**SSCAFCA Criteria Manual**

Volume 2: Hydraulics

*Part 1: Open Channel*

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# 1 Document Revision History

SSCAFCA Board of Directors Approval Date: ________________________________

Revisions:

| Version | Date | Description |
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| | | |

# 2 Introduction

***Volume 2: Hydraulics – Part 1: Open Channels*** provides *Open Channel* design criteria and standards required by SSCAFCA. There may be other requirements by local, state, and federal agencies in addition to the criteria provided herein.

In general, the criteria set forth in this Chapter must be met for SSCAFCA to consider ownership and/or maintenance responsibility of open channel infrastructure.

*This is a working document. SSCAFCA welcomes feedback, suggestions, and corrections to the information within. SSCAFCA may periodically update the document, and the most current version will be available on SSCAFCA's website (https://www.sscafca.org).*

# 3 General Design Guidance

Open Channels (arroyos) within SSCAFCA's jurisdiction are ephemeral and flow only in response to intense rainfall events over the contributing watershed. In general, the upstream portions of SSCAFCA's watersheds are undeveloped, while the lower portions contain urban and semi-urban development.

## 3.1 Joint Use Considerations

Opportunities for providing quality of life and trails (non-flood control) elements may be considered with the design of open channel facilities within SSCAFCA's jurisdiction. These "joint use" facilities may include parks, walking trails, utility alignments, open space, etc. The inclusion of non-flood control uses must in no way impair or delay the implementation of the drainage / flood control function of any facility.

When joint use facilities are implemented, maintenance responsibilities for each use must be defined and formalized in either an agreement or plat. If easements are required to allow other agencies access to SSCAFCA property, a plat is required. SSCAFCA maintains the flood control function of facilities, while other agencies are responsible for the maintenance of the non-flood control elements.

SSCAFCA's *Quality of Life Master Plan* and *Maintenance Access & Trails Master Plan* outline some of SSCAFCA's objectives for implementation of other uses in flood control facilities. These master plans are available on SSCAFCA's Resources webpage.

## 3.2 Channel Geometry Considerations

Open Channel geometry selection is dependent on many factors, but the selected design should comply with applicable *SSCAFCA Watershed Management Plans*, *Quality of Life Master Plan, and Maintenance Access & Trails Master Plan*. SSCAFCA's technical staff is available to assist in open channel geometry selection.

See Section 4.2 for hydraulic engineering guidance.

A minimum Open Channel bottom width of 10-feet is required for maintenance access.

## 3.3 Channel Lining Materials

In January 2022, the SSCAFCA Board of Directors adopted Resolution 2022-05: Arroyo Bed Conservation Policy. This Resolution includes four statements:

1. Conservation of natural arroyo beds as corridors of infiltration and groundwater recharge shall be incorporated as an integral component of flood control systems owned and operated by SSCAFCA.
2. Construction or installation of impermeable surfaces in or on natural arroyo beds shall be considered the least desirable option for management of floods or flood control systems.
3. Any proposal to construct or install impermeable surfaces in or on natural arroyo beds owned or operated by SSCAFCA shall be required to receive approval to proceed by the SSCAFCA Board of Directors at a duly published Board Meeting.
4. The Drainage Policy, dated December 16, 2021, shall be amended to adopt this Resolution.

See Table 1 below. *In general, the strategic combined use of bank armoring and grade control structures is preferred to fully lining Open Channels.* In cases where full channel lining cannot be avoided, or for newly constructed channels that do not replace an existing arroyo, both impermeable and permeable materials are acceptable. However, fully lined impermeable channels will require SSCAFCA Board of Directors approval per the above referenced Resolution and Policy.

Use of concrete rubble in the channel banks is prohibited.

*Table 1: Open Channel Material Selection Guide*

| Lining Material | Benefit | Demerit | Installed Cost ($-$$$) | Max. Slope | Minimum Material Thickness | Commonly-Used Specifications |
|---|---|---|---|---|---|---|
| Earth<br>*(Native Soil)* | • Promotes infiltration.<br>• Suitable when a natural aesthetic is desired.<br>• Lowest cost to construct. | • Larger footprint requires more right-of-way.<br>• Lateral and vertical migration will occur.<br>• Lateral Erosion Envelope (LEE) analysis required.<br>• Low Allowable Velocity: 3 ft/s or less. | $ | 6:1 | N/A | SSCAFCA 1510 |
| Dumped Riprap | • Promotes Infiltration.<br>• Suitable when pervious armoring is desired.<br>• Suitable when rock source is available.<br>• Suitable when naturalistic aesthetic is desired.<br>• Flexible material, can move over time | • Labor intensive.<br>• Riprap sizing calculations required (Dumped only).<br>• Requires installation of Filter Fabric or Gravel Filter. | $ - $$ | 2:1 | No less than 2 x D50 | APWA 109<br>NMDOT 602 |
| Gabion Baskets | • Promotes Infiltration.<br>• Suitable when pervious armoring is desired.<br>• Good option where steep slopes are required.<br>• Suitable when rock source is available.<br>• Suitable when naturalistic aesthetic is desired. | • Labor intensive.<br>• Larger material quantity required.<br>• Overall footprint increases as height of protection increases.<br>• Requires installation of Filter Fabric or Gravel Filter.<br>• Relatively high installation cost. | $$ - $$$ | near vertical, spec. dependent | N/A | APWA 109<br>NMDOT 602 |
| Wire-Enclosed Riprap<br>*(AKA Reno Mattress, Gabion Mattress)* | • Promotes Infiltration.<br>• Suitable when pervious armoring is desired.<br>• Suitable when rock source is available.<br>• Suitable when naturalistic aesthetic is desired.<br>• Flexible material, can move over time | • Labor intensive.<br>• Requires installation of Filter Fabric or Gravel Filter.<br>• Relatively high installation cost. | $$ - $$$ | 1:1 in stepped applications<br><br>2:1 in all other applications | Varies.<br><br>Generally, 1 foot min. thickness | APWA 109<br>NMDOT 602 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Erosion Control Geotextile | • Promotes Infiltration.<br>• Suitable when pervious armoring is desired.<br>• Promotes vegetation growth through material.<br>• Easily transportable.<br>• Shortened time of installation.<br>• Flexible material, can move over time. | • Not suitable for vehicle traversing, material can tear.<br>• Shear stress resistance is not well documented across manufacturers.<br>• UV stabilization is required.<br>• Actual service life is unknown. | $$ | Steeper than 2:1 with anchors | Per manufacturer | Per manufacturer |
| Reinforced Concrete & Shotcrete | • Most resistant to very high velocities.<br>• Good option when space is limited.<br>• Robust, long proven service life.<br>• Can add color to improve aesthetics. | • Requires SSCAFCA Board Approval if fully-lined<br>• Impervious, no infiltration<br>• Cut-off walls (to scour depth) are required to prevent undermining.<br>• Potential for Alkali-Silica Reaction (ASR). | $$$ | Vertical | 6 inches | APWA 101<br>NMDOT 511<br>NMDOT 519<br>CORR 535 |
| Soil Cement | • Utilizes on-site soil as main ingredient.<br>• Resistant to high flow velocities.<br>• Visually pleasing aesthetic.<br>• Long service life | • Requires SSCAFCA Board Approval if fully-lined<br>• Impervious, no infiltration<br>• Requires large production quantity to be cost-effective.<br>• Impervious, no infiltration<br>• Number of contractors qualified to install soil cement is limited.<br>• Requires large quantity of on-site excess soil.<br>• Subject to more weathering and abrasion than concrete. | $$-$$$ | 1:1 in stepped applications | 1 foot *(Lift Thickness)* | CORR 540 |
| Grouted Riprap | • Resistant to high flow velocities.<br>• Passively dissipates flow energy.<br>• Visually pleasing aesthetic. | • Limited successful applications in SSCAFCA's jurisdiction.<br>• Proper installation requires an experienced & qualified contractor.<br>• Actual service life is unknown. | $$$ | 2:1 | Varies | NMDOT 602 |

## 3.4 Boundary Setback Requirements

A minimum of 5-feet must be observed between the channel and the SSCAFCA Right-of-Way (ROW) boundary. This setback requirement is shown in Figure 1 and does not consider the width of maintenance access roads, turnarounds, etc. SSCAFCA may waive this requirement if providing the minimum setback distance is not achievable.

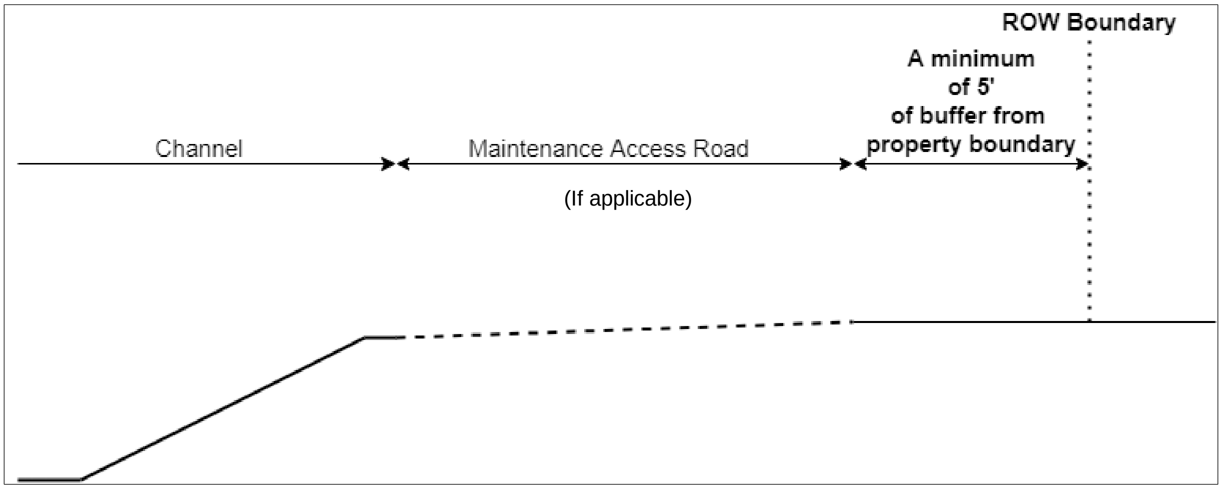


*Figure 1: Setback Requirements for Open Channels*

## 3.5 Maintenance Access Road

Access roads must be constructed along Open Channels for operations and maintenance access.

See SSCAFCA's Resources webpage for Maintenance Access Road details.

The designer shall ensure that all road alignment curves have an appropriate radius to provide access for the project's anticipated maintenance activities. Because the nature of maintenance activities for each project varies widely (as do the maintenance vehicles required for such), discussions with SSCAFCA early in the design process is highly encouraged.

If an access loop for ingress/egress is not provided, a turnaround shall be provided at all dead ends of the maintenance access road. The target design radius for turnarounds (or cul-de-sacs) is 45 feet. Realizing that available ROW on each project varies, if the target turnaround radius cannot be provided, discuss with SSCAFCA an acceptable alternative.

If a maintenance access road is longer than one-half mile in length, provide a 14-foot wide, 35-foot long turnout every 1300-feet to allow oncoming maintenance vehicles to pass one another, or to provide a staging area for maintenance activities.

*Figure 2: Channel Degradation & Damaged Maintenance Access Ramp.*

## 3.6 Ramps

Ramps from the maintenance access road to the channel bottom must be provided to allow for operations and maintenance access. Unless site conditions prohibit, ramps shall be oriented in the direction of flow, meaning the downhill direction of the ramp is oriented downstream.

The ramps shall be constructed of reinforced concrete extending from the Design Storm water surface elevation (plus freeboard, superelevation, and roll wave heights) to the calculated scour depth elevation. If not hardened, ramps will erode during storm events and render the channel inaccessible (Figure 2).

Ingress and egress ramps are required for each segment of channel; if the channel contains grade control structures or other in-line features that limit access, additional ramps shall be provided so that all segments of the channel can be accessed.

See SSCAFCA's Resources webpage for Ramp details.

*Figure 3: Maintenance Access Road & Ramp Configuration.*

## 3.7 Gates

Unless otherwise specified by SSCAFCA, gates shall be provided where access roads intersect with property lines.

See SSCAFCA's Resources webpage for Gate details.

At locations where maintenance access roads intersect non-residential roads (i.e. roads classified as arterial or collector roads, etc.), the access gate must be installed offset from the non-residential road to allow maintenance vehicles to pull off and not block traffic while accessing the facility. A base course driveway shall be provided between the non-residential road and the gate.

## 3.8 Signage

A minimum of 2 facility signs are required to be installed with each open channel project.

See SSCAFCA's Resources webpage for sign details.

Ideally, signs are placed at points of ingress/egress, or in locations most visible to the public. Confirm signage locations with SSCAFCA prior to final placement.

## 3.9 Fencing & Fall Protection

All open channel facilities shall be fenced using 5-strand Barbless Wire Fencing.

See SSCAFCA's Resources webpage for 5-strand Barbless Wire Fencing details.

When possible, fencing should be provided along SSCAFCA's ROW boundary adjacent to the channel to prevent unwanted access to the channel. Generally, SSCAFCA installs perimeter fencing 6-inches inside SSCAFCA's property line.

Post & Cable Fencing can be used to restrict access into/across an open channel by installing it perpendicular to flow.

See SSCAFCA's Resources webpage for Post & Cable Fencing details.

Open channel designs incorporating any vertical walls (including headwalls, wingwalls, etc.), shall incorporate **fall protection** (pipe rail, etc.) on or in front of the vertical drop per applicable OSHA safety regulations.

## 3.10 In-channel Water Quality Treatment

Due to the rarity and wide range of design options for In-Channel Water Quality Treatment, consult with SSCAFCA prior to considering this option. Water Quality is discussed in the *SSCAFCA Criteria Manual – Volume 3*.

## 3.11 Offsite Runoff – Historic Flow Path

Offsite runoff historically reaching the proposed open channel must be preserved. Open channel designs shall ensure offsite runoff is discharged into the channel in a controlled manner (i.e. concrete rundown, channel side weir, piped conveyance, etc.).

# 4 Technical Design Guidance

## 4.1 Design Storm

The Design Storm is defined as the 100-year, 24-hour recurrence interval storm. The Design Storm will guide the design for all open channel hydraulic analyses. Hydrologic information may be obtained from the applicable SSCAFCA *Watershed Management Plan* or calculated using the *SSCAFCA Criteria Manual – Volume 1: Hydrology*.

To ensure compliance with local municipalities and county jurisdictions, the designer shall verify all hydrologic land use assumptions with the applicable agency and SSCAFCA prior to proceeding with the open channel design.

## 4.2 Hydraulic Analysis

1-dimensional (1D) and 2-dimensional (2D) hydraulic models are acceptable methods for hydraulic analysis of open channels. The designer should obtain SSCAFCA approval of the hydraulic analysis methodology prior to beginning this effort.

### 4.2.1 Open Channel Geometry

#### *4.2.1.1 Alignment*

In general, naturalistic Open Channel alignments should follow the historic flow path.

To the greatest extent possible, Open Channel alignments shall avoid sharp curves and multiple curves in a short distance. If it is not possible, special attention to roll wave disturbances and superelevation is required.

#### *4.2.1.2 Height*

The minimum Open Channel height is determined by four factors:

1. Water Surface Elevation
2. **Freeboard**
3. **Superelevation**
4. **Roll Waves**

#### *4.2.1.3 Longitudinal Slope*

Unlined Open Channel longitudinal slopes shall be determined using the *SSCAFCA Sediment and Erosion Guide (SEDG) - Section 3.4.3.1 - Equilibrium Slope* calculations.

Lined Open Channel longitudinal slopes can vary widely and are determined by engineering analyses specific to the project.

For both lined and unlined open channels, the design longitudinal slope shall ensure that existing and proposed connecting drainage infrastructure is located a minimum of 6-inches above the channel invert, unless otherwise approved in writing by SSCAFCA.

### 4.2.2 1D Model Cross Section Placement

For guidance on placing cross sections, see *Federal Highway Administration – Hydraulic Engineering Circular No. 14 (HEC-14)* or the applicable version of the HEC-RAS *User's Manual*.

When modeling in 1D, the designer must place cross sections at all locations of change (channel top/bottom widths, side slope angles, longitudinal slopes, material roughness of bank/channel lining, inline structures, inflow locations, etc.) so that the channel geometry is accurately reflected.

### 4.2.3 Channel Transitions

A channel transition is defined as the change of upstream and downstream sections in geometry, longitudinal slope, channel material changes, flow regimes, etc.

Transition designs shall include energy dissipation to release flows in a non-erosive manner.

The designer shall consider the following subsections when a channel transition is required.

#### *4.2.3.1 Transition Design - Earthen to Lined Channel*

The earthen channel geometry shall match the lined channel geometry as closely as possible at the point of transition.

The maximum allowable channel bottom width transition from an earthen to lined channel is 1 to 7.5.

Wing walls and/or other guide structures must be provided to direct flow from the earthen channel to the lined channel entrance.

The upstream end of the lined channel must include a cutoff wall below grade to a depth of 1.5 times the design flow depth or 3-feet, whichever is greater.

Erosion protection, typically riprap, shall extend a minimum of 12-feet upstream of the lined channel and cover the full open channel width.

#### 4.2.3.2 Transition Design - Lined to Earthen Channel

The downstream end of the lined transition shall include energy dissipation and a cutoff wall with depth equal to the computed scour depth extending the full width of the lined channel section. The downstream cutoff wall shall be no less than 5-feet deep.

If a transition from lined channel to earthen channel is required, use the following maximum ratios of *channel bottom width* transitions:

*Table 2: Bottom Width Transition Ratios – Lined to Earthen Channels*

| Velocity, ft/s | Transition Ratio |
|---|---|
| 0-15 | 1:10 |
| 16-30 | 1:15 |
| 31-40 | 1:20 |

### 4.2.4 Froude Number

When Froude Number is below 1, the flow is in the **subcritical** state. The flow with Froude Number of 1 is at its **critical** state and unstable, causing large shifts in flow depth. When Froude Numbers are greater than 1, the flow is in the **supercritical** state.

Where possible, channel designs with Foude numbers between 0.87 and 1.13 shall be avoided.

Although it is desirable to design a channel for a Froude Number under 2.0, this is not always possible in many parts of SSCAFCA's jurisdiction due to steep terrain.

### 4.2.5 Shear Stress

Shear stress, also known as tractive force, is the force of friction from water acting on the surface of the flow path. The computed shear stress along the channel shall be used to help determine the appropriate channel lining material. Shear stress can be calculated manually or using hydraulic analysis software (HEC-RAS or similar). Shear stress is manually calculated as follows:

$$\tau_o = \gamma R S_e$$

Where:

$\tau_o$ = Shear stress, lb/ft$^2$

$\gamma$ = Unit weight of water, 62.4 lb/ft$^3$

$R$ = Hydraulic radius ft

$S_e$ = Energy slope, ft/ft

*Source of Equation: SEDG*

### 4.2.6 Hydraulic Jump

A hydraulic jump occurs when the flow regime changes from supercritical to subcritical.

Locations of hydraulic jumps are a concern for scour and must be identified in the hydraulic analysis to provide sufficient channel height and scour protection.

Hydraulic jump locations can be determined manually or using hydraulic analysis software (HEC-RAS or similar). Submerged hydraulic jumps must be avoided as much as practical.

**For trapezoidal channels**, the length of the jump can be manually calculated using the following equation:

$$L = 5D_2\left(1 + 4\left(\frac{t_2 - t_1}{t_1}\right)^{0.5}\right)$$

Where:

$L$ = Length of hydraulic jump, ft

$t_1$ = Width of water before jump, ft

$D_2$ = Sequent depth after jump, ft

$t_2$ = Width of water after jump, ft

**For rectangular channels** (Froude Numbers between 2 and 20), the length of the jump is given by the following equation:

$$L = 6.9(D_2 - D_1)$$

Where:

$L$ = Length of hydraulic jump, ft

$D_1$= sequent depth before jump at Section 1, ft

$D_2$= sequent depth after jump at Section 2, ft

## 4.3 Freeboard, Superelevation, and Roll Waves

There are 3 height-related hydraulic factors that shall be considered in addition to the height required to contain the Design Storm: **Freeboard, Superelevation,** and **Roll Waves**.

If the combined calculated height for Freeboard, Superelevation, and Roll Waves yields a total less than 2-feet, the designer shall provide 2-feet of channel lining above the calculated WSEL.

### 4.3.1 Freeboard

Freeboard is computed as follows:

$$FB = 0.25\left(y + \frac{V^2}{2g}\right)$$

Where:

$FB$ = freeboard, ft

$y$ = depth of flow, ft

$V$ = average flow velocity, ft/s

$g$ = gravitational acceleration, 32.2 ft/s$^2$

*Source of Equation: Maricopa County Drainage Design Manual-Hydraulics*

- For subcritical flow, use the larger of 1-foot or the result of the above freeboard equation.
- For supercritical flow, use the larger of 2-feet or the result of the above freeboard equation.

**For channels with a natural channel bed with no lining**, verify the Froude number along the channel and use the greater value of $0.027V^2$ or the result of above freeboard equation. The designer is referred to the *Maricopa County Drainage Design Manual - Hydraulics* - *Section 6.5.4* for more information.

### 4.3.2 Superelevation

Curving open channel alignments experience a rise in WSEL around curves due to centrifugal force. The superelevation height around curves shall be calculated using the following equations:

*Table 3: Superelevation Equations*

| Flow Regime | Trapezoidal Channel | Rectangular Channel* |
|---|---|---|
| Subcritical | $S = 1.15\, V^2 \dfrac{b + 2zD}{2gr}$ | $S = \dfrac{V^2 b}{2gr}$ |
| Supercritical | $S = 1.3\, V^2 \dfrac{b + 2zD}{2gr}$ | $S = \dfrac{V^2 b}{gr}$ |

*If the channel alignment includes a ***spiral transition curve***, follow guidance provided in USACE Engineering Manual 1110-2-1601, 1994.

*Where:*
$S$ = superelevation, ft
$V$ = velocity, ft/s
$z$ = cotangent of bank slope, dimensionless
$b$ = channel bottom width, ft
$D$ = depth of water, ft
$g$ = acceleration of gravity, 32.2 ft/s$^2$
$r$ = radius of the curve, ft

### 4.3.3 Roll Waves

Roll waves are surge waves that are known to occur when Froude Number is 2.0 or greater and the longitudinal channel slope is greater than the quotient of 12 divided by Reynolds Number.

Conditions that lead to roll waves should be avoided. If roll waves are unavoidable, appropriate channel wall heights may be determined using *Brock, R. R. (1967). Development of Roll Waves in Open Channels. California Institute of Technology*.

## 4.4 Channel Velocity Considerations

The ideal channel velocity should target a condition where sediment is neither deposited in, nor eroded out of the channel.

The theoretical maximum allowable channel velocity is determined by the proposed channel material's ability to resist the shear forces experienced during the design storm.

Generally, a channel flow velocity of 25 ft/s is the maximum advisable design velocity, regardless of channel lining material. The minimum advisable design velocity is 3 ft/s, regardless of channel lining material.

## 4.5 Scour Analysis

Designers are encouraged to read SEDG - *Section 3.4.5.1 - Bank Erosion Processes*.

Local scour is discussed in the SEDG - *Section 3.5.*

A scour analysis must be included in all open channel designs to identify the extent of below-grade protection required to mitigate scour damage from the design storm. In cases where a proposed drainage system is connecting to an existing SSCAFCA open channel, a scour analysis will be required for both the connecting infrastructure and the existing channel.

## 4.6 Energy Dissipation

Energy dissipation is required for all proposed SSCAFCA open channels and any proposed discharge to SSCAFCA open channels where velocities exceed the shear force resistance of the receiving channel material. Energy dissipation features can come in many different forms and materials.

In addition to the *SEDG*, commonly referenced Energy Dissipation design guides include:

- *Mile High Flood District - Criteria Manual - Volume 2 - Chapter 9 - Hydraulic Structures*
- *Federal Highway Administration – Hydraulic Engineering Circular No. 14 (HEC-14) Hydraulic Design of Energy Dissipators for Culverts and Channels (2006)*
- *Bureau of Reclamation – Engineering Monograph No. 25 – Hydraulic Design of Energy Dissipators, Eighth Printing (1984)*

## 4.7 Bank Protection Around Channel Curves

In addition to the superelevation considerations around curves, bank protection must be provided on the outside of curves from the Point of Curvature (PC) well beyond the Point of Tangency (PT). The additional length of protection necessary beyond the PT is calculated using the following equation:

$$L_p = \alpha\left(\frac{R^{7/8}}{n}\right)$$

Where:

$Lp$ = Length of protection, ft
$\alpha$ = Unit conversion constant (0.6 for English Units)
$R$ = Hydraulic radius of the channel, ft
$n$ = Manning's roughness for lining material in the bend

*Source of Equation: HEC-15*

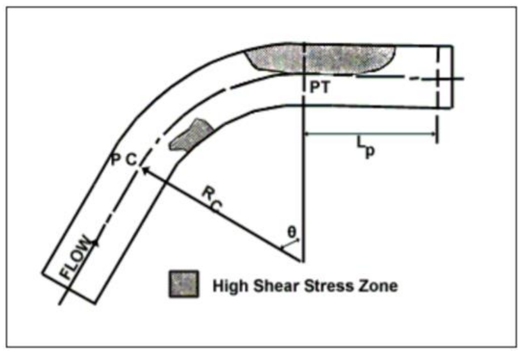


*Figure 4: High Shear Stress Zones in a Channel Curve*

## 4.8 Confluence with Another Channel

Flowrates of 25% or more of the main channel flow must be introduced to the main channel by a side channel hydraulically similar to the main channel. The velocity and depth of the flows in the side channel when introduced into the main channel must be matched to within 1-foot of velocity head and to within 20% of the flow depth for both the 10-year and 100-year design flowrates.

The junction angle between the design channel and the receiving channel shall be 90 degrees or smaller, and the design channel shall not point to the receiving channel in a direction oppositional to flow. If the confluence must be "T"- shaped or the converging angle between the channels is greater than 45 degrees, consult with SSCAFCA on protecting the banks through the confluence.

## 4.9 Levees

If the proposed channel creates a 'levee' or 'levee system' as defined by 44 Code of Federal Regulations Section 59.1, the engineer must meet requirements by applicable federal and/or state agencies and obtain certification from such agencies. The design and certification efforts shall be coordinated with the local floodplain administrator and SSCAFCA. Requirements of applicable state and/or federal agencies must be satisfied prior to SSCAFCA acceptance.

# 5 Naturalistic Channel Design

A naturalistic channel is defined as a channel that has an unlined/natural channel bottom. Naturalistic channels may include components like grade control structures and/or bank stabilization improvements. When designing or modifying a naturalistic channel, consider the following in addition to the open channel requirements previously discussed in this section.

## 5.1 Naturalistic Channel Stability

A stable naturalistic channel is often referred to as "a channel in equilibrium". *SEDG* shall be the primary reference for channel stability calculations. A channel at equilibrium slope will theoretically operate in an equal balance of sediment supply and sediment carrying capacity, reducing erosion (channel degradation) and sediment deposition (channel aggradation).

Prior to designing a new or modifying an existing channel, a field visit is strongly recommended. In most cases, a field visit will inform the designer whether the existing channel is in a state of aggradation or degradation, and therefore inform the required design approach.

## 5.2 Aggradation & Degradation

Figure 5 shows a concrete storm drain energy dissipator outfall to a naturalistic channel. The 6-foot-tall structure is buried and completely ineffective at discharging storm water. The channel bottom has risen vertically by several feet, in this case, due to heavy sediment-laden flow in a channel with a longitudinal slope very near zero. This condition is called **aggradation**. Aggradation reduces the flood carrying capacity of the channel and prevents channel connections from functioning as designed.

*Figure 5: Buried Energy Dissipator in an Aggraded Channel*

On the contrary, the condition where a channel's bed material is being eroded away (invert dropping vertically), is called **degradation**. The channel shown in Figure 6 has lost a significant amount of soil since the culvert and energy dissipation structure were constructed. In this case, urban (sediment-starved) runoff from the upstream neighborhood has caused the receiving naturalistic channel to degrade and the structure is now compromised.

A naturalistic channel in a degradational state often undermines and threatens connecting structures, bank lining, maintenance access ramps, and (in extreme cases) critical roadway or utility infrastructure. As a result of channel degradation, the channel will often also become laterally unstable due to the channel bed eroding significantly lower than the banks. In naturalistic channels, the channel bottom is unlined. The designed channel bed must be at the equilibrium slope. If the channel slope is set at equilibrium, it is assumed that the sand bed will receive sediment from upstream and be filled back at the same rate it is removed from the channel bed.

*Figure 6: Loss of Sediment in a Degraded Channel*

Channel degradation may cause extensive damage to bridges and other structures due to the undermining of their foundations. For degrading naturalistic channels, grade control and bank protection are integral pieces to consider in designing solutions.

## 5.3 Erosion Setback / Lateral Erosion Envelope

Erosion setback distances along arroyos in the SSCAFCA jurisdictional area are established based on the maximum lateral migration distance that can be expected over the next 30-50 years. The Lateral Erosion Envelope (LEE) is the area enclosed by the erosion setback distance lines ("LEE lines") calculated for each side of the channel.

The "LEE Lines" are developed to define the boundary along an arroyo or drainageway that would have a possibility of being disturbed by erosion, scour, or lateral migration of a natural channel by storms up to and including the 100-year storm.

See *SEDG Section 3.4.5*, which includes an example problem in Appendix E.

## 5.4 Lateral Migration

Lateral migration is a process that occurs when flow in the channel erodes sediment from one bank and deposits it on the opposite bank. Lateral migration can happen in both vertically stable and vertically unstable reaches. The lateral migration process is described in detail in *SEDG Section 3.4.5*.

Figure 7 and Figure 8 below show aerial images of the same naturalistic channel taken 30 years apart. These figures indicate that both the main channel and tributaries have experienced lateral migration over the years. If the system is not stabilized, the erosion process will continue, creating encroachment issues with adjacent land and utility owners.


*Figure 7: 1991 Aerial Imagery of the Black Arroyo*

*(Photo credit: Google Earth, visited 11/16/2022)*


*Figure 8: 2021 Aerial Imagery of the Black Arroyo*

*(Photo credit: Google Earth, visited 11/16/2022)*

## 5.5 Channel Bank Stabilization

The need for channel bank stabilization is determined by many factors including: a desire to protect adjacent land or utilities or a desire to mitigate channel migration outside of existing ROW. In any case, Naturalistic Channel design must include a LEE analysis to determine the extent of lateral erosion. Once the LEE has been determined, the designer can decide if Channel Bank Stabilization is needed. See *SEDG Section 3.4.5* for LEE considerations and calculation.

Channel bank stabilization is most successful when grade control structures are constructed in conjunction with bank armoring. The bank stabilization provides the lateral (horizontal) protection of the open channel, while the grade control structures provide vertical stability.

*Figure 9: Concrete-lined Bank Failure Due to Erosion & Degradation*

*Figure 10: Shotcrete-lined Bank Failure Due to Erosion & Degradation*

### 5.5.1 Bank Stabilization Materials

Channel bank stabilization materials and general design requirements are discussed in Table 1 and Table 4, respectively.

Naturalistic open channels must provide bank stabilization when the shear stress exceeds the channel material's ability to resist. In general, this velocity is approximately 3 ft/s for sandy-bottom channels in

SSCAFCA's jurisdiction.  Refer to Section 4.2.5 of this chapter. Channel transitions and/or cut-off walls must be provided at the upstream and downstream ends of the bank stabilization measures.

*Table 4: Stabilization Materials - General Requirements*

| Stabilization Material | General Design Requirements *(additional info in Table 1)* |
|---|---|
| **Riprap** | Size rock using MHFD Vol. 1 – Chapter 8, Section 8.1 – Riprap Sizing. |
| | Filter fabric and/or gravel filter must be used below riprap lining. |
| | Verify channel shear stress against the size of the rock. |
| | Minimum riprap thickness shall be 2 times $D_{50}$. |
| **Erosion Control Geotextile** | Geotextile must consider site soils and be installed per manufacturer specification, as approved by SSCAFCA. |
| | The terminus of the fabric shall be properly keyed into the ground in all directions per manufacturer's specification, as approved by SSCAFCA. |
| **Soil Cement** | Geotechnical testing of source materials /soil properties. |
| | Specification which matches soil properties found in geotechnical testing. |
| | Height of soil cement lifts are limited to 12-inches. |
| | A cut-off wall is to be constructed normal to the bank slope at upstream and downstream terminus of soil cement installation. or tie in to existing hardened structure. A cut-off wall depth is determined based on scour calculations. |
| **Concrete and Shotcrete** | A 'thickened edge' must be provided at locations adjacent to vehicle or pedestrian movement and at the top of all channel or bank lining applications. |
| | If the channel is anticipated to have supercritical flow, minimize bends and curves to prevent waves. |
| | If bank slopes are steeper than 2:1, the bank protection shall be designed by structural engineer and implement Fall Protection. |

### 5.6 Grade Control Structures (Drop Structures)

Grade control structures (GCS) are essential for controlling the vertical stability in open channels, while lateral movement of open channels is mitigated through bank stabilization. Both sloping and vertical grade control structures are used within SSCAFCA's jurisdiction. See *SSCAFCA Criteria Manual – Vol. 2: Hydraulics, Part X* for design guidance of GCSs.

In general, the maximum GCS drop height shall be limited to 5-feet for safety reasons.

A low flow notch, sized for 2% of the 100-year flowrate, shall be added to the center of all GCS.

It is necessary to provide energy dissipation directly downstream of all GCS to mitigate flanking, erosion, scour, and other hydraulic forces. Fall Protection design may also be required.

# 6 Concrete-Lined Channel Design

Per SSCAFCA's Arroyo Bed Conservation Policy (*Board of Directors Resolution 2022-05*), any proposal to construct or install impermeable surfaces in or on natural arroyo beds that are owned or operated by SSCAFCA shall be required to receive approval to proceed by the SSCAFCA Board of Directors at a duly published Board Meeting.

Provide concrete open channel lining thickness & compressive strength as shown below:

*Table 5: Channel Lining Thickness & f'c Requirements*

| Flowrate, cfs | Lining Thickness, in | Compressive Strength (f'c), psi |
|---|---|---|
| 500-1000 | 6 | Minimum 3,000 |
| 1000+ | 8 | Minimum 3,000 |
| If velocity is greater than 25 fps | Add 2-inches above rebar | |

Concrete lining shall be provided with a "tined" (roughened) finish. Tined finish shall be oriented perpendicular to flow. For channel velocities of 25 ft/s or greater, an additional 2-inches of sacrificial concrete is required above the minimum required thicknesses provided above. SSCAFCA approval of an open channel design with flow velocities in excess of 25 ft/s is required.

Expansion joints are to be installed where new concrete lining is connected to a rigid structure or to existing concrete lining which is not continuously reinforced. All joints shall be watertight. Construction joints are required at the end of a day's placement and where lining thickness changes.

Concrete-lined open channels must be provided with ladder-type steps at a spacing of 700 feet on both sides of the channel. The bottom rung shall be placed 12 inches vertically above the channel invert.

# 7 Composite Channel Design

The concept of Composite Channel Design is to provide a non-uniform channel section where frequently occurring nuisance flows are constrained to a low-flow area of the channel, allowing higher elevation areas of the channel section to inundate only during high flows (Design Storm). This concept allows the designer to vary the channel lining material(s) in different areas of the cross section, allowing floodplain areas of the channel section to be improved with “Joint-Use” and/or “Quality of Life” opportunities like parks and trails.

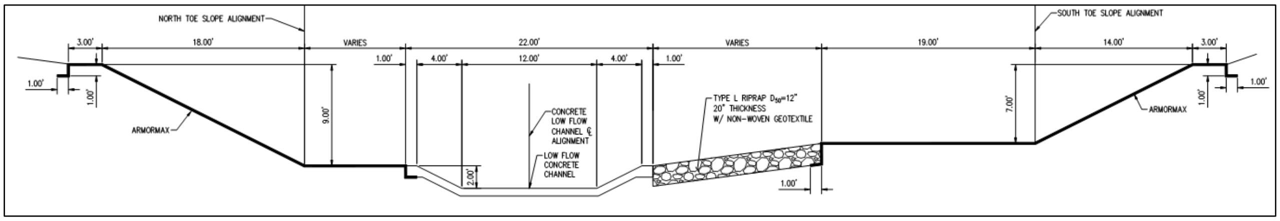


*Figure 11: Composite Channel – SSCAFCA Lower Montoyas Arroyo*

In the example of Figure 11, the lowest tier of the channel contains small and more frequent storm flows, while the top tier of the channel is set to a higher elevation to contain the design storm. Part of the material selection process must consider the material’s resistance to shear stress.

Modelling composite channels requires that each lining material roughness coefficient be specified appropriately in the selected hydraulic model.

# 8 Discharging to SSCAFCA Open Channels

The designer shall use the Hydraulic Grade Line in the receiving channel as the downstream boundary condition in the hydraulic analysis. Flap gates may be required for new storm drain connections to existing SSCAFCA open channels.

Unless otherwise approved by SSCAFCA, USBR Stilling Basin Type VI shall not be used in SSCAFCA open channels due to access and maintenance issues (see *Bureau of Reclamation – Engineering Monograph No. 25 – Hydraulic Design of Energy Dissipators, Eighth Printing (1984)*).

## 8.1 Discharge to an Unlined SSCAFCA Channel

Scour resulting from sediment-starved, fast-travelling storm water discharges to SSCAFCA’s Open Channels is a common issue for SSCAFCA. Storm water discharges typically take the form of a storm drain pipe, concrete box culvert, or open channel connection to an existing SSCFACA channel.

Any proposed storm water discharge to a SSCAFCA channel shall include energy dissipation and scour mitigation measures. The proposed structure must be protected from main channel scour and erosion from local runoff. Hardened protection shall be provided to scour depth along the entire width of the structure. Stabilization of a portion of the channel bank upstream, downstream, and on the opposing channel bank of the discharge location may be required, depending on the aggradational or degradational status of the receiving channel and local constraints.

Storm water discharges must enter the channel at less than or equal to 90-degrees to the channel alignment and should never discharge in a direction opposing receiving channel flow.

### 8.2 Discharge to a Lined SSCAFCA Open Channel

Ensure that the invert of the proposed discharge structure is located at least 6-inches above the receiving channel invert.

Prior to beginning design, consult with SSCAFCA staff to determine design constraints at the proposed discharge location.

## 9 Reporting & Submittal Requirements

Design Analysis Reports (DAR) are typically provided in two separate submittals: Preliminary DAR and Final DAR.

The Preliminary DAR submittal should follow the outline in Table 6 and typically includes an evaluation of design alternatives. The Preliminary DAR submittal can only occur before construction plans are drawn since it typically contemplates multiple design alternatives.

The Final DAR submittal occurs after the construction plans are approved (or are near approval). The Final DAR submittal should incorporate the construction plans into the report analyses.

### 9.1 Design Analysis Report Outline

The format below outlines relevant items to be documented in the DAR.

In addition to the Hydraulic Analysis Description shown in the table below, exhibits showing labeled cross sections (1D), mesh layout (2D), existing and proposed contours, extents of floodplain(s), and storm drain/utility sizes & invert elevations must be included in the DAR.

*Table 6: General Outline for Drainage Analysis Reports*

| DAR Section | Description |
|---|---|
| Executive Summary | Brief, concise summary of analysis results and recommendations. |
| Introduction | Project background information, location, required permits, FEMA floodplain status. |
| Hydrology | Assumptions used in determining the design flowrate (or the origin of the flowrate) including land use assumptions upstream of the project reach. Include an electronic copy of the hydrologic model, if applicable. |
| Channel Stability | Note current stability status, provide equilibrium slope computation. |
| Hydraulic Analysis | Confirmation that the proposed geometry provides sufficient height for the design storm WSEL plus freeboard, superelevation, and roll waves. Description of assumptions used in the hydraulic model. Verify shear stress for proposed lining materials. Include analysis and discussion of downstream infrastructure capacity constraints. Include an electronic copy of the hydraulic model, if applicable. |

| | |
|---|---|
| Scour Analysis | Computation and discussion of scour depths along the proposed channel. Computation and discussion of proposed scour mitigation measures. Include an electronic copy of scour calculations, if applicable. |
| Attachments | A. Floodplain Maps.<br>B. Permits Required/Obtained: USACE, FEMA, Local Floodplain Administrator, Environmental documentation, etc.<br>C. Project ROW ownership information and identification of additional ROW, if required.<br>D. Hydraulic model and supporting documentation – cross section exhibit, plan and profile views of the model to be included.<br>E. Freeboard, Superelevation, and Roll Wave calculations to verify channel height.<br>F. Shear stress calculations to support proposed lining material selection.<br>G. Scour calculations.<br>H. Hydraulic model for the proposed channel. |

# 10 References


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