SCOUR PROCEDURES AND GUIDELINES FOR SANITARY SEWER CROSSINGS OF ALLUVIAL WATERCOURSES

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SCOUR PROCEDURES AND GUIDELINES

I. BACKGROUND

This report presents scour procedures and guidelines for the computation of scour/erosion and lateral migration at sanitary sewer crossings of alluvial watercourses.

Over the past 20 years, advancements in the fields of hydraulic engineering, scour/erosion assessment, and sediment-transport technology have provided improved generalized methods for computing the components of scour. Historically, local design standards available for computing scour/erosion depths and lateral-migration limits of sanitary sewer and other types of pipeline crossings of alluvial watercourses have been found to provide reasonable results when all components of the scour/erosion and lateral-migration processes are considered and when they are properly applied to each individual scenario. The difficulty is that, occasionally, within the environs of central and southern Arizona in particular, hydraulic conditions which prevail in a given watercourse may fall outside of the envelope within the set of standard scour equations that were originally developed, and thus publicized procedures may not be strictly applicable under all ranges of conditions. This document is intended to provide such an approach to the computation of scour/erosion and lateral migration—one that would not only have applicability within the urban/metropolitan areas of Pima County, but would also apply in a more regional fashion to the majority of alluvial watercourses located in rural Pima County, as well as in the semi-arid and arid desert areas of Arizona, in general.

II. CONDITIONS OF USE

This simplified hydraulic design procedure contains technical concepts and guidelines to aid the engineer in the planning and design of pipelines to be placed across and/or parallel to alluvial watercourses. This procedure has been developed for use only with alluvial watercourses that are primarily composed of sands and gravels, and that are subject to erosion with a regulatory (i.e., 100-year) peak discharge of less than 10,000 cfs ($Q_{p100} < 10{,}000$ cfs).

When used in this type of conditions, the procedure presented herein should produce adequate results. However, site-specific evaluations, which encompass more detailed analyses and consider ALL local factors, are recommended whenever and wherever possible. This procedure has been developed using both sound engineering judgment and the best information currently available. Nonetheless, this procedure should only be accepted and used by the recipient individual or group entity with the express understanding that Pima County and/or the Authors of this procedure make no warranties, either express or implied, concerning the accuracy, reliability, usability, or suitability for any particular purpose of the information contained herein. As such, Pima County and/or the Authors of this procedure assume no liability, whatsoever, to any such individual or group entity by reason of any use made thereof. Furthermore, use of the procedure shall not be presumed to be the best engineering practice for any site-specific situation.

III. FOUR-STEP INITIAL EVALUATION PROCESS

Before beginning any scour/erosion assessment, the four-step initial-evaluation process which is described below should be conducted. This process is intended to assist the user in determining whether he or she can prepare his or her own scour evaluation; or, whether there needs to be a consultant retained to prepare the investigation who is an expert in the field of erosion and sediment transport. Please note that the following section is only a guideline meant to assist the user in determining the risk associated with computing his or her own scour estimates for sanitary sewer crossings of alluvial watercourses.

The Project Risk (R) can be evaluated by the equation, $R = R_1+R_2+R_3$, as follows:

Step 1) What is the risk/expectation of vegetal growth (R_1) in areas that are environmentally restricted, particularly with regard to maintenance concerns? (Scale from 1-10). Example:
- Low—shallow weeds/grasses within maintained channels, $R_1 = 1$,
- High—shrubs/trees growing in environmentally protected watercourses, $R_1 = 10$.

Step 2) What is the Social/Economical Risk (R_2) that is associated with failure of a sanitary sewer? (Scale from 1-10). Example:
- Low Contamination/Cost—Improvements within Small Service Area, $R_2 = 1$.
- High Contamination/Cost—Improvements within Regional Service Area, $R_2 = 10$.

Step 3) Local Risk Factors (R_3) within the proximity of the sanitary sewer are equal to the sum of the associated risks as presented in the table below, where, $R_3 = \sum R_i$:

Table 1: Factors That influence Local-Erosion Risk Evaluation, (Scale from 0-10)

Local Risk within proximity of Sanitary Sewer (R_i)	Point Value
Flow Contraction Due to Bridge Abutment Encroachments, (R_{BE})	0 or 1
Bridge Piers, (R_{BP})	0 or 1
Presence of Drop Over a Rigid Grade-Control Upstream of Crossing, (R_D)	0 or 1
Sanitary Sewer Partially or Fully Exposed to Flow, (R_P)	0 or 2
Presence of In-Stream Sand-and-Gravel Mine in Proximity of Sanitary Sewer, (R_M)	0 or 3
Curvature of Watercourse where Sanitary Sewer Crossing Is Located	0, 1 or 2
-If $(r_c/T) \geq 10$	0
-If $0.5 < (r_c/T) < 10$	1
-If $(r_c/T) \leq 0.5$	2

Step 4) Upon completion of the preceding three steps, sum R_1 thru R_3 , and compare risk level with the table below:

Table 2: Scour/Erosion-Hazard Risk Evaluation

Computed Risk ($R=R_1+R_2+R_3$)	Risk Potential	Recommendation
$0 < R < 10$	Low	Proceed with Caution
$10 \leq R < 20$	Moderate	Experienced Professional Is Recommended
$20 \leq R \leq 30$	High	Experienced Professional and Detailed Investigation Are Recommended

IV. STANDARD SCOUR PROCEDURE

The following text summarizes the scour procedures and the guidelines to be used for evaluating scour/erosion and lateral-migration impacts at sanitary sewer crossings of alluvial watercourses.

4.0 Total Scour

Total scour potential (including future conditions) is loosely defined as the sum of the individual scour components described in the following subsections of this document. All recommended sanitary sewer cover depths are to be measured from the thalweg (i.e., the lowest elevation in the streambed) when the sanitary sewer is placed at the watercourse crossing. If the crossing is braided, then the burial depth is to be measured from the thalweg of the most deeply entrenched thread. As a general rule-of-thumb, the user should recognize that the upper limit of maximum scour (Z_{MAX}) computed should not exceed five times the maximum flow depth (Y_{MAX}); that is $Z_{MAX} \leq 5Y_{MAX}$.

4.1 Maximum Scour Depth

$$Z_{MAX} = Z_{TSE} + Z_{LTD} \qquad \text{Where, } Z_{MAX} \leq 5Y_{MAX} \qquad \text{(Equation 4.1.1)}$$

$$Z_{MAX} = 5Y_{MAX} \qquad \text{Where, } Z_{MAX} > 5Y_{MAX} \qquad \text{(Equation 4.1.2)}$$

Where:

Z_{TSE}	=	Total single-event (100-year) scour depth, in feet;
Z_{LTD}	=	Long-term aggradation or degradation depth, in feet;
Y_{MAX}	=	Maximum depth of flow in channel, in ft;
Z_{MAX}	=	Upper limit of maximum predicted scour depth, in feet;

A general equation for computing the single-event scour depth, Z_{TSE}, for a 100-year peak discharge along either a curved or a straight reach of an alluvial watercourse is:

$$Z_{TSE} = C_U(Z_G + Z_A + Z_T + Z_B + Z_C + Z_L) \qquad \text{(Equation 4.1.3)}$$

Where:

C_U*	=	Non-uniform scour coefficient to account for flow irregularities (per factor-of-safety from Table 3), unitless;
Z_{TSE}	=	Total single-event (100-year) scour depth, in feet;
Z_G	=	General scour depth, in feet;
Z_A	=	Anti-Dune scour depth, in feet;
Z_T	=	Low-flow thalweg depth, in feet;
Z_B	=	Bend scour, in feet;
Z_C	=	Confluence scour, in feet; and
Z_L	=	Local scour depth, in feet

*The C_U coefficient is meant to account for increased unit discharge due to flow irregularities.

Table 3: Non-Uniform Scour Coefficients[1] (C_U)		
Channel Geometry	**Value for Erodible Bed and Banks**	**Value for Erodible Bed and Protected Banks**
Natural/Irregular	1.55	1.75
Parabolic	1.50	1.70
Trapezoidal	1.33	1.55
Rectangular	1.20	1.33

[1]As derived from Blodgett (1986)

4.2.1 General Scour (Z_G):

It is reasonable to assume that general scour processes would be strongly correlated to the unit discharge of flow within the channel of an alluvial watercourse. Therefore, for purposes of this document General Scour, Z_G, has been quantified in terms of unit discharge, q, as shown below:

$$Z_G = 0.293q^{2/3}\left[q^{1/15} - 1.073\right] \qquad \text{(Equation 4.2.1.1)}$$

(*If Z_G < 0.10 feet, assume Z_G = 0.10 feet*)

Where:

Z_G = General scour depth, in feet; and,
q = Average peak discharge per unit width of the channel, in cfs/ft.

4.2.2 Anti-Dune Scour (Z_A):

Anti-dunes are bed forms, similarly shaped to dunes, but which move along the streambed in an upstream direction, rather than downstream as do dunes, and move in phase with the surface waves in the channel. Anti-dunes typically form when transitional flow occurs or when the flow in the channel is at near-critical or critical flow conditions—conditions which, by far, are indicative of the most common flow regimes which are found along alluvial watercourses in metropolitan Pima County during major flow events. As noted, the corresponding surface waves are in phase with the anti-dunes, and tend to break like surf when the waves reach a height approximately equal to 0.14 times the length of the wave. From this knowledge, a relationship has been established that relates the average channel flow velocity to the predicted anti-dune scour depth along the streambed. This relationship, excerpted from the *City of Tucson Standards Manual for Drainage Design* (1989, and revised in 1998) is shown below (see Figure 1, Page 5):

$$Z_A = 0.0137V^2 \qquad \text{(Equation 4.2.2.1)}$$

Where:

Z_A = Anti-Dune scour depth, in feet; and
V = Average channel flow velocity, in ft/s.

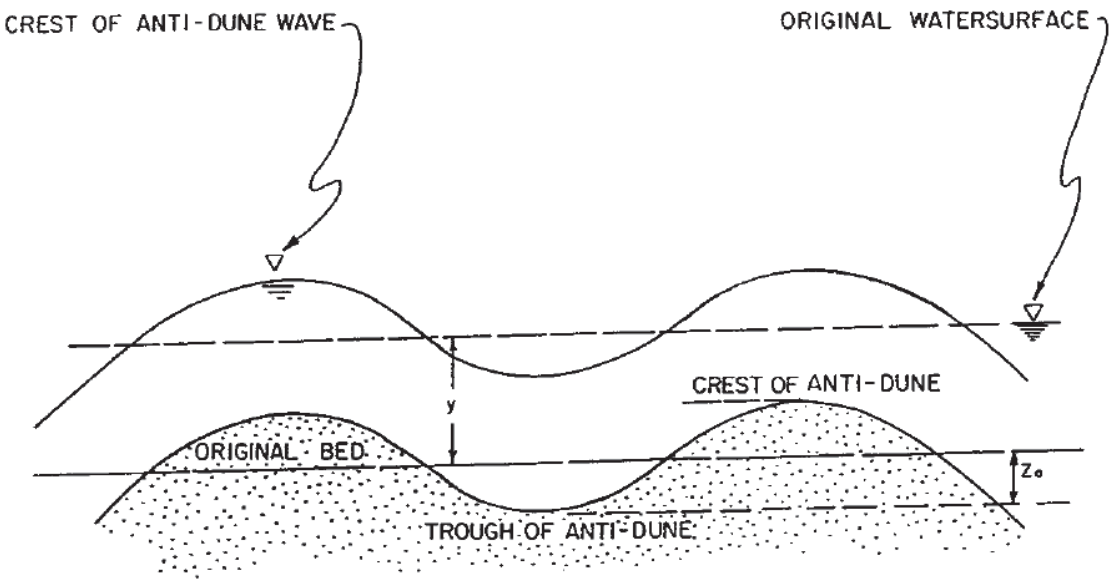


FIGURE 1

When computing Z_A, it is important for the user to keep in mind that the height of an anti-dune can never exceed one-half the maximum depth of flow ($1/2Y_{MAX}$). Accordingly, if Z_A should exceed $1/2Y_{MAX}$, then Z_A should be set equal to $1/2Y_{MAX}$ (i.e., $Z_A = 1/2Y_{MAX}$

4.2.3 Low-Flow Thalweg (Z_T):

The low-flow thalweg is a small "inner channel" which forms in the streambed of the main channel. A low-flow thalweg typically develops when the width-to-depth ratio of the main channel of an alluvial watercourse is large in comparison to the ordinary flows which occur on an annual basis. Depending upon the relationship between flow velocity, V, and flow depth, Y, during a 100-year event, the scour depth to account for a low-flow thalweg (Z_T) follows the relationships adopted from the *City of Tucson Standards Manual for Drainage Design* (1989, and revised in 1998), as shown below:

$Z_T = 0$	$Y \leq 1.15V$		(Equation 4.2.3.1)
$Z_T = 1$	$Y > 1.15V$	($DA < 30$ mi^2)	(Equation 4.2.3.2)
$Z_T = 2$	$Y > 1.15V$	($DA \geq 30$ mi^2)	(Equation 4.2.3.3)

Where:

Z_T	=	Low-flow thalweg scour depth, in feet;
Y	=	Average flow depth of channel, in ft; and
V	=	Average velocity of the channel, in ft/s

Note, however, that if a low-flow thalweg is present at the site of a sanitary sewer crossing, the observed thalweg depth should be used in lieu of results generated by the preceding equations.

4.2.4 Bend Scour (Z_B):

Bend scour occurs along the outside (concave side) of a bend. It is created by spiral, transverse currents which form within the flow as the water moves through the curved alignment in the bend. The following relationships for bend scour, Z_B, are expansions of Equation 4.2.1.1, found in Section 4.2.1 of this document, upon consideration of curvature effects. These relationships are designated for use based upon different magnitudes of the ratio r_c/T, and are an additive component of the total scour, Z_{TSE}.

$$Z_B = 0.243q^{0.733}$$

If $\alpha > 60°$ $[(r_c/T) \leq 0.5]$
(use for nearly direct impingement [e.g., right-angle bends) (Equation 4.2.4.1)

$$Z_B = 0.293q^{0.733}\left(2.1\left[\frac{\sin^2\left(\frac{\alpha}{2}\right)}{\cos\alpha}\right]^{0.2} - 1\right)$$

If $17.75° < \alpha < 60°$ $[0.5 < (r_c/T) < 10]$
(Equation 4.2.4.2)

$$Z_B = 0$$

If $\alpha \leq 17.75°$ $[(r_c/T) \geq 10]$
(Equation 4.2.4.3)

The relationship between α and r_c/T is mathematically described below (also, see Figure 2):

$$\frac{r_c}{T} = \frac{\cos\alpha}{4\sin^2\left(\frac{\alpha}{2}\right)}$$

(Equation 4.2.4.4)

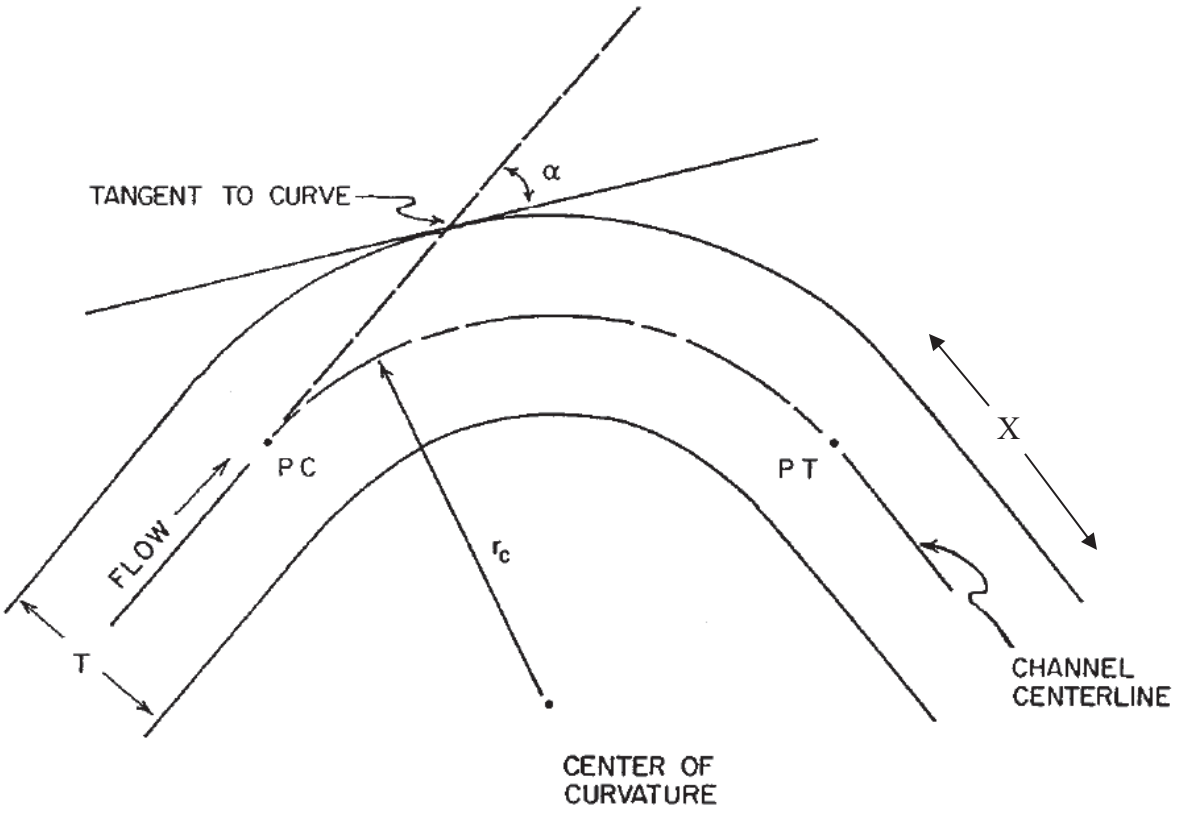
Note: Bend scour should not be applied beyond X_B, which is the downstream distance where scour is no longer influenced by flow curvature, and is mathematically defined as:

$$X_B = \left(\frac{0.6}{n}\right)Y_{max}^{1.17}$$

(Equation. 4.2.4.5)

Where:

Z_B	=	Bend scour depth, in feet;
q	=	Unit discharge of flow, Q/T, approaching bend, in cfs/ft;
r_c	=	Radius of curvature along centerline of channel, in ft;
T	=	Channel top-width immediately upstream of the bend, in ft;
α	=	Angle formed by the projection of the channel centerline from the point of curvature to a point that meets a line tangent to the outer bank of the channel, in degrees (see Figure 2);
X_B	=	Distance from bend to where scour is no longer influenced by flow curvature (see Figure 2);
n	=	Manning's "n" value; and
Y_{max}	=	Maximum depth of flow immediately upstream of the bend, in ft.



PT = Downstream point of tangency to the centerline radius of curvature
PC = Upstream point of curvature at the centerline arduous of curvature

FIGURE 2

4.2.5 Scour at Confluence of Two or More Watercourses:

Confluence scour for two or more watercourses is determined by the following relationship:

$$Z_C = Y_{MC} - Y \qquad \text{(Equation 4.2.5.1)}$$

Maximum flow depth in a confluence, Y_{MC}, can be calculated for different sediment classes using the following relationship (Ashmore and Parker 1983; Klaassen and Vermeer 1988):

$$\frac{Y_{MC}}{\overline{Y}_{MS}} = 2.24 + (0.031)\alpha_c \text{ (non-cohesive sands/gravels } [30° < \alpha_c < 90°]) \qquad \text{(Equation 4.2.5.2)}$$

Where:

Z_C	=	Scour due to a confluence of two or more watercourses, in ft;
Y_{MC}	=	Maximum flow depth in the confluence scour hole, in ft;
Y_{MS}	=	Average flow depth, from water surface to mean scoured depth, in ft;
Y	=	Average flow depth, in ft.
α_c	=	Angle of confluence of two watercourses, in degrees (Note: This is not the same α depicted in Figure 2).