9. Pipeline Stream Crossings.

a. General.

1) In most cases stream bank stabilization for pipelines crossing streams can be accomplished using Standard Detail SC/3.0, however, see if this Standard Detail is applicable by considering the following guidelines in this section: Selection of Crossing Alignments, Data Collection, Estimate of Stream Design Flow, and Determination of Cover Depth.

2) Calculations are presented in this section to provide examples of the types of analysis required at a minimum. They are not intended to be used as a step by step procedure for stream crossing design. Exercise professional judgment and perform the necessary analysis required for the particular design.

3) General guidelines for cases that may require a more in depth evaluation of instability are presented in Special Considerations, in this section.

4) For selection of pipe material, see Part One, Section 2 (Pipe Materials and Fittings) for water pipelines and Part Two, Section 2 (Pipeline Sizes and Materials (Gravity Sewer)) for sewer pipelines and for general vertical alignment requirements for pipeline crossings at streams, see Part One, Section 11 (Vertical Alignment, Profiles) and Part Two, Section 8 (Vertical Alignment, Profiles) for sewer pipelines.

b. Selection of Crossing Alignment.

1) Base the selection of the crossing alignment primarily on the consideration of channel stability and environmental and regulatory compliance.

2) Minimize the number of crossings, the total length of the crossing, and the disturbed area. Try to select an alignment that is perpendicular to the stream flow.

3) Determine requirements and constraints set forth by agencies having jurisdiction over the area of the crossing alignment. Such agencies may include Maryland National Capital Park & Planning Commission (MNCPPC), Maryland Department of the Environment (MDE) and the Army Corps of Engineers.

4) Identify existing and potential long term channel instability problems at the alignment location, by the use of available topographic maps, land use information and field investigation. Channel instability can lead to failure/erosion of channel banks, shifting of channel positions and channel bed erosion.

5) <u>Selecting stream crossing locations</u>. Avoid locations with severe channel instability problems. Crossing alignments may be strategically located to minimize the adverse effects of channel instability. The following are guidelines for selecting locations of stream crossings.

   a) At meandering channel bends, stream flow velocities can severely erode channel banks and scour holes on the channel bottom. The crossing can be placed approximately midway between two adjacent meandering bends or upstream of the meandering bend.

   b) Abrupt drop in channel bed, flow depth, riffles or localized scour holes indicate existing or potential channel bed instability. Alignment should not be placed in close proximity to and especially downstream of these locations.

c) Where flow constriction occurs, e.g., due to bridge construction or channelization, the crossing should be placed upstream of the location of flow constriction, if possible.

d) Stream channels which show noticeable increase in channel widths, meandering, steeply sloped channel banks, and lack of vegetation, indicate existing or potential problems of channel widening and changes in channel position. If the pipeline alignment parallels the stream channel, provide a buffer width between the nearest channel bank and the limit of disturbance. Determine the buffer width on a case by case basis. The minimum buffer width required by the State of Maryland, Department of Natural Resources, is twenty five (25) feet from the limit of construction area to the top of the nearest of stream bank.

e) Sediment traps and storm water control ponds can drastically reduce sediment supply and increase channel bed and bank erosion in downstream channels. Pipeline crossings should not be placed in close proximity downstream of these structures, if possible.

f) Activities such as channel dredging or cleaning can cause channel bed erosion due to decrease in flow depth and increases in flow velocity. Pipeline crossings should not be placed in close proximity upstream of these activities.

g) Alteration in stream flow path/direction by others, due to construction activities and channel work, can drastically affect stream hydraulics. Pipeline crossings should not be placed in close proximity upstream or downstream of these locations.

h) Select the crossing alignment such that the pipeline will be protected from impacts of construction of other utilities or structures.

i) Select the vertical alignment of gravity sewer to avoid the use of an inverted siphon.

c. Data Collection.

1) Recommended data/information collection requirements are as follows:

a) Topographic contour map of the stream channel and drainage area at the location of stream crossing.

b) From field surveys determine the existing channel elevation, dimensions (depth, width), cross-sectional profile, longitudinal profile, channel bank and bed slopes with sufficient detail to define the channel conditions.

c) Soil samples of channel bed materials for grain size distribution analysis, for pipeline sizes 12-inch and smaller diameter soil samples are not required.

d. Estimate of Stream Design Flow.

1) Determine the estimated stream design flow for pipeline crossings larger than 12-inch diameter as follows, for pipelines 12-inch and smaller, it is not necessary to estimate the stream design flow. Stabilization of channel banks and determination of cover depth should be done for the design flow, which is defined as 1.2 times the existing Mean Annual Flood (MAF). The MAF represents a flood having a return period of approximately one (1) to two (2) years and can be assumed to be associated with the existing bankful flood stage. This may be obtained from published hydrologic study reports. It can also be estimated by applying Manning's equation to a representative channel cross section and channel slope. For example calculations, see Design

Examples in this section. The 1.2 factor applied to the MAF is intended to account for future increase in flow due to land use changes in the watershed. If more than one crossing is located at various segments of the same stream, assure consistency in the defined design flow magnitude.

e. Determination of Cover Depth.

1) The design for the pipeline cover depth below the existing stream bed is to be determined after considering the factors below, whichinclude the minimum required depth of cover, protection against frost penetration, pipe flotation and channel bed erosion. Measure the cover depth from the lowest point in the channel bed to the top of the pipe and show the required depth on the pipe profile.

a) For the minimum cover depth. For water pipelines, see Part One, Section 11 (Vertical Alignment (Profiles)) and for sewer pipelines, see Part Two, Section 9 (Vertical Alignment (Profiles)). The cover depth must be greater than the minimum cover depth.

b) Protection against frost penetration. Frost protection will be attained by providing the minimum cover depth as stated above. Due to a higher fluid temperature in the sewer pipeline, frost penetration generally may not be a problem for sewer pipelines crossing streams.

c) Protection against flotation. Check for pipe flotation and determine the required cover depth, see requirements for evaluating the possibility of pipe flotation, Part Three, Section 4, (Buoyancy of Pipelines). If the cover depth is not adequate to protect against the potential of pipe flotation, provide a special design, see Preventive Procedures under Part Three, Section 4 (Buoyancy of Pipelines).

d) Protection against channel bed erosion.

(1) For pipelines 12-inch and smaller diameter. The required cover depth for protection against channel bed erosion may be assumed to be the same as the minimum cover depth as stated above. No calculation is required to estimate channel depth susceptibility to bottom erosion. However, calculations should be done to estimate this depth for cases where significant channel bottom erosion is anticipated due to stream channel configuration or other factors.

(2) For pipelines larger than 12" diameter. Protect the pipeline from exposure to direct stream flow and undermining of the channel bed beneath the pipeline due to erosion. Estimate the depth of soil cover above the pipeline that would be susceptible to erosion under the design flow according to the following procedure.

(a) Calculate a "new" channel depth at which the bed materials would theoretically be stable under the design flow. The difference between the new channel depth and the existing channel depth will give the soil depth that is susceptible to erosion, and hence the required cover depth.

(b) Calculations of the "new" channel depth can be based upon two approaches, namely the Tractive Force Method or the Permissible Velocity Method. Technical basis for these methods can be found in hydraulics textbooks and practice handbooks. The Tractive Force Method is not strictly applicable to channels with bed materials smaller than medium sand. For such channels, the Permissible Velocity Method can be applied. Examples of calculations, see Design Examples in this section. In order to properly apply these calculations methods, soil samples of channel bed material should be collected and analyzed for grain size distribution.

(c) Start the calculations with an estimate of stability of bottom material under the existing bankful flow condition. If this shows that the bottom materials are stable, then no further calculation is needed.

(d) If the cover depth is shallower than the depth calculated for the protection against channel bed erosion using the above procedure, then provide special designs for protection against channel erosion as indicated below. Also verify that the depth of cover is adequate for protection against frost penetration and flotation. If the channel bed is not armored with erosion-resistant material, provide armoring of the channel bed downstream of the pipeline crossing, Standard Detail SC/3.1. (This Standard Detail is based on Maryland's Guidelines To Waterway Construction, January 1986, published by the former State of Maryland Water Resources Administration. For other methods of armoring the stream bed, see Maryland's Guidelines To Waterway Construction, January 1986.)

2) Submit the following data and information: Layout of crossing alignment on topographic maps of the stream valley with five (5) foot vertical contour intervals, results from gradation analysis of channel bed materials for pipelines larger than 12-inch diameter, existing channel dimensions, cross section profile, channel bank and bed slopes obtained from the field survey, environmental/regulatory compliance and constraints, and justification for the design of bank stabilization and cover depth with applicable calculations.

f. Post Construction Stabilization of Channel Banks.

1) Stabilize channel banks to provide protection against surficial erosion of bank materials, slope instability and lateral movements of stream channel at the location of the stream crossing.

a) Standard design. If the primary problem is surficial erosion and the maximum bankful flow velocity is no greater than 10 feet per second (fps), provide riprap stabilization of channel banks, in accordance with Standard Detail SC/3.0. The maximum bankful flow velocity can be estimated by applying Manning's Equation to a representative channel cross section and bottom slope. Provide calculations for maximum bankful velocity estimation.

b) Special design. If certain field conditions are considered to be not entirely applicable to the Standard Design SC/3.0, consider alternative methods of channel bank stabilization, these may include modification to standard detail, use of geotextiles or vegetation, methods to reduce flow velocities, and/or directing flow path away from the banks. Provide calculations for maximum bankful velocity estimation. The following conditions may require special design:

(1) Stream channels where maximum bankful flow velocity is greater than or much lower than 10 fps. Riprap stone sizes other than Class 2 as indicated on Standard Detail SC/3.0 may be required under these cases. Estimate the maximum bankful flow velocity and specify the riprap stone size on the drawings.

(2) Stream banks subject to potential risks of overall slope instability. Perform slope stability analysis and determine if such risks exist. Take a soil boring at the channel bank at a depth of at least three (3) feet below the proposed invert elevation of the pipe.

(3) Channel banks that may be subject to direct impact of high flow velocities, or lateral movements, e.g., meandering channel bends or channel constrictions.

(4) Channel banks with existing bank slopes much steeper than the maximum 2:1 (H:V) slope.

g. Special Considerations.

1) Stream crossing design can be done based on site specific conditions at the location of crossing. However, some cases may call for an evaluation of stream instability for a segment of the stream. Special considerations in alignment selection and in design for channel bank stabilization and pipeline cover depth may be needed. Consult with WSSC regarding the need, approach and method of investigation and design.

2) Examples of such cases are: Major pipelines aligned predominately parallel to the stream channel, but which may cross the stream at more than one location due to a highly meandering flow course with severe bank and bed erosion problems; major pipelines crossing streams having serious historical channel instability problems; and field conditions that require special designs, other than using the standard details, as stated in this section.

3) Additional work may involve investigation of historical changes in channel conditions e.g. meandering, channel depth and width. Special designs for channel bank stabilization and channel bed erosion protection may be needed, other than applying the standard detail. Consult with federal, state and local agencies regarding any riverine hydraulics and erosion studies which may have been done for a particular stream, or a stream segment. These agencies may include Federal Highway Administration, Army Corps of Engineers, Federal Emergency Management Agency, State Highway Administration, Park and Planning Commission and the County Department of Transportation.

h. Calculations for Existing Mean Annual Flood and Existing Bankful Flood Discharge.

1) First, obtain from field surveys, representative existing channel dimensions (depth, top width, bottom width) and channel slope. The average channel slope can be checked against topographic maps available with five (5) foot contour intervals.

2) To determine Mean Annual Flood, apply Manning's Equation to the representative existing cross section:

$$Q_{mean} = (1.486/n)\, A\, R^{2/3}\, S_o^{1/2}$$

Where:

Q_{mean} = Mean Annual Flood, or bankful flood discharge (cfs)
A = cross sectional area (sq. feet)
R = hydraulic radius in feet, $R = A/P$
P = wetted perimeter (feet)
S_o = average slope of the water surface (ft/ft). It can be assumed to be the same as the channel slope under normal flow condition. The steepest slope should be used if the channel slope varies in the general vicinity of the crossing.
n = Manning's roughness coefficient

(a) Exercise judgment when selecting an appropriate value for the Manning's coefficient. In general, the range of values shown in Table 22, may be used:

TABLE "22"

Manning's Roughness Coefficient for Stream Channel Material

Stream Channel Material	Manning's Roughness Coefficient
Predominately cohesionless sandy/silty bed	$0.015<n<0.020$
Coarse sand, fine gravel to medium gravel	$0.02<n<0.03$
Coarse gravel	$n>0.03$
Cobbles/shingles	$n>0.04$

(b) Streams with meanders, vegetative growth on the channel banks and irregularities in flow depths and flow paths can have higher Manning's coefficients than those listed above. Suggested Manning's coefficients for a variety of stream conditions can be found from the following references; Handbook of Hydraulics, by Brater & King, McGraw-Hill Book Company and Open Channel Hydraulics, Vente Chow, McGraw-Hill Book Company

3) To determine design flood (Q_{design}), multiply the existing Mean Annual Flood (MAF) by 1.2. The magnitude of MAF is considered the same as the bankful flood.

Example Number 1.

Assume:

channel width = 10 feet flow depth = 4 feet

channel bed slope = 0.001 ft/ft channel materials mainly of medium/coarse sand

To determine Q_{mean}, apply Manning equation. $Q_{mean} = (1.486/n)\ A\ R^{2/3}\ S_o^{1/2}$

Where

A = area P = wetted perimeter R = hydraulic radius

$A = 40\ \text{feet}^2$ $= 2d + w$ $= A/P$

$P = 18$ feet $R = 2.222$ feet

Assume Manning coefficient, From Table "22", $n = 0.02$ (for medium sandy materials).

$Q_{mean} = (1.486/0.02)\ (40)\ (2.222)^{2/3}\ (0.001)^{1/2}$

$Q_{mean} = \underline{160\ \text{cfs}}$

Bankful Flood Velocity is therefore = 4.0 fps

$V = Q_{mean} \div A$

$= 160\ \text{ft}^3/\text{s} \div 40\ \text{ft}^2$

$V = 4$ fps

Design flood,

$Q_{design} = 1.2\ Q_{mean}$

$= 1.2\ (160\ \text{cfs})$

$Q_{design} = \underline{192\ \text{cfs}}$

i. Calculations for the Required Cover Depth for Protection Against Channel Bed Erosion.

1) Tractive Force Method, use the following equation for calculations:

$\tau_S = W\ R\ S$

Where:

τ_S = shear force of flowing water that will move the bed materials (lb/ft^2)

R = hydraulic radius of the stream channel (feet)

S = channel slope (ft/ft). The steepest slope should be used if the channel slope varies in the general vicinity of the crossing.

W = unit weight of water (lb/ft^3)

$\tau_C = 0.05\ W(S_S - 1)\ d$

Where:
τ_C = critical shear required to move the bed materials (lb/ft^2)
S_S = specific weight of the bed materials S_S is usually assumed to be 2.65
d = representative grain size of the bed materials (ft)

Manning equation. $Q = (1.486/n)\ A\ R^{2/3}\ S_o^{1/2}$
If $\tau_S > \tau_C$. Bed particle is considered <u>unstable</u>.
If $\tau_S \leq \tau_C$. Bed particle is considered <u>stable</u>.

<u>Example Number 2</u> - Using the Tractive Force Method.

Assume:

channel width	=	10 feet.	hydraulic radius	R	=	A/P
channel depth	=	5 feet.			=	10 x 50/20
slope	=	0.00075 ft/ft.		R	=	2.5 feet

From grain size analysis, the median size is coarse sand, d = 0.005 feet (1.5mm).

Assume Manning's coefficient, from Table "22", n = 0.022 for coarse sand

Therefore: Q_{mean} = 170 cfs $Q_{design} = 1.2\ Q_{mean}$
= 200 cfs

Check critical shear. $\tau_C = 0.050 \times 62.4 \times (2.65 - 1) \times 0.005 = 0.026\ lb/ft^2$
$\tau_S = 62.4 \times (2.5) \times (0.00075) = 0.117\ lb/ft^2$
Therefore: $\tau_S > \tau_C$. Bed particle is considered unstable.

Assume: A new channel depth, due to channel bed erosion by Q_{design}.
Assuming 7.0 feet of soil being eroded under Q_{design}.
Therefore:
new channel depth = 12.0 feet width remains at 10 feet
new area = 120 feet. new hydraulic radius R_{new} = 3.5294 feet

Calculate new slope. S_{new} by Manning's equation.
$Q_{design} = 1.486/n\ (A_{new})\ (R_{new})^{2/3}\ (S_{new})^{1/2}$
Therefore: S_{new} = 0.000113 ft/ft

Check: $\tau_S = W\ R_{new}\ S_{new}$
$= (62.4)\ (3.5294)\ (0.000113)$
$\tau_S = 0.025\ lb/ft^2 < \tau c$
Therefore: Required cover depth = 7.0 feet.

2) Permissible Velocity Method, use the following equation for calculations:

a) This method can be applied to channels with relatively fine materials, preferably in the range of sand to fine gravel sizes. Perform soil sampling of channel bed materials and determine the representative grain size of the bed material and type of bed materials.

b) Define the permissible velocity V, for the type of bed materials, see Table 23.

c) Apply the following equations:
Manning's Equation $Q = (1.486/n)\ A\ R^{2/3}\ S^{1/2}$

Continuity equation $Q = V A$

Where:

V = average channel velocity (ft/s)

Q = discharge, rate of flow (ft^3/s)

A = cross-sectional flow area (ft^2)

TABLE "23"

Permissible Velocities for Stream Channel Material

Stream Channel Material	Permissible Velocities (V)
Sandy silt or cohesive silty clay, disturbed during construction	1.5 to 2.0 fps
Cohesionless fine to medium sand	Less than 1.5 fps
Coarse sand	1.5 to 2.0 fps
Coarse sand to fine gravel	2.0 to 2.5 fps
Fine to medium gravel	2.5 to 3.0 fps

Example Number 3, using Permissible Velocity Method.

Assume the same channel dimensions as in Example Number 2.

Calculate the average velocity for existing Mean Annual Flood by Manning's equation.

$V = 1.486/0.022 \times (2.5)^{2/3} \times (0.00075)^{1/2}$

$V = 3.4$ ft/s

It is noted that 3.4 ft/s exceeds the permissible velocity of the coarse sandy material, which can be assumed at 1.8 ft/s average.

Therefore:

We need to assume new channel dimensions, under Q_{design}.

By the same approach as employed in Example Number 2 assume new channel depth at 12.0 feet, 5.0 feet plus 7.0 feet of eroded soil depth.

Estimate new channel slope, S_{new}, then calculate new flow velocity:

$V_{new} = 1.486/0.022 \times (R_{new})^{2/3} (S_{new})^{1/2}$

$= 1.486/0.022 \times (3.5294)^{2/3} (0.000113)^{1/2}$

$V_{new} = 1.7$ ft/s

Average velocity 1.7 ft/s is less than the permissible velocity, O.K.