STD & SPEC 3.18

OUTLET PROTECTION

OP

Definition

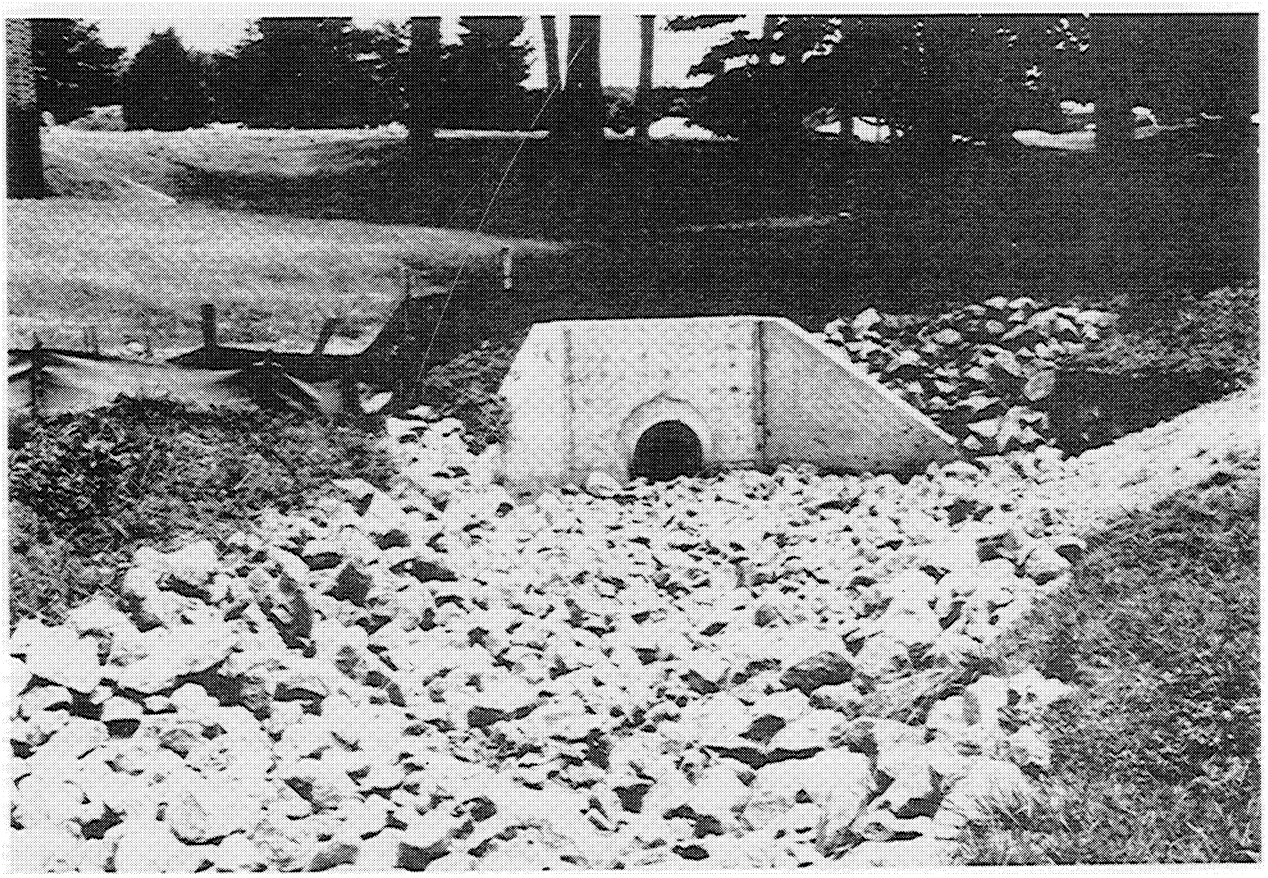
Structurally lined aprons or other acceptable energy dissipating devices placed at the outlets of pipes or paved channel sections.

Purpose

To prevent scour at stormwater outlets, to protect the outlet structure, and to minimize the potential for downstream erosion by reducing the velocity and energy of concentrated stormwater flows.

Conditions Where Practice Applies

Applicable to the outlets of all pipes and engineered channel sections.



Planning Considerations

The outlets of pipes and structurally lined channels are points of critical erosion potential. Stormwater which is transported through man-made conveyance systems at design capacity generally reaches a velocity which exceeds the capacity of the receiving channel or area to resist erosion. To prevent scour at stormwater outlets, a flow transition structure is needed which will absorb the initial impact of the flow and reduce the flow velocity to a level which will not erode the receiving channel or area.

The most commonly used device for outlet protection is a structurally lined apron. These aprons are generally lined with riprap, grouted riprap or concrete. They are constructed at a zero grade for a distance which is related to the outlet flow rate and the tailwater level. Criteria for designing such an apron are contained in this practice. Sample problems of outlet protection design are contained in Appendix 3.18-a.

Where flow is excessive for the economical use of an apron, excavated stilling basins may be used. Acceptable designs for stilling basins may be found in the following sources:

1. Hydraulic Design of Energy Dissipators for Culverts and Channels, Hydraulic Engineering Circular No. 14, U. S. Department of Transportation, Federal Highway Administration (83).

2. Hydraulic Design of Stilling Basins and Energy Dissipators, Engineering Monograph No. 25, U.S. Department of the Interior - Bureau of Reclamation, (74).

   Note: Both of the above are available from the U.S. Government Printing Office.

Design Criteria

The design of structurally lined aprons at the outlets of pipes and paved channel sections applies to the immediate area or reach below the pipe or channel and does not apply to continuous rock linings of channels or streams (See STORMWATER CONVEYANCE CHANNEL, Std. & Spec. 3.17). Notably, pipe or channel outlets at the top of cut slopes or on slopes steeper than 10% should not be protected using just outlet protection as a result of the reconcentration and large velocity of flow encountered as the flow leaves the structural apron. Outlet protection shall be designed according to the following criteria:

Pipe Outlets

(See Plate 3.18-1)

1. Tailwater depth: The depth of tailwater immediately below the pipe outlet must be determined for the design capacity of the pipe. Manning's Equation may be used to determine tailwater depth (see Chapter 5, Engineering Calculations). If the tailwater depth is less than half the diameter of the outlet pipe, it shall be classified as a

Minimum Tailwater Condition. If the tailwater depth is greater than half the pipe diameter, it shall be classified as a Maximum Tailwater Condition. Pipes which outlet onto flat areas with no defined channel may be assumed to have a Minimum Tailwater Condition. Notably, in most cases where post-development stormwater runoff has been concentrated or increased, MS #19 will be satisfied only by outfall into a defined channel.

2. Apron length: The apron length shall be determined from the curves according to the tailwater condition:

   Minimum Tailwater - Use Plate 3.18-3.
   Maximum Tailwater - Use Plate 3.18-4.

3. Apron width: When the pipe discharges directly into a well-defined channel, the apron shall extend across the channel bottom and up the channel banks to an elevation one foot above the maximum tailwater depth or to the top of the bank (whichever is less).

   If the pipe discharges onto a flat area with no defined channel, the width of the apron shall be determined as follows:

   a. The upstream end of the apron, adjacent to the pipe, shall have a width three times the diameter of the outlet pipe.

   b. For a Minimum Tailwater Condition, the downstream end of the apron shall have a width equal to the pipe diameter plus the length of the apron.

   c. For a Maximum Tailwater Condition, the downstream end shall have a width equal to the pipe diameter plus 0.4 times the length of the apron.

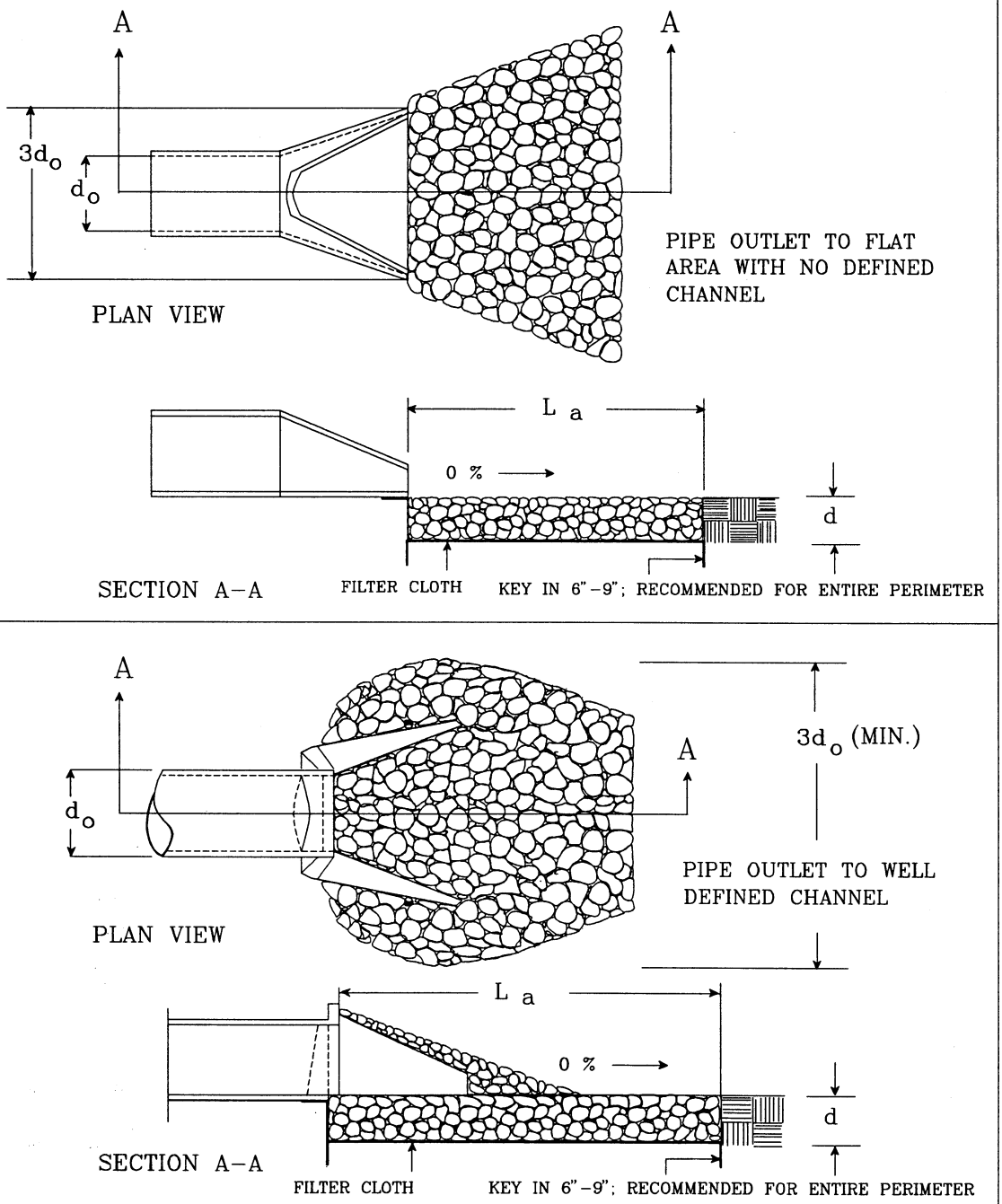
4. Bottom grade: The apron shall be constructed with no slope along its length (0.0% grade). The invert elevation of the downstream end of the apron shall be equal to the elevation of the invert of the receiving channel. There shall be no overfall at the end of the apron.

5. Side slopes: If the pipe discharges into a well-defined channel, the side slopes of the channel shall not be steeper than 2:1 (horizontal: vertical).

6. Alignment: The apron shall be located so there are not bends in the horizontal alignment.

7. Materials: The apron may be lined with riprap, grouted riprap, concrete, or gabion baskets. The median sized stone for riprap shall be determined from the curves in Appendix 3.18-a (Plates 3.18-3 and 3.18-4) according to the tailwater condition. The gradation, quality and placement of riprap shall conform to Std. & Spec. 3.19, RIPRAP.

PIPE OUTLET CONDITIONS



NOTES: 1. APRON LINING MAY BE RIPRAP, GROUTED RIPRAP, GABION BASKET, OR CONCRETE.
2. La IS THE LENGTH OF THE RIPRAP APRON AS CALCULATED USING PLATES 3.18–3 AND 3.18–4.
3. d = 1.5 TIMES THE MAXIMUM STONE DIAMETER, BUT NOT LESS THAN 6 INCHES.

Source: Va. DSWC

Plate 3.18-1

8. Filter cloth: In all cases, filter cloth shall be placed between the riprap and the underlying soil to prevent soil movement into and through the riprap. The material must meet or exceed the physical properties for filter cloth found in Std. & Spec. 3.19, RIPRAP. See Plate 3.18-1 for orientation details.

Paved Channel Outlets

(See Plate 3.18-2)

1. The flow velocity at the outlet of paved channels flowing at design capacity must not exceed the permissible velocity of the receiving channel (see Tables 3.18-A and 3.18-B)

2. The end of the paved channel shall merge smoothly with the receiving channel section. There shall be no overfall at the end of the paved section. Where the bottom width of the paved channel is narrower than the bottom width of the receiving channel, a transition section shall be provided The maximum side divergence of the transition shall be 1 in 3F where;

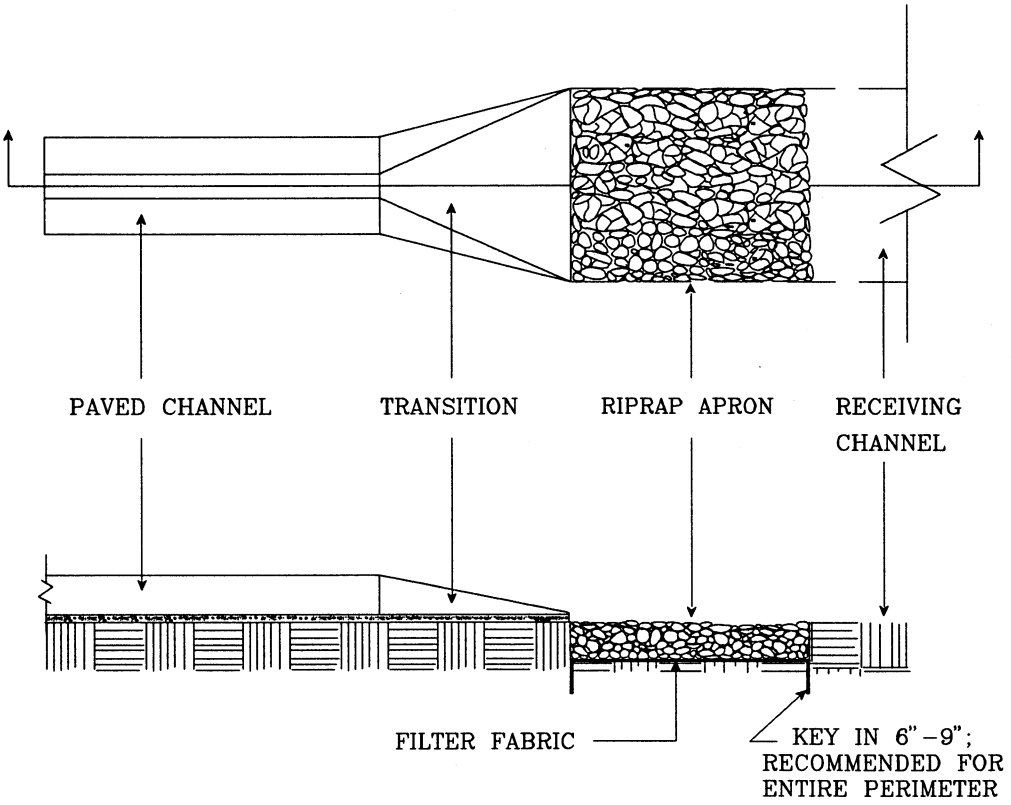
$$F = \frac{V}{\sqrt{gd}}$$

where,

F	=	Froude number
V	=	Velocity at beginning of transition (ft./sec.)
d	=	depth of flow at beginning of transition (ft.)
g	=	32.2 ft./sec.^{2}

3. Bends or curves in the horizontal alignment at the transition are not allowed unless the Froude number (F) is 1.0 or less, or the section is specifically designed for turbulent flow.

PAVED CHANNEL OUTLET



NOTES:

1. RIPRAP APRON REDUCES THE FLOW VELOCITY BELOW THE PERMISSIBLE VELOCITY OF THE NATURAL RECEIVING CHANNEL.
2. TRANSITION SIDE DIVERGENCE IS 1 IN 3F, WHERE

$$F = \text{FROUDE NUMBER} = \frac{V}{\sqrt{gd}}, \text{ WHERE}$$

V = VELOCITY AT THE BEGINING OF THE TRANSITION
d = DEPTH OF FLOW AT THE BEGINING OF THE TRANSITION

$g = 32.2 \text{ ft./sec}^2$

Source: Va. DSWC Plate 3.18-2

TABLE 3.18-A

PERMISSIBLE VELOCITIES FOR GRASS-LINED CHANNELS

Channel Slope	Lining	Velocity* (ft./sec.)
0 - 0.5%	Bermudagrass	6
	Reed canarygrass Tall fescue Kentucky bluegrass	5
	Grass-legume mixture	4
	Red fescue Redtop Sericea lespedeza Annual lespedeza Small grains Temporary vegetation	2.5
5 - 10%	Bermudagrass	5
	Reed canarygrass Tall fescue Kentucky bluegrass	4
	Grass-legume mixture	3
Greater than 10%	Bermudagrass	4
	Reed canarygrass Tall fescue Kentucky bluegrass	3
* For highly erodible soils, decrease permissible velocities by 25%.		

Source: Soil and Water Conservation Engineering, Schwab, et. al. and American Society of Civil Engineers

TABLE 3.18-B?

PERMISSIBLE VELOCITIES FOR EARTH LININGS

Soil Types	Permissible Velocities (ft./sec.)
Fine Sand (noncolloidal)	2.5
Sandy Loam (noncolloidal)	2.5
Silt Loam (noncolloidal)	3.0
Ordinary Firm Loam	3.5
Fine Gravel	5.0
Stiff Clay (very colloidal)	5.0
Graded, Loam to Cobbles (noncolloidal)	5.0
Graded, Silt to Cobbles (colloidal)	5.5
Alluvial Silts (noncolloidal)	5.5
Alluvial Silts (colloidal)	5.0
Coarse Gravel (noncolloidal)	6.0
Cobbles and Shingles	5.5
Shales and Hard Plans	6.0

Source: Soil and Water Conservation Engineering, Schwab, et.al. and American Society of Civil Engineers

APPENDIX 3.18-a

Sample Problems: Outlet Protection Design

Example 1

Given: An 18-inch pipe discharges 24 cfs at design capacity onto a grassy slope (no defined channel).

Find: The required length, width and median stone size (d_{50}) for a riprap-lined apron.

Solution:

1. Since the pipe discharges onto a grassy slope with no defined channel, a Minimum Tailwater Condition may be assumed.

2. From Plate 3.18-3, an apron length (L_a) of 20 feet and a median stone size (d_{50}) of 0.8 ft. are determined.

3. The upstream apron width equals three times the pipe diameter; 3 x 1.5 ft = 4.5 ft.

4. The downstream apron width equals the apron length plus the pipe diameter; 20 ft. + 1.5 ft. = 21.5 ft.

Example 2

Given: The pipe in example No. 1 discharges into a channel with a triangular cross-section, 2 feet deep and 2:1 side slopes. The channel has a 2% slope and an "n" factor of .045.

Find: The required length, width and the median stone size (d_{50}) for a riprap lining.

Solution:

1. Determine the tailwater depth using Manning's Equation.

$$Q = \frac{1.49}{n} R^{\frac{2}{3}} S^{\frac{1}{2}} A$$

$$24 = \frac{1.49}{.045}\left(\frac{2d}{2\sqrt{2^2+1}}\right)^{\frac{2}{3}}(.02)^{\frac{1}{2}}(2d^2)$$

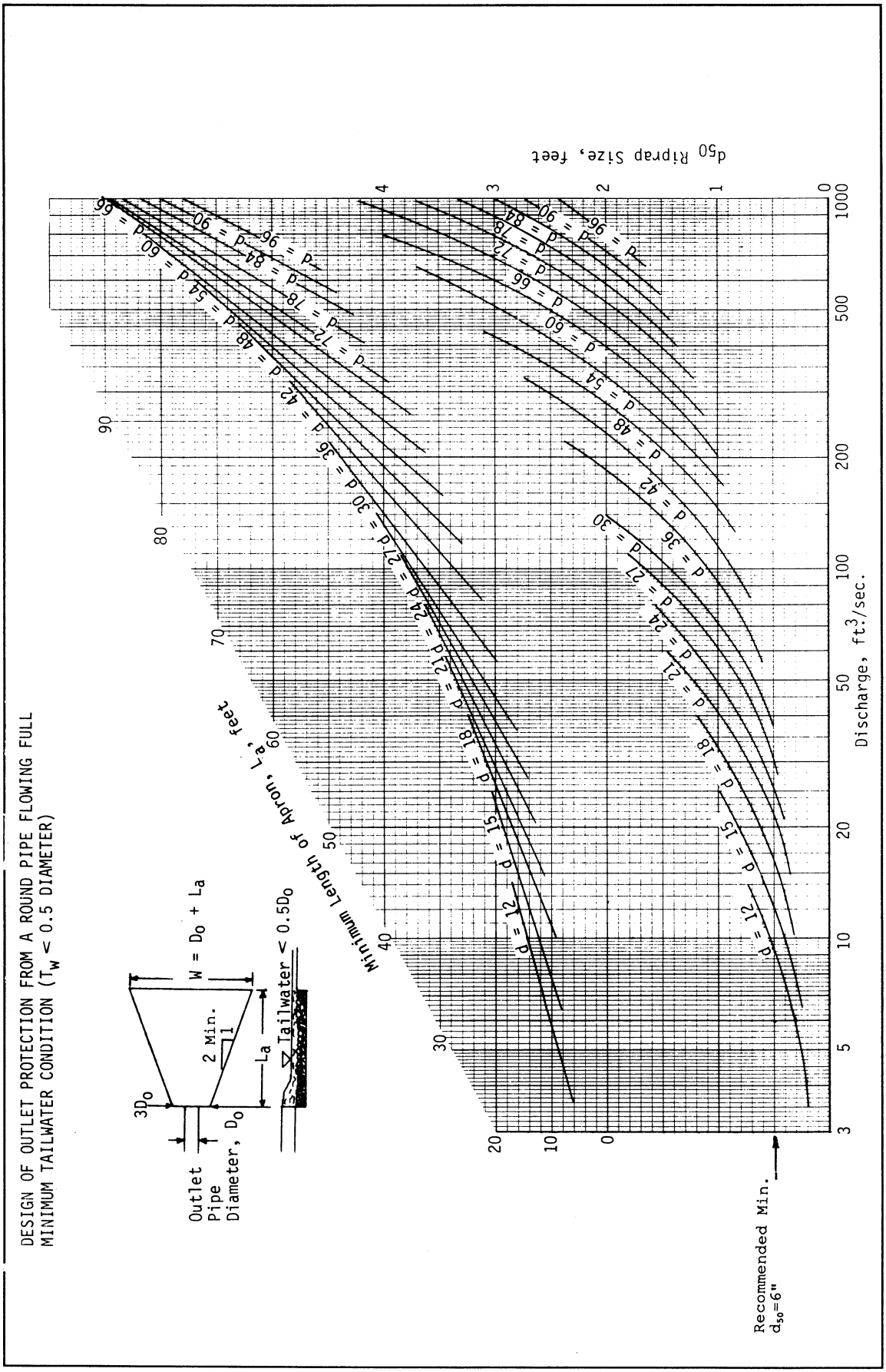
where,

d = depth of tailwater
d = 1.74 ft. *

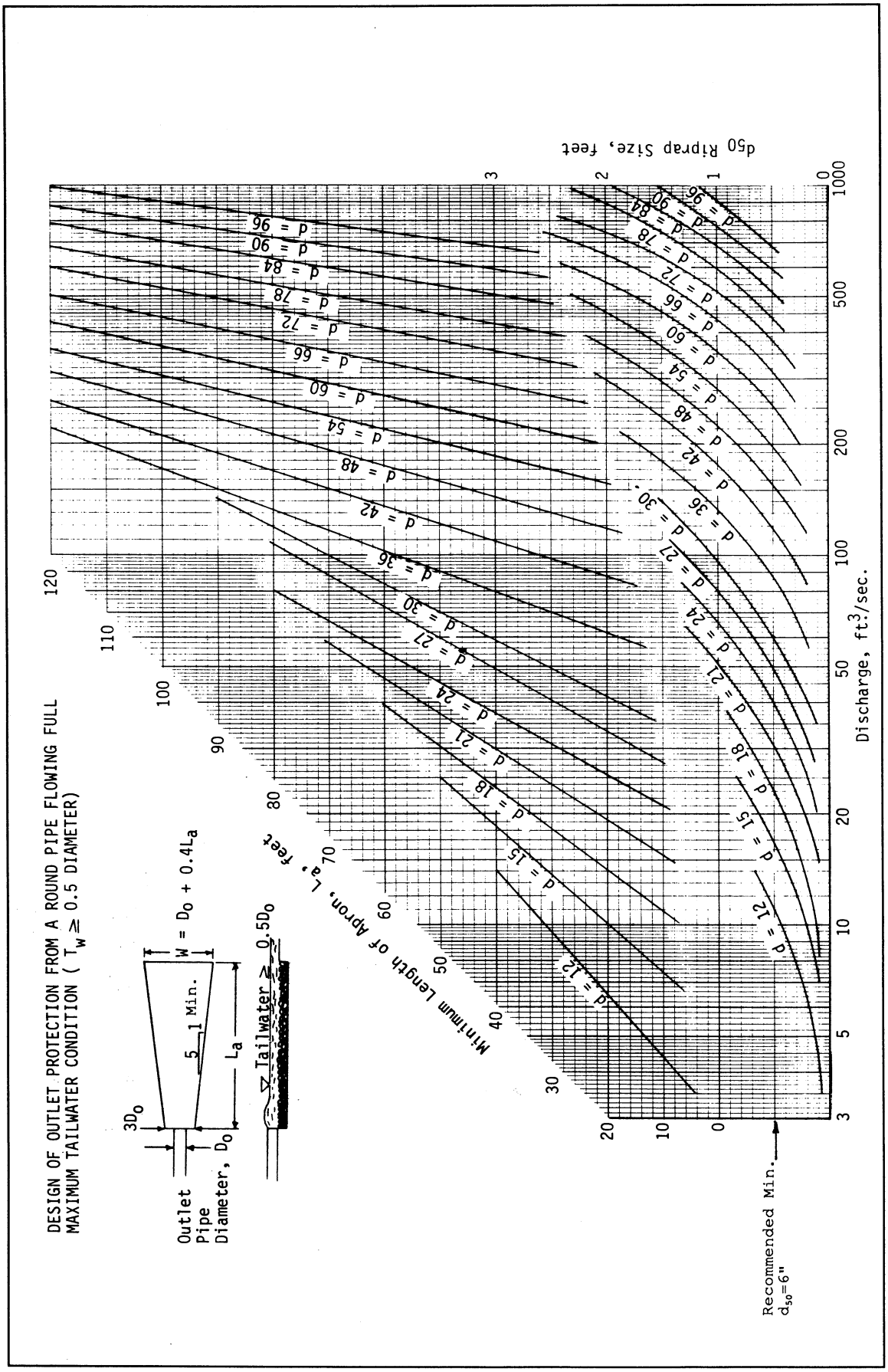
* since d is greater than half the pipe diameter, a Maximum Tailwater Condition exists.

2. From Plate 3.18-4, a median stone size (d_{50}) of 0.5 ft. and an apron length (L_a) of 41 ft. is determined.

3. The entire channel cross-section should be lined since the maximum tailwater depth is within one foot of the top of the channel.



Source: USDA-SCS Plate 3.18-3



Source: USDA-SCS Plate 3.18-4