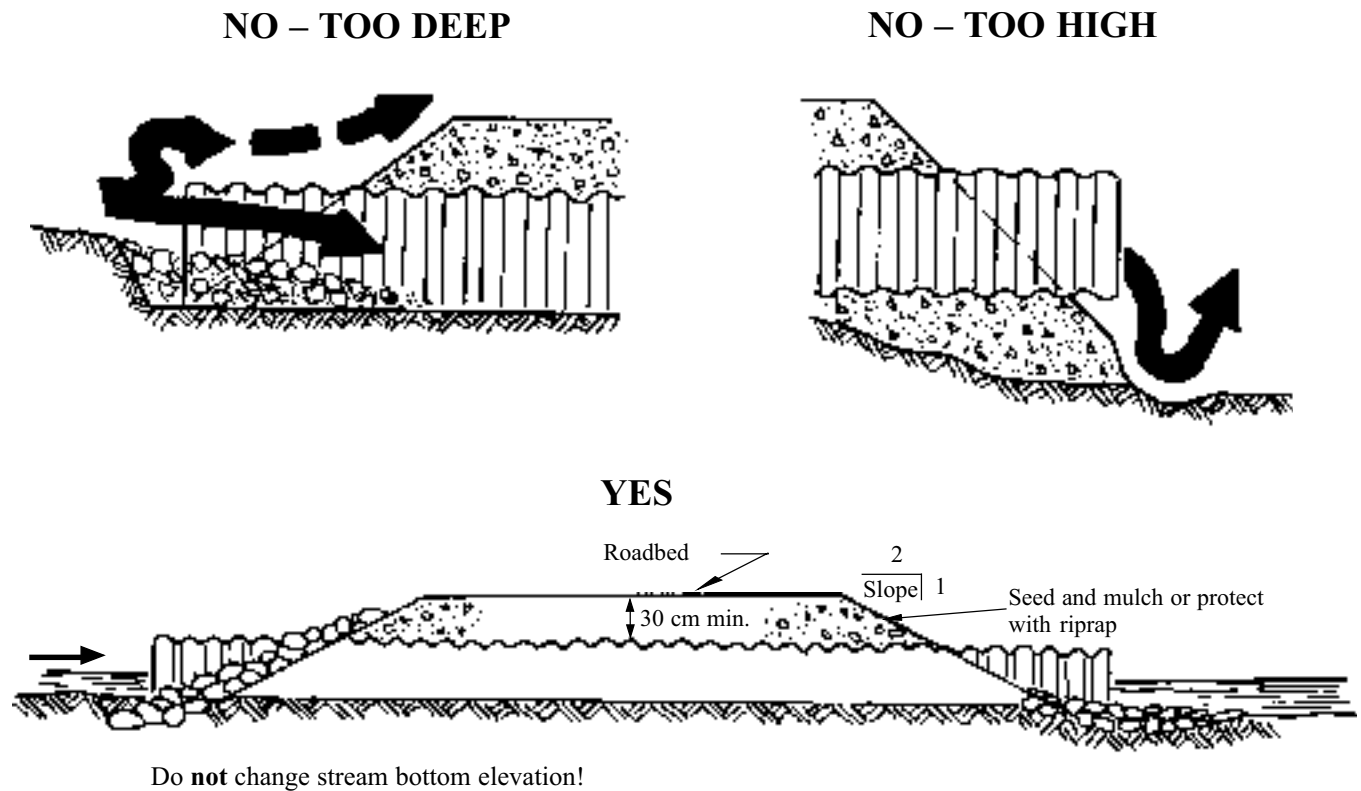
**Poor** – Single pipe concentrates flow in the broad channel or floodplain.



**Better** – Multiple pipes disperse the flow across the channel. Middle pipe may be slightly lower to pass the normal low flow and to promote fish passage.

**b. Culvert installation in a broad channel.**

Figure 8.2 (continued)



c. Install culverts at natural stream grade.

Figure 8.3 Culvert backfill and compaction. (Adapted from Montana Department of State Lands, 1992)

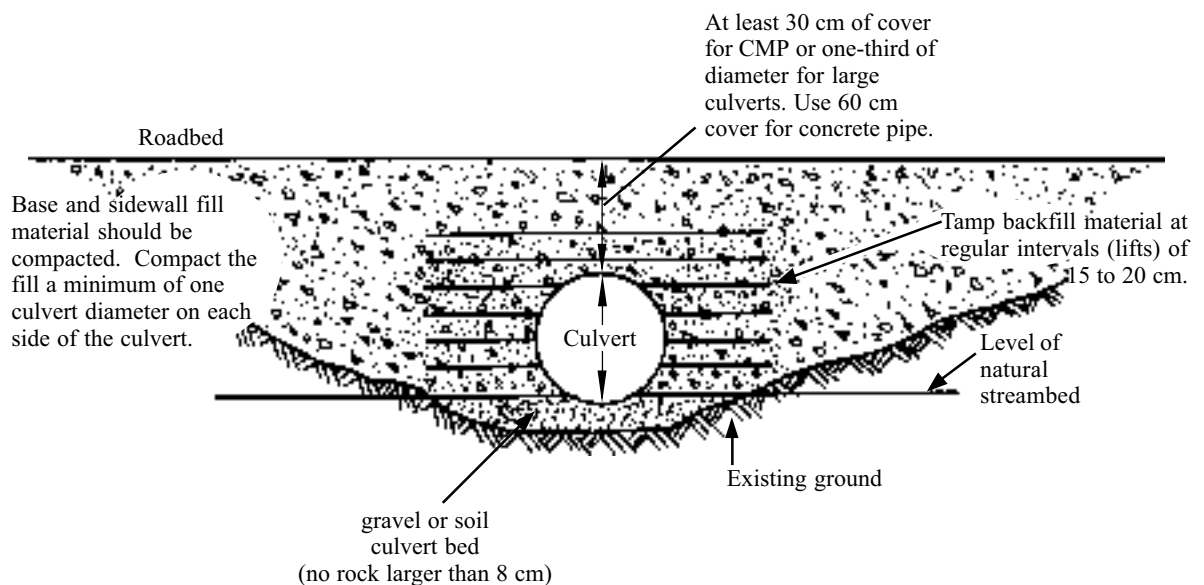
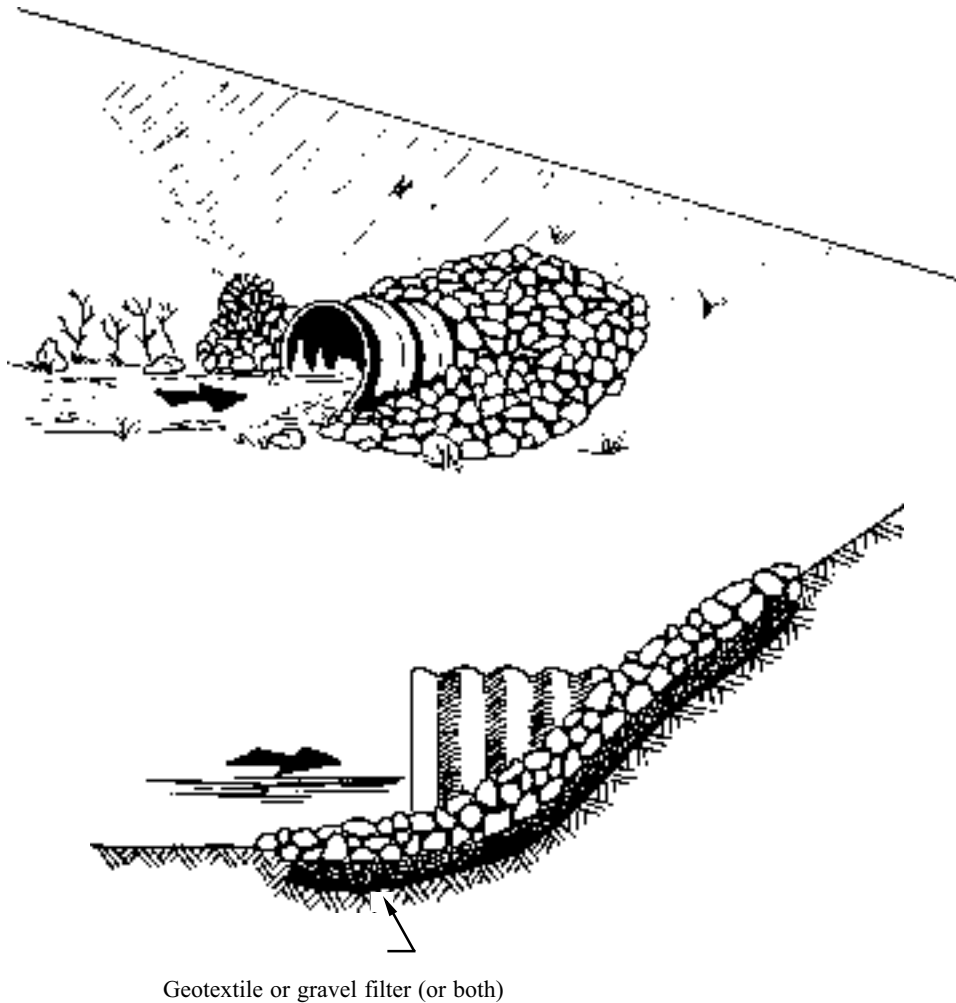
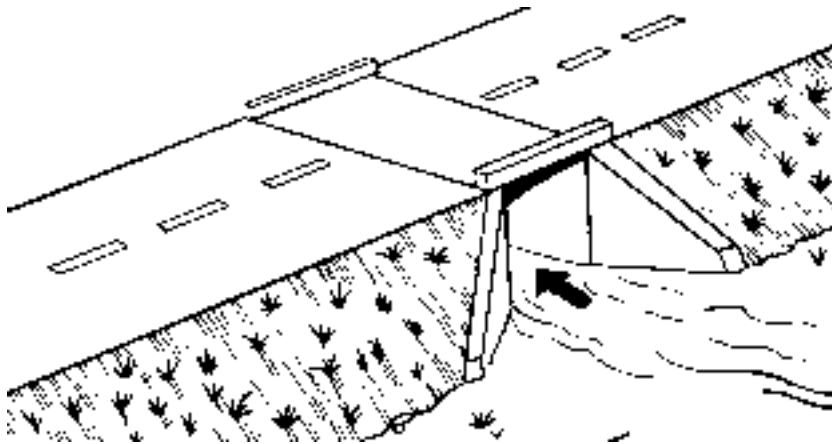




Figure 8.4 Culvert inlet and outlet protection.

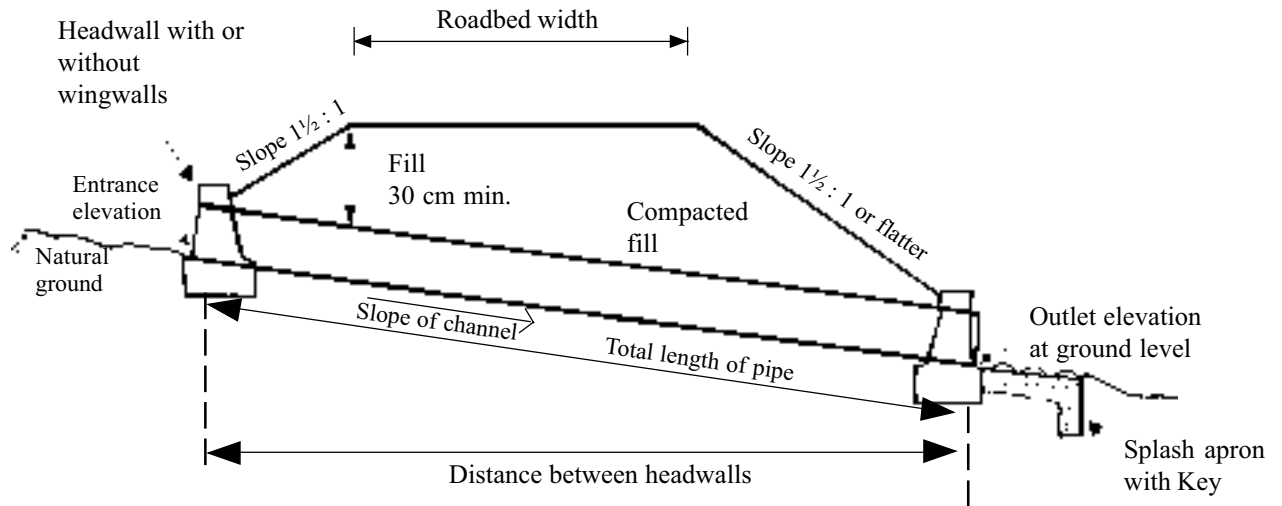


**a. Normal metal culvert installation using riprap around the inlet and outlet of culverts. Also use geotextile (filter fabric) or gravel filter beneath the riprap for most installations. (*Adapted from Wisconsin's Forestry Best Management Practice for Water Quality, 1995*)**

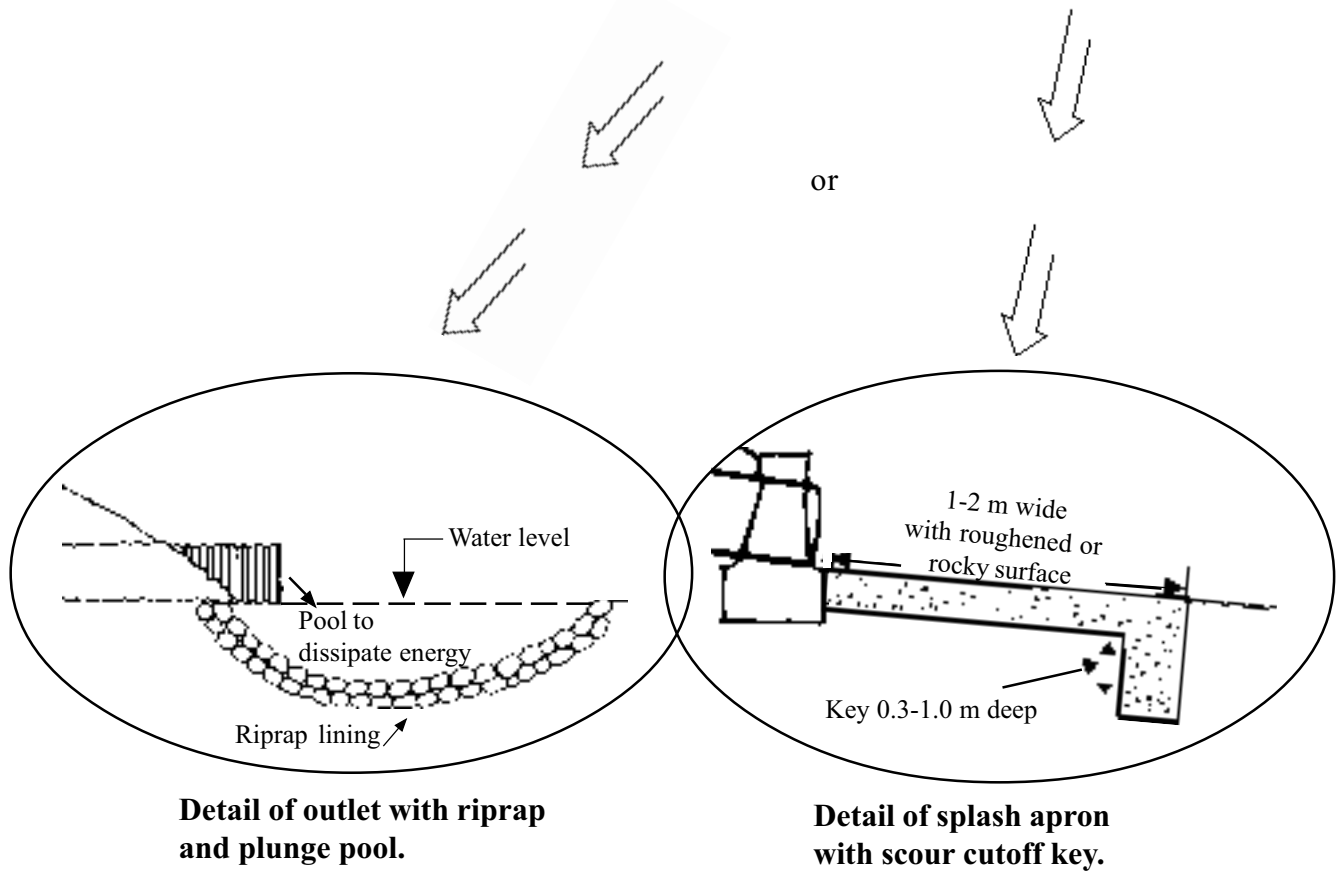


**b. Concrete box culvert with concrete wingwalls for inlet/outlet protection and fill retention.**

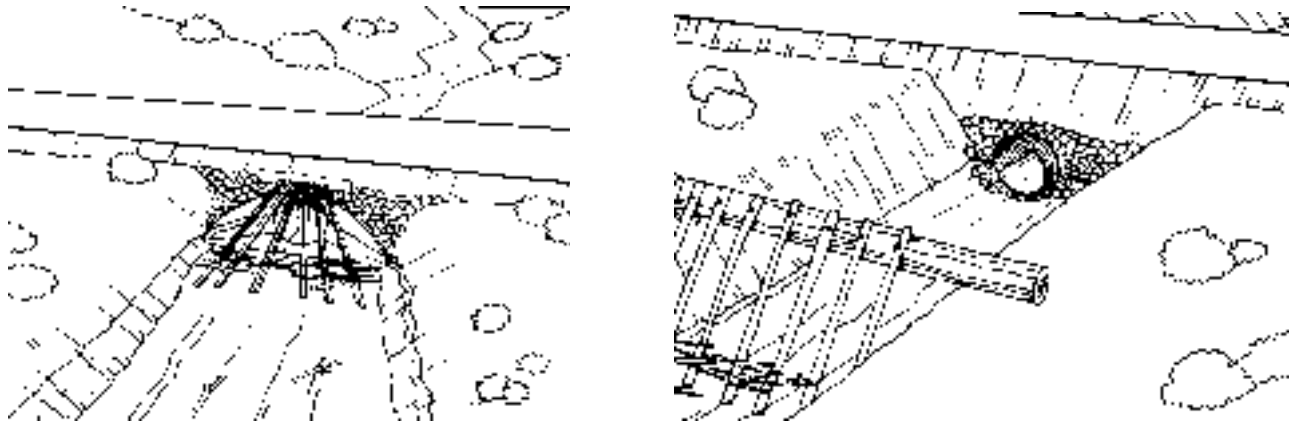
**Figure 8.5** Culvert installation and outlet protection details with splash apron or riprap lined plunge pool.



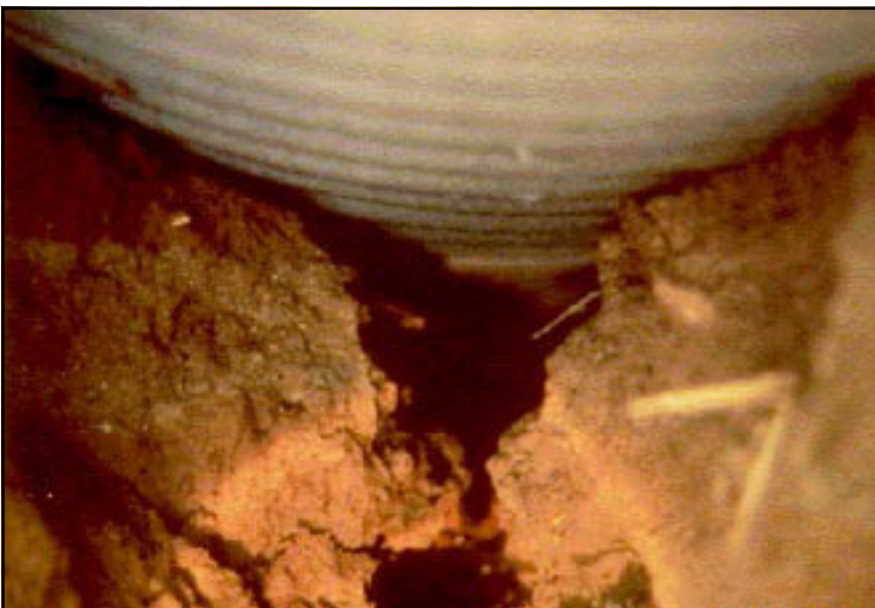
**Typical culvert installation with headwalls and splash apron or plunge pool with riprap for energy dissipation and scour control.**



**Figure 8.6** Trash rack options for culverts to prevent plugging from debris. Note that some trash racks are located at the pipe and others are located upstream of the pipe, depending on site conditions and access for cleaning and maintenance. Location at the pipe is typically best.

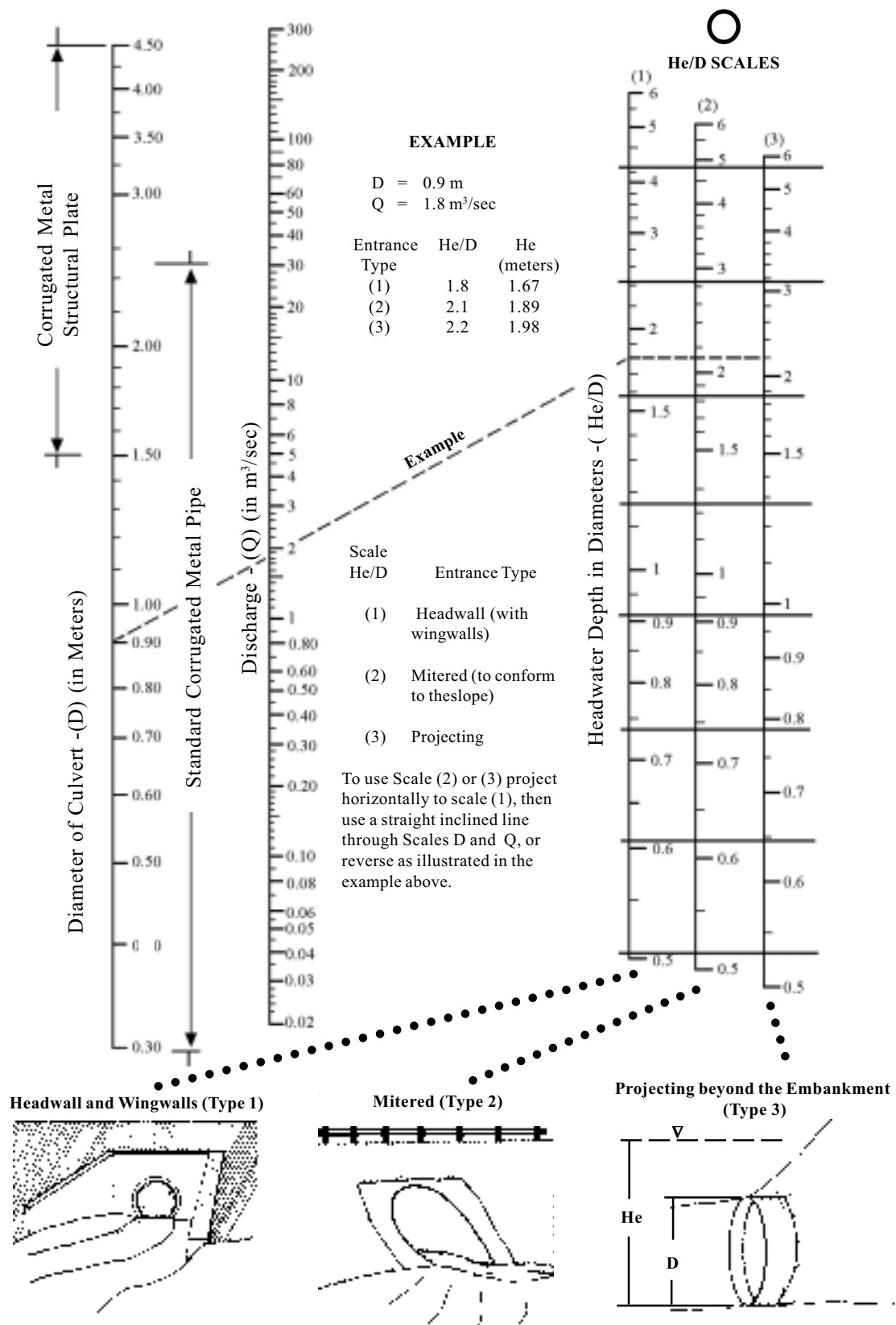


**Photo 8.5** Use trash racks on culverts where a lot of debris is found in the channel. Remember that trash racks require cleaning and maintenance.



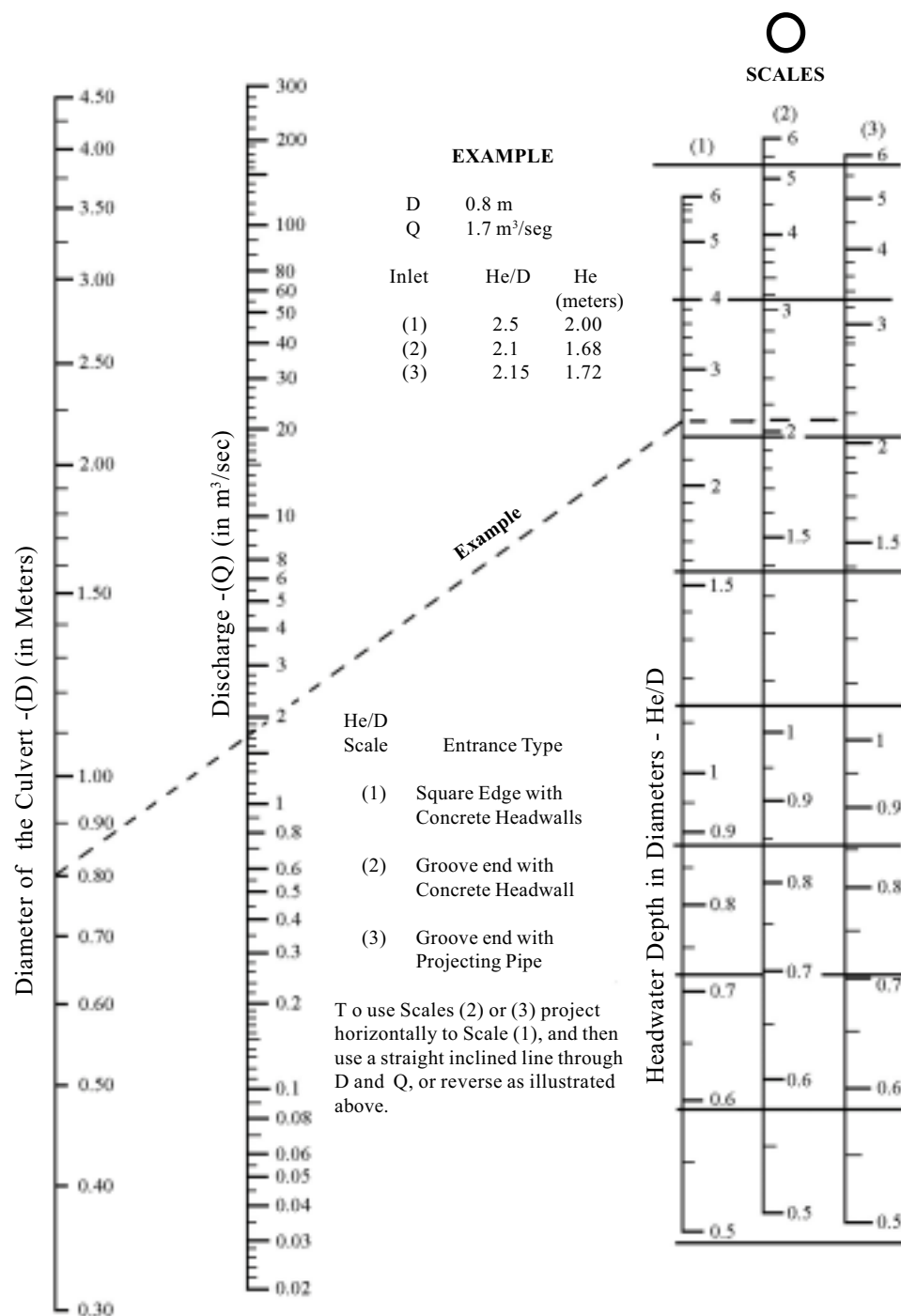
**Photo 8.6** Piping can occur under poorly installed culverts and lead to failure. Avoid the use of fine sand and silt bedding and backfill soil, and ensure that the material is well compacted. Use clay plugs or anti-seepage collars as needed.

**Figure 8.7a** Headwater depth and capacity for **corrugated metal pipe culverts** with inlet control (metric system). (Adapted from FHWA, HDS 5, 1998)

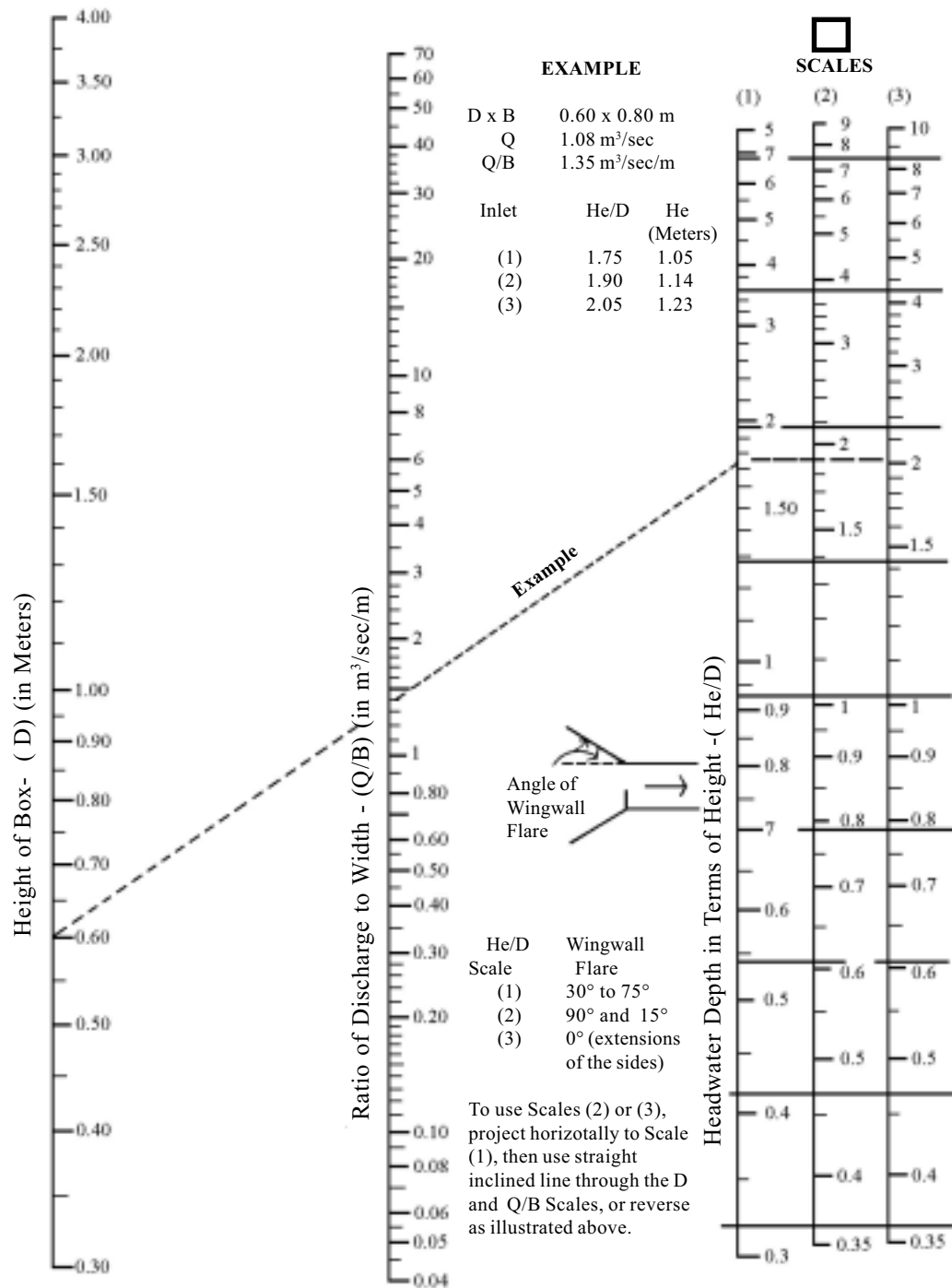




**Figure 8.7b Headwater depth and capacity for concrete pipe culverts with inlet control.**  
 (Adapted from FHWA, HDS 5, 1998)



**Figure 8.7c Headwater depth and capacity for concrete box culverts with inlet control.**  
 (Adapted from FHWA, HDS5, 1998)



# RECOMMENDED PRACTICES

## Ditch Relief Cross-Drain Culverts

- Ditch relief cross-drain pipes should typically have a diameter of 45 cm (minimum diameter of 30 cm). In areas with debris, unstable cut slopes, and raveling problems, use 60 cm or larger pipes.
- Ditch relief cross-drain pipe grade should be at least 2% more (steeper) than the ditch grade and skewed 0 to 30 degrees perpendicular to the road (see *Figure 7.4*). This additional grade helps keep the pipe from plugging with sediment.
- Ditch relief cross-drains should exit at the toe of the fill near natural ground level, at least 0.5 meters beyond the toe of the fill slope. Armor the pipe outlet (see *Figures 7.6, 7.7, and Figure 8.1*). Don't discharge the pipe on unprotected fill material, unstable slopes, or directly into streams (see *Photo 8.1* vs. *Photo 8.9*).
- In large fills, culvert down-drains may be needed to move the water to the toe of the fill (*Figure 8.1*). Anchor down-drains to the slope with metal stakes, concrete anchor blocks, or cable. Pipes, flumes, or armored ditches may be used.

## Drainage Crossing Culverts

- Install permanent culverts with a size large enough to pass design flood flows plus anticipated debris. Design for 20- to 50-year storm events. Sensitive streams may require designs to pass a 100-year flood. Pipe size can be determined using general design criteria, such as in *Table 8.1*, but is ideally based upon site-specific hydrologic analysis.
- Consider impacts of any structure on fish passage and the aquatic environment. Select a structure such as a bridge or bottomless arch culvert that is as wide as the ordinary high water width (bankfull width), that minimizes channel disturbance, and that maintains the natural channel bottom material (*Photo 8.7*).
- Make road crossings of natural drainages perpendicular to the drainage to minimize pipe length and area of disturbance (*Figure 8.2a*).
- Use single large pipes or a concrete box versus multiple smaller diameter pipes to minimize plugging potential in most channels (unless roadway elevation is critical). In very broad channels, multiple pipes are desirable to maintain the natural flow spread

across the channel (*Figure 8.2b*).

- For sites with limited height, use “squash pipe” or arch pipes and box culverts that maximize capacity while minimizing height.
- Use concrete or masonry headwalls on culvert pipes as often as possible. The advantages of headwalls include: preventing large pipes from floating out of the ground when they plug; reducing the length of the pipe; increasing pipe capacity; helping to funnel debris through the pipe; retaining the backfill material; and reducing the chances of culvert failure if it is overtopped (*Photo 8.8*).
- Install culverts long enough so that both ends of the culvert extend beyond the toe of the roadway fill (*Figure 8.2c, Photo 8.9*). Alternatively, use retaining walls (headwalls) to hold back the fill slope (*Figure 8.5*).
- Align culverts in the bottom and middle of the natural channel so that installation causes no change in the stream channel alignment or stream bottom elevation. Culverts should not cause

## RECOMMENDED PRACTICES (cont.)

damming or pooling or increase stream velocities significantly (*Figure 8.2*).

- Firmly compact well-graded fill material around culverts, particularly around the bottom half, using placement in layers to achieve a uniform density (*Figure 8.3*). Use slightly plastic sandy gravel with fines. Avoid the use of fine sand and silt rich soils for bedding material because of their susceptibility to piping. Pay particular attention to culvert bedding and compaction around the haunches of the pipe. Do not allow the compaction to move or raise the pipe. In large fills, allow for settlement by installing the pipe with camber.
- Cover the top of metal and plastic culvert pipes with fill to a depth of at least 30 cm to prevent pipe crushing by heavy trucks. Use a minimum cover of 60 cm of fill over concrete pipe (*Figure 8.3*). For maximum allowable fill height, follow the manufacturer's recommendations.
- Use riprap, flared metal end sections or masonry/concrete headwalls around the inlet

and outlet of culverts to prevent water from eroding the fill or undercutting the pipe, as well as to improve pipe efficiency. With riprap, use graded small rock, gravel or a geotextile filter under the coarse riprap slope protection (*Figure 8.4*).

- At culvert outlets where pipe velocities are accelerated, protect the channel with either a plunge pool (on gentle slopes), rock armoring (riprap) or with a splash apron with a rough or rock inset surface and cutoff key (*Figure 8.5*).
- On existing pipes with plugging potential, add a trash rack upstream of the pipe or at the pipe entrance (inlet) to trap debris before plugging the pipe (*Figure 8.6, Photo 8.5*). Trash racks may be constructed with logs, pipe, rebar, angle iron, railroad rail, H-Piles, and so on. However, trash racks typically require additional maintenance and cleaning. They are undesirable if other alternatives, such as installing a larger pipe, are available.

- Examine stream channels for the amount of debris, logs, and brushy vegetation. In channels with large amounts of debris, consider using a **low-water ford**, oversized pipes, or placing a trash rack upstream of the pipe entrance.
- Install overflow dips off the side of the culvert in drainage channels with a large fill that could be overtopped. Also use overflow dips on long sustained road grades where a plugged culvert could divert water down the road, plugging subsequent culverts and causing extensive off-site damage (see Chapter 7, *Figure 7.11*).
- Temporary log culverts ("Humboldt" culverts) usually have very little flow capacity. When used, ensure that the structure and all fill material are removed from the channel before the rainy season or expected large runoff events (*Photo 8.10*).
- Do periodic maintenance and channel cleaning to keep culverts protected and clear of debris that could plug the pipe.



## PRACTICES TO AVOID

- Discharging cross-drain pipes on a fill slope unless the slope is protected or a down drain is used.
- Using non-cohesive fine sands and silt bedding materials that are very susceptible to piping.
- Placing pipes improperly (i.e. buried or aligned with the natural stream channel bottom).
- Using pipes undersized for the expected flow and amount of debris.
- Installing pipes too short to fit the site.
- Leaving low-capacity temporary drainage crossing structures in place over the rainy season.



**Photo 8.7** Use structures with natural stream bottoms, such as arch pipes, bottomless arches, or concrete box culverts, to promote fish passage and minimize impacts to the stream.



**Photo 8.8** Install culverts with adequate capacity. Use headwalls to improve culvert capacity, protect the roadway fill, resist overtopping damage, and prevent bank scour, particularly at a bend in the channel.



**Photo 8.9** Avoid culvert outlets in the middle of a fill slope. Use culverts long enough to extend to the toe of the slope, or use headwall structures to retain the fill material and minimize the pipe length.



**Photo 8.10** Most log culverts have very little flow capacity. Remove temporary log (Humboldt) culverts before major rainstorms or before the rainy season.