COACHELLA VALLEY WATER DISTRICT
GUIDELINE K-3
SCOUR CALCULATION GUIDANCE

K-3.1 General Requirements

Calculating scour is part of the design of stormwater conveyance facilities with natural, erodible beds. Scour calculations are part of the design of in-stream structures – such as bank protection, bridges, pipelines, constrictions or encroachments, grade controls, and other structures. Scour is also calculated to assess the potential impacts of proposed projects on existing facilities. For instance, an encroachment into a stormwater channel might result in deeper scour depths that will require extending the toe of existing concrete slope protection.

Where structures or actions are proposed that may affect hydraulic conditions within CVWD's stormwater facilities, the project proponent is responsible for identifying impacts on scour by comparing existing and project scour conditions, then developing a plan for mitigation.

K-3.2 Description of Scour

Scour occurs in CVWD's stormwater facilities during infrequent floods, when bed sediments are eroded, transported, and deposited. Scour refers to erosion of bed sediments and the lowering of the channel bed below its normal level that occurs during floods
Scour can be classified into various categories or types. For the purposes of this guideline, CVWD has adopted the following categories:

- **General (or Natural) Scour**
  - Refers to the lowering of a channel bed during the peak of a flood; the channel bed often re-fills on the recessional limb. General scour is used in this Guideline rather than natural scour because most of CVWD's facilities have protection on the banks that fixes the channel width and contains the 100-year flood. Hence, the adjustments to accommodate a flood can result in lowering of sizeable areas of the bed.
  - Occurs in straight sections of channels and is more severe in bends or sinuous sections of the channels. .
- **Constriction Scour**
  - Occurs where a channel is narrowed by natural features or engineering structures, such as bridges, or where levees or berms are built to contain flows within the channel that previously spilled onto the floodplain.
  - Includes pressure flow scour, which occurs when the water surface elevation exceeds the minimum elevation of a bridge deck. Pressure flow scour is not common in CVWD's facilities.
- **Local Scour**
  - Occurs when the flow interacts with a structure, such as a bridge pier, abutment, intake, grade control or drop structure, spur or other feature.
  - Is generally restricted to the bed in the immediate vicinity of the structure.

- **Channel Incision (Profile Degradation)**
  - Bed lowering results from the lowering of the bed slope towards a stable or equilibrium gradient. The slope adjustment generally affects long reaches of CVWD's stormwater channels.
  - The change in bed slope may result from natural or human-induced changes in flow, sediment supply or sediment character, or from removal of grade control structures, low water road crossings, or other structures that fix the bed in place.

General, Constriction and Local Scour depths generally reach a maximum near the peak of large floods. The bed may subsequently re-fill or re-deposit to about previous levels on the falling limb of the hydrograph. This pattern of scour and fill is particularly common in sand-bed channels. Channel Incision is different from the first three scour processes in that it is progressive and approaches equilibrium slowly over a series of floods.

Maximum scour depths are calculated sequentially for the four processes above. For instance, at a bridge crossing, Channel Incision is calculated first, particularly if a grade control structure will be removed or if there is a history of incision in the reach. This is followed by Constriction Scour if the bridge narrows the waterway. Next, General Scour is calculated for the altered channel bed and associated hydraulic characteristics that result from Channel Incision and Constriction Scour, if either or both occurs. Local Scour (if piers and abutments lie within the waterway) is then calculated using the bed elevation and hydraulic conditions created by General or Constriction Scour.

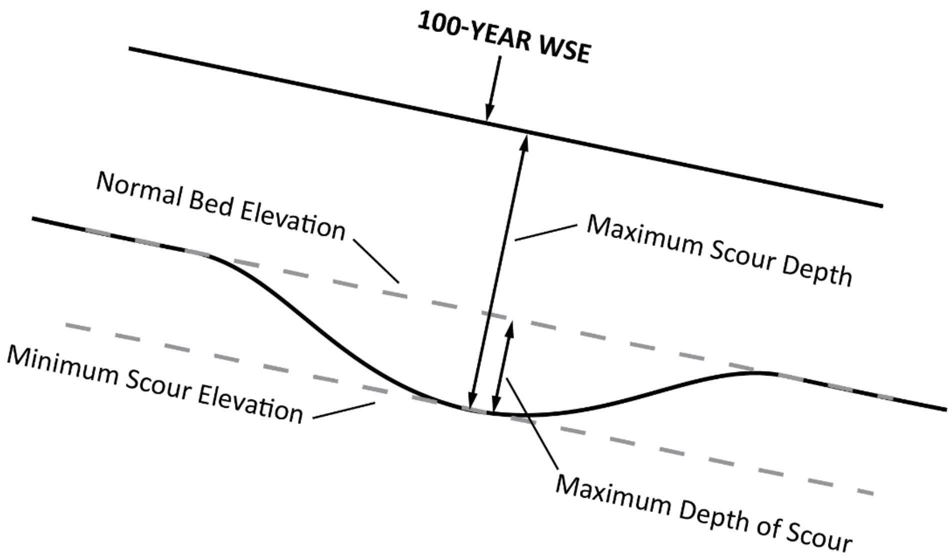
Plunging jets or complex flows over the crests of grade control structures, drop structures, or low water crossings, such as are found along the Whitewater River/ Coachella Valley Stormwater Channel (WWRSC/CVSC), are also an important source of Local Scour. The depth and length of the scour holes downstream of these structures are discussed in Section K-3.11.

K-3.3 Definitions

CVWD has adopted the following definitions of scour. The various terms are also defined on a diagram on page 3:

- **Scour (or Scoured) Depth:**
  - The difference in elevation between the water surface and the lowest scoured point below the channel bed for any particular flow.
- **Maximum Scour (or Scoured) Depth:**
  - The difference in elevation between the design flow water surface elevation and the lowest scoured point for the design flow. General Scour is typically calculated as a Maximum Scour Depth. The Maximum Scour Depth can be a total from several different types of scour.
- **Maximum Depth of Scour:**
  - The difference in elevation between the design or normal channel bed and the lowest scoured point for the design flow. Local scour is typically calculated as a Maximum Depth of Scour.
- **Minimum Scour Elevation:**

- The elevation calculated by subtracting the Maximum Scour Depth from the design water surface elevation or the Maximum Depth of Scour from the normal or design channel bed elevation.
- CVWD recommends that scour calculations are reported as Minimum Scour Elevations to simplify comparisons to toe elevations of existing bank protection, crowns elevations of pipelines or elevations of other existing features along the channel.



Scour Definition Diagram (Section K-3.3)

K-3.4 Design Flow for Minimum Scour Elevations

CVWD has adopted the 100-year Plus standard for the design of regional stormwater facilities (refer to Section 8 of the DDM). Maximum Depths of Scour and Maximum Scour Depths are calculated from the existing and project condition 100-year peak flows, 100-year water surface elevations, channel geometries and structure dimensions.

Scour calculations proceed after the existing and project condition hydraulic models have been reviewed and accepted by CVWD.

K-3.5 Approach to Calculation of Scour

The prediction of scour is very complex at the theoretical level. Local Scour has been studied experimentally for structures, such as bridge piers and grade control structures. Empirical techniques for calculating Maximum Depths of Scour are available from a number of publications. CVWD recommends the most recent U.S. Federal Highway Administration's HEC-18 for estimating Local Scour (piers and abutments), and Constriction Scour. Section K-3.11 provides procedures for calculating scour for grade control structures.

There are various procedures for estimating General Scour but none of them were developed for arid, semi-natural channels, such as the WWRSC/CVSC, where banks are often protected, flows are contained by channel banks or levees, and flood peaks are of short duration. Given these limitations, CVWD reviewed procedures adopted by various Federal, State and local agencies to calculate Minimum Scour Elevations in straight and curved channels. These procedures are of varying complexity, calculate total scour from various scour components (some include profile incision, bedform scour and low flow incision), and have varying levels of empirical or theoretical support. Comparisons of Minimum Scour elevations calculated for the WWRSC/CVSC with these different procedures showed reasonable agreement on average.

CVWD has adopted the Blench regime equation to calculate General Scour for the design of toe elevations for bank protection. The equation has a long history of successful use in North America, is fairly simple to apply, and is flexible in that it can be applied to estimate General Scour in straight reaches, bends, and at some structures. Further background on the regime approach is available in Lacey (1930), Blench (1957, 1969), May et al (2002), TAC (2004) and other publications.

CVWD is generally not willing to consider General Scour calculated from changes in bed elevations derived from sediment routing programs (HEC-6T or HEC-RAS) applied over the design hydrograph. The hydraulic calculations that underlie the sediment transport calculations are not of sufficient detail to provide useful or reliable predictions of scour associated with structures nor will they provide reliable predictions in bends. CVWD will review General Scour calculations from alternative procedures, but the proponent will also be required to calculate General Scour by the procedures in Section K-3.7 and should expect additional costs for review.

K-3.6 Time to Reach Maximum Scour Depths

General, Constriction, and Local Scour equations calculate scour depths that are the greatest depths reached in experimental facilities after a long period of time or are a practical limit to the maximum scour that can develop. CVWD examined various publications to determine whether an adjustment for incomplete scour development is required for their facilities and the short duration floods they experience.

In general, there are no studies that demonstrate whether or not scour would fully develop in a channel such as the WWRSC/CVSC. However, several publications provide general guidance for sand-bed channels. For instance, Melville and Coleman recommend using calculated Maximum Scour Depths or Maximum Depths of Scour for the design of facilities because scour develops very rapidly in sand beds. Similarly, Arneson et al (2012) indicate that Maximum Scour Depths are reached in sand-beds within a few hours and recommend equations that predict Maximum Scour Depths or Maximum Depths of Scour for calculating Minimum Scour Elevations.

Given the above advice, CVWD does not adjust calculated Minimum Scour Elevations to account for short duration flood peaks or other factors that might prevent the full development of scour.

K-3.7 Calculating General Minimum Scour Elevations

For General Scour, CVWD has adopted the Blench (1957, 1969) regime equation, as follows:

$$d_{fo} = (q_f^2/F_{b0})^{1/3} \qquad \text{(K3-1)}$$

In this equation, d_{fo}, is the regime depth (feet) below the design water surface, q_f is the unit 100-year discharge calculated from the 100-year peak flow divided by the channel width (ft^2/sec), and F_{b0} is the zero-bed factor (ft/sec^2), which is a function of the median grain size of the bed material. Appendix K-3-A provides a figure that relates the zero-bed factor to the median bed material size. The equation predicts the depth of flow that is expected to develop in the channel for the 100-year peak flow and median grain size. Inerodible or less-erodible subsurface sediments may limit the development of the regime depth. Scour calculations in the vicinity of structures are described in Section K.3.11.

The Maximum Scour Depth, d_s, is then calculated by applying a Z-factor to the regime depth from Equation K3-1, as follows:

$$d_s = Z^* d_{fo} \qquad \text{(K3-2)}$$

In the above equation, Z varies with the alignment of the channel or the presence of some structures. Section K-3.11 provides appropriate Z-factors for the design of bank protection and other in-channel structures. The Minimum Scour Elevation is then calculated by subtracting the Maximum Scour Depth from the 100-year water surface elevation.

Calculation of Minimum Scour Elevations requires the 100-year peak flow, the 100-year water surface elevation, cross-sections, and the bed material size distribution at the site of interest.

<u>100-Year Peak Flow and Water Surface Elevation</u>

Section 8 of CVWD's Development Design Manual (DDM) provides standards for determining the 100-year peak flow and the 100-year water surface elevation. For scour calculations, the 100-year peak flow is the peak flow within the channel banks. Where flows overtop the banks or levees, the portion of the peak flow within the channel bank will be used for calculations unless CVWD plans to construct levees or other features to contain flows within the channel.

<u>100-Year Unit Discharge</u>

The 100-year unit discharge is calculated by dividing the 100-year peak flow by the channel width at the 100-year water surface elevation. Originally, Blench (1957) calculated the unit discharge from the width at one-half of the flow depth. However, CVWD has adopted the water surface width, resulting in a somewhat lower unit discharge compared to Blench.

When calculating Maximum General Scour Depths over a long reach with constant 100-year peak flow, an average channel width can be used to calculate the unit discharge rather than the variable widths at individual cross-sections. This results in a smooth Minimum Scour Elevation profile, roughly paralleling the water surface profile, for design and construction. This guidance applies to reaches of relatively constant width between levees – calculations using local topwidths are recommended for general scour calculation in the vicinity of major structures/crossings.

If a two-dimensional hydraulic model has been developed, 100-year unit discharges can be calculated from the depths and velocities at grid cells near the site of interest (DDM Chapter 8 provides recommendations on 2D models). The depths and velocities at grid cells near the site of interest are used to calculate unit discharges and the maximum unit discharge at the cells is selected for scour calculations under the assumption that this product could occur anywhere in the channel during a flood. If this approach is adopted to calculate the unit discharge, a Z-factor of 1.0 is applied in the calculation of Maximum General Scour Depths.

Bed Material and the Zero-bed Factor

The zero-bed factor, F_{b0}, is determined from the median bed material size at the site of interest. The zero-bed factor for a particular median size can be obtained from Appendix K-3-A. The chart in the appendix was developed by Pemberton and Lara (1984) from the original chart in Blench (1969). Other publications also provide charts and equations but they should be checked against Appendix K-3-A.

Median bed sediment sizes vary along the WWRSC/CVSC. Based on samples from the surface and five feet below the bed, Bechtel (1995) determined that median sizes declined from about 0.9 mm near Palm Springs to about 0.2 mm near Rancho Mirage, and then to 0.15 mm near the Thermal Drop Structure. CVWD requires the collection and analysis of surface bed sediments near the project site to calculate an up-to-date median size for the project scour calculations.

Bed Material Variation with Depth

In general, the bed material observed along the surface of the WWRSC/CVSC and other facilities extends to a considerable depth below the bed. However, if boring logs are available near the project site, such as for the design of bridge abutments and piers, CVWD recommends inspecting the logs for subsurface materials that might limit scour. If a geotechnical engineer identifies a relatively inerodible stratum underlying the project site, this can be incorporated in setting the Minimum Scour Elevation as follows:

- If the top elevation of the inerodible stratum is higher than the Minimum Scour Elevation calculated from the surface bed material (as described above), then the top elevation of the inerodible stratum is adopted as the Minimum Scour Elevation; or
- If the top elevation of the inerodible stratum is lower than the Minimum Scour Elevation calculated from the surface bed material (as described above), then the calculated Maximum General Depth of Scour is used to calculate the Minimum Scour Elevation.

Where there are no nearby boring logs or subsurface investigations, CVWD recommends calculating the Minimum Scour Elevation from the zero-bed factor for the surface bed material median size.

K-3.8 Calculating Contraction Minimum Scour Elevations

Where a proposed project will encroach into a stormwater facility and narrow the waterway or where overbank flows will be directed into the channel by constructing berms or levees, it is expected that Maximum Scour Depths will increase over those for existing conditions. For long constrictions where the design flow is maintained within the channel and where new regime conditions will establish, the project maximum scour depth can be re-calculated from Equations K.3-1 and K.3-2 with the unit discharge calculated for the new width.

The following equation from Neill (1973) can also be used to calculate the project regime depth that will result from contraction at a bridge:

$$d_p = d_{fo}(q_p/q_f)^m \qquad \text{(K.3-3)}$$

Here, d_{fo} and q_f were defined earlier; d_p is the project regime depth, q_p is the with-project unit discharge, and m is an exponent, set to 0.67 for sand channels and 0.85 for gravel channels. The project unit discharge may differ from the existing unit discharge as a result of a narrower top width in the case of encroachment or an increased design peak flow in the case where overbank flows are now contained in the channel, or both. The project regime depth will be multiplied by the appropriate Z-factor to calculate the with-project Maximum Scour Depth.

For bridge constrictions, CVWD also recommends the procedures in the chapters on constriction scour in the most recent edition of HEC-18. This topic is also addressed in other publications. CVWD will usually not accept a rise in upstream water surface elevations at a proposed bridge, thereby eliminating constriction of their stormwater channels by new facilities and reducing the requirement for constriction scour calculations.

For short and abrupt encroachments, such as spurs or guide banks, CVWD recommends that scour depths at the noses of these structures for the design of protection are calculated from Blench’s regime equation with Z=2.5. These structures are rare in CVWD’s facilities and are unlikely to be approved, if proposed.

K-3.9 Calculating Local Minimum Scour Elevations

The most recent edition of Hydraulic Engineering Circular No. 18 (HEC-18); shall be utilized for calculation of local scour at piers and abutments. Scour calculations for grade control structures are described in Section K-3.11.

K-3.10 Calculating Degradation or Bed Incision

General Discussion

Bed incision or degradation refers to the long-term lowering of the bed profile towards some stable or equilibrium slope. Aggradation is the opposite, the long-term raising of the bed profile towards a stable slope. The stable or equilibrium slope is defined as the average slope that would develop over a long reach after several decades or a century, in response to particular peak flow and sediment supply regimes.

Degradation or bed incision typically occurs over long reaches and is progressive, in that it does not reverse after the passage of a flood. The lowering of the bed tends to start just upstream of a hard point, such as a grade control structure, and progress upstream towards the next hard point. Galay (1983) provides a good discussion of the causes of degradation and the typical nature of the bed response.

In CVWD’s stormwater channels, bed slopes were often imposed during construction. Since the end of construction, these slopes have begun to adjust in response to the peak flows and sediment supply conditions over the past 40 years. CVWD has observed channel degradation along the WWRSC/CVSC. A recent example occurred after the replacement of the Jefferson Street low-water crossing with a bridge. The old crossing was removed before the January and December 2010 floods (peaks flows of about 5,500 and 9,600 cfs, respectively) and the bed degraded rapidly upstream of Jefferson Street to the Dune Palms low water crossing, exposing and damaging a sewer crossing, and necessitating the installation of a grade control structure to replace the old Jefferson Street low water crossing and re-construction of the sewer pipeline.

Project Bed Slope Analyses

As a result of the experience at Jefferson Street, CVWD requires an analysis of bed profile adjustments whenever a project proposes to modify, remove, or less commonly, install a grade control structure. CVWD considers low-water crossings that have functioned without significant erosion or damage during historical floods as grade control structures for the above analyses. In general, the project bed slope analysis will extend from the grade control structure downstream of the project site to the next upstream grade control structure or from the modified structure upstream to the next one. The proponent should discuss the extent of the analysis with CVWD before proceeding.

The purpose of the profile analysis is to identify if utility crossings or the toes of existing slope protection will be exposed, or if other facilities will be damaged, as a result of profile adjustment following the modification, removal or construction of a grade control facility. The project proponent shall compare historic profiles along the WWRSC/CVSC or other facilities in order to gain an understanding of bed level trends at the project site. CVWD will provide a recent sediment transport study of the WWRSC/CVSC for considering degradation along this facility and will provide advice on approaches to evaluate potential slope lowering and degradation on other facilities.

Once the stable or equilibrium slope is estimated, channel hydraulics are re-calculated and the long-term project condition scour profile is calculated from the new 100-Year water surface elevation profile and channel geometry and compared to the existing condition minimum scour profile and existing toes of bank protection or other facilities in order to evaluate project impacts.

K-3.11 Scour Calculations for Structure Design

This section discusses CVWD policies and procedures for scour calculations for design or evaluation of bank protection, constrictions, bridges, grade control structures, utility crossings, and other instream structures.

Project impacts on scour along CVWD stormwater facilities are generally determined by repeating the scour procedures for the conditions expected in the facility once the project is constructed and comparing them to existing conditions.

Concrete Bank Protection

Bank Protection is required along CVWD stormwater facilities wherever the local materials will erode during the design flood. Guideline K-2 describes the design standards for the protection typically used for soft-bottom or natural bed stormwater facilities.

Guideline K-2 requires a determination of the Minimum Scour Elevation for the toes of the left bank and right bank protection. As discussed earlier, the General Minimum Scour Depth will vary with the Z-factor, which will vary with channel alignment.

Where the bank protection will be constructed within a relatively straight or mildly sinuous section of the channel and the unit discharge is calculated from the 100-year peak flow and the channel width, the recommended Z-factor is 1.25, applied to both banks.

Minimum Scour Elevations on the outside (concave) bank of bends will be greater than in straight sections. Consequently, adjustments for bend curvature will need to be incorporated when calculating Minimum Scour Elevations on the outside or concave bank of channels.

A number of different procedures have been developed to estimate scour depths for stabilized bends and Maynord (1996) provides a recent summary. Many of these procedures were developed for alluvial channels and are not applicable to the WWRSC/CVSC or other CVWD stormwater channels. Instead of adopting these procedures, CVWD provides the following adjustments to the Z-factor in Equation K3-2 to predict scour in bends:

- Mild bend or straight reach (radii of curvature to width ratios greater than 10): Z=1.25
- Moderate bend (radii of curvature to width ratios of 5 to 10), Z=1.5
- Severe or tight bend (radii of curvature to width ratios of 2 to 5), Z=1.75
- Right angle bend (radii of curvature to width ratios of less than 2) or direct impingement, Z= 2.0

The lower Minimum Scour Elevation is only applied to the outside or concave bank of a bend. On the inside bank, the Minimum Scour Elevation can be calculated with Z=1.0, given that scour here is unlikely. The lower elevation for the toe of the bank protection on the concave bank and the higher elevation on the convex bank will extend from the straight section upstream of the bend to the straight section downstream of the bend. At both ends, the lower and higher toes will transition to join existing protection at a 2H:1V slope. USACE (1991) and other publications provide details.

<u>Bank Protection at Bridges</u>

FHWA (Arneson et al 2012) states that the foundations for new bridges are to be designed to withstand scour for a flood greater than the design flood for passage. For example, if the bridge is to be designed to pass the 100-year flood, scour design is for the 200-year flood and structure stability is checked for scour at the 500-year flood. The scour design flood is set to a 200-year return period because it is likely that the bridge will experience a flood greater than the 100-year flood during its lifetime. This standard applies to all bridges constructed with Federal funding.

In recognition of the need for roads, bridges, and other facilities to remain operational during extreme floods; both for access and evacuation, CVWD has adopted a more conservative standard for Minimum Scour Elevations for bank protection in the vicinity of bridges than described in the previous section.

The procedures to meet this standard are based on the 100-year peak flow and the Blench regime equation but with a different Z-factor. In the vicinity of the bridge, The Maximum Scour Depth, d_s, is calculated by applying a Z_b-factor to the regime depth from Equation K3-1, as follows:

$$d_{bs} = Z_b * d_{fo} \qquad \text{(K3-4)}$$

In the above equation, Z_b varies with the alignment of the channel at the bridge, as follows:

- Mild bend or straight reach (radii of curvature to width ratios greater than 10): Z_b=1.5
- Moderate bend (radii of curvature to width ratios of 5 to 10), Z_b=1.9
- Severe or tight bend (radii of curvature to width ratios of 2 to 5), Z_b=2.2
- Right angle bend (radii of curvature to width ratios of less than 2) or direct impingement, Z_b= 2.5

Minimum Scour Elevations are calculated by subtracting the Maximum General Depth of Scour calculated in K3-4 from the 100-year water surface elevation. The lower Minimum Scour Elevation in bends is only applied to the outside or concave bank of a bend. On the inside bank, the Minimum Scour Elevation can be calculated with Z_b=1.0, given that scour here is unlikely.

CVWD will also consider maximum scour depths calculated for the 200-year peak flow to establish toe elevations at bridges.

There is very little guidance on how far the enhanced protection should extend upstream and downstream of the bridge. Various design guidelines (such as USACE 1991) quote Brown and Clyde (1989) who suggested that at severe bends the outer bank protection should extend one channel width upstream and 1.5 widths downstream of the tangent point. They also recommend that in straight channels, bank protection extends one width downstream for bridges that did not encroach on the channel and 4 widths downstream where there was a significant constriction. Unfortunately, most guidelines do not provide specific advice on the extent of protection required and none provide advice on the extent of enhanced protection at bridges that would meet CVWD objectives.

Scour depths are typically greater in narrow reaches than in wide reaches. Consequently, the required extent of protection is established as a multiple of channel depth rather than width. Width-to-depth ratios in the narrow parts of the WWRSC/CVSC at the 100-year peak flow are typically about 40 and this ratio was used to develop the following criteria for the extent of enhanced protection:

- Mild bends and straight reaches: Ten (10) 100-year flow depths upstream and 20 100-year depths downstream from the abutments on each bank;
- Moderate bends: Twenty (20) 100-year flow depths upstream and 30 100-year depths downstream from the abutment on the outside or concave bank. The inside or convex bank will meet the criterion for mild bends above;
- Severe bends or Right-Angle Bends: Forty (40)100-year flow depths upstream and 60 100-year depths downstream from the abutment on the outside or concave bank. The inside or convex bank will meet the criterion for mild bends above.

CVWD may require a greater extent of enhanced scour protection for some specific sites.

At the downstream and upstream ends of the enhanced protection, the toe elevation will rise (or fall) at a 2H:1V slope to meet the adjacent bank protection.

Pier Scour and Bank Protection

CVWD also requires that the proponent confirms that scour holes at piers or abutments (if in the channel) do not require lower toe elevations for the bank protection at the bridge. For piers close to the banks or abutments that project into the channel, the analysis will confirm that the scour cone associated with these features does not intersect or undermine the toe of the proposed bank protection. If so, the toe elevation of bank protection at the bridge section will need to be lowered appropriately.

For CVWD's purposes, the scour at the piers is to be calculated for the 200-year peak flow following adjustments of the bed for General Scour. CVWD will provide advice on determining appropriate hydraulic characteristics for the scour analysis.

Grade Control Structures

The grade control structures discussed here are those with inerodible cross-channel sills and include low water crossings as well as structures with upstream and downstream sloping concrete faces. They are also sometimes referred to as "grade stabilization structures" or "hard points". This guidance does not apply to drop structures, which typically consist of a vertical drop leading to a concrete floor and sill that are designed to contain a hydraulic jump. These structures are uncommon in CVWD's soft-bottom channels. It is recommended that a proponent contacts CVWD before designing or evaluating a drop structure.

CVWD treats grade control structures as "low head" structures where scour results from a submerged jet plunging over their downstream faces (Breusers and Raudkivi 1997; May et al 2002). The calculations focus on the Maximum Depth of Scour and the length of the scour hole that develops downstream of the structure. The Maximum Depth of Scour is used to define the Minimum Scour Elevation for the toe elevation of the downstream face (apron) of the structure and the protection on each downstream bank. The length of the scour hole defines the extent of the protection required on each bank downstream of the structure. Where a grade control structure is associated with a bridge, toe elevations will be lowered to provide a greater standard of protection, as described in the second following subsection.

Grade Control Structures
A variety of specialized publications describe procedures for calculating depths of scour downstream of grade control structures. The various equations produce quite different results, depending on the values selected for coefficients and exponents, and there does not appear to be reliable guidance on this topic. Given the uncertainties in these calculations, CVWD recommends a physical model for major projects, for non-standard designs, or where a serious hazard might potentially occur from scour downstream of the structure.

Previous grade control design studies for the CVSC relied on Bormann and Julien's (1991) equations for scour calculations. For typical structures, CVWD recommends calculating Maximum Depths of Scour with the Bormann and Julien (1991) equations for the 100-year peak flow, tailwater elevations, and the local bed material. The calculated depth of scour can be roughly checked with the Blench equation, assuming a unit discharge calculated from the width of the grade control crest, downstream water levels, and Z = 1.5 or more (Bruesers and Raudkivi 1991).

If the crest of the structure is skewed to the channel, a greater Maximum Depth of Scour will occur at the end of the crest that is further upstream. Adjustments of the depth of scour for skew are complex and discussions with CVWD are recommended.

On the upstream side of the grade control structure, the toe of bank protection will be set to the typical standard for bank protection. On the downstream side, the minimum toe elevation of the cutoff wall and the downstream bank protection will be determined from the Maximum Depth of Scour. The length or extent of the bank protection will be defined by the typical geometry of the scour hole associated with the grade stabilization structure.

Based on observations in Bormann and Julien (1991) and D'Agostino and Ferro (2004), the geometry of the scour hole will be a function of the 100-year Maximum Depth of Scour, S_d. The longitudinal scour hole geometry is:

- Minimum Distance to Bottom of Hole = $2S_d$ to $3S_d$
- Typical Distance to Bottom of Hole = $5S_d$ to $6S_d$
- Typical Distance to Downstream lip of Hole = $10S_d$ to $12S_d$

The length of protection on each bank will be 10 to 12 times the Maximum Depth of Scour, as discussed above. For skewed structures, the minimum toe elevation and the extent of protection may differ on each bank. At the downstream end of the protection for the scour hole, Minimum Scour Elevations will transition to meet the toe of the existing bank protection at a 2H:1V slope.

Grade Control Structures at Bridges
Where the crest of a grade control structure is located with 200 feet upstream of downstream of a bridge, the design is revised as follows:

- Upstream of the crest of the grade control structure the Minimum Scour Elevations for the design of bank protection will be the same as calculated for bank protection distant from a bridge. This reflects the low potential for significant scour upstream of grade control structures. Where a bridge lies upstream of the grade control structure, the toe of the bank protection will meet the standard for grade control structures rather than the enhanced standard for bridges.
- The toe of the upstream cutoff wall of the structure will be set to the Minimum Scour Elevation for the bank protection.
- The Maximum Depth of Scour downstream of the grade control structure will be increased by 25% and this revised Depth of Scour will be used to calculate Minimum Scour Elevations for the toe of the downstream cutoff wall and the adjacent bank protection.
- The extent of the bank protection downstream of the grade control structure will be calculated from the Maximum Depth of Scour multiplied by 1.25 and the typical distances above.

CVWD recommends that a scour profile is developed for each bank by plotting Minimum Scour Elevations for bank protection, Minimum Scour Elevations for bank protection at a bridge and Minimum Scour Elevations for a grade control structure at appropriate stations. The final profile then is the lowest Minimum Scour Elevation at the various stations.

Utility Crossings

Minimum Scour Elevations for utility crossings of soft-bottom channels are based on the procedures for bank protection described above or the procedures for bridges, grade control or other structures. Guidance for depth of the crown of the crossing below the Minimum Scour Elevation is provided in Guideline K-2.

Other Instream Structures

CVWD will provide guidance for other instream structures on a case by case basis.

K-3.12 Submissions

The scour analyses for a particular project will be incorporated in a Hydraulic Design Report or in the Existing and Project Condition Reports submitted by a proponent. CVWD requires that a combined minimum scour elevation profile be prepared for both banks over the project reach for existing and project conditions. The profiles will include scour from Incision, General Scour and Local Scour at structures (if required) to provide minimum construction elevations for bank protection and other features. The project profiles will be compared to existing condition scour profiles, profiles of existing bank protection toe elevations and elevations of other features constructed within the channel.

K-3.13 References

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APPENDIX K-3-A
FIGURE FROM PEMBERTON AND LARA (1984)
CHART FOR ESTIMATING F_{B0} (AFTER BLENCH 1969)

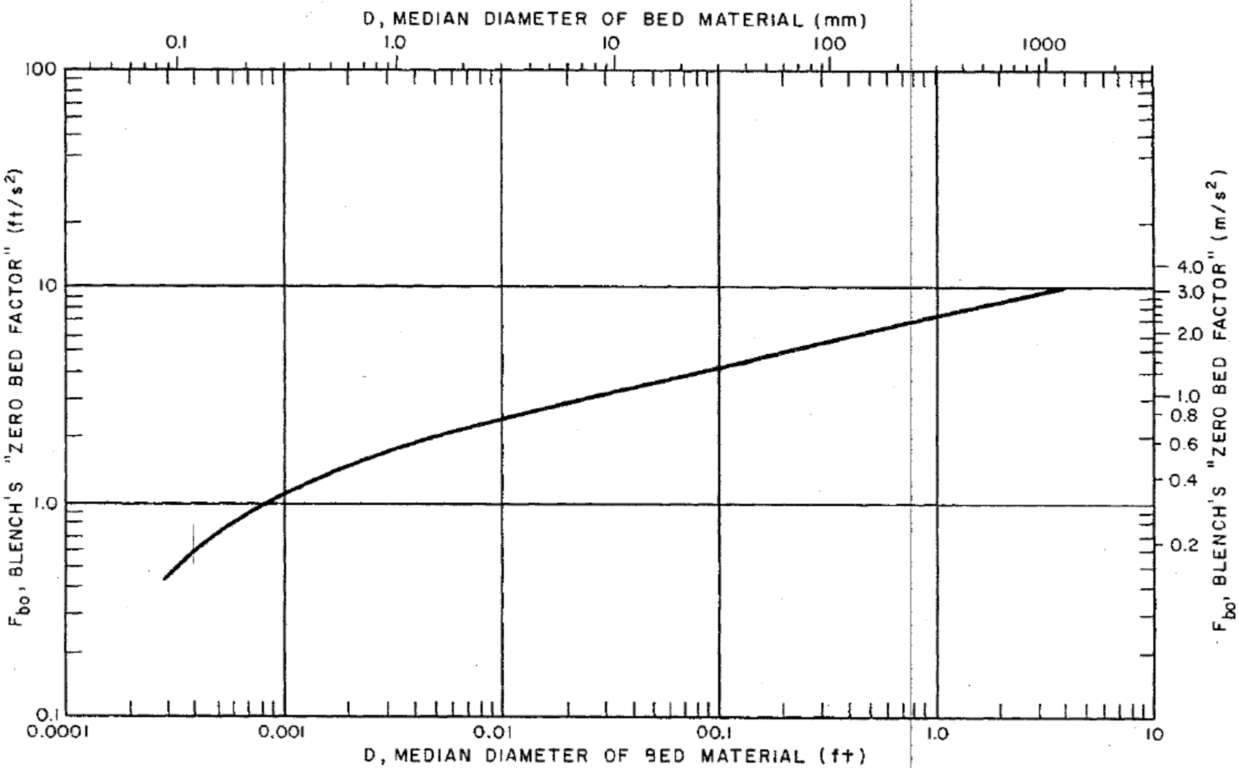

CHART FOR ESTIMATING F_{bo} (AFTER BLENCH)

Figure 9. - Chart for estimating F_{bo} (after Blench, 1969).