Appendix G: Geomorphically-Referenced Basis of Design Guidance Document

Table of Contents

G-1. INTRODUCTION

G-1.1 Purpose of Guideline

The purpose of this Conceptual Geomorphically Referenced Basis of Design Guideline (GRBoD Guideline) is to describe a conceptual design approach to rehabilitate (or improve) geomorphic form and function of reaches identified as impacted by hydromodification. This Conceptual GRBoD Guideline presents the overall design concept, potential rehabilitation design elements, performance standards, and conceptual design guidance. This Guideline is intended to support preliminary feasibility studies. It is not intended to support detailed design in its present form. Ongoing refinement and adaptation of this document is anticipated to be needed.

G-1.2 Overall Design Approach

This guideline focuses on development of channel rehabilitation strategies and associated physical parameters to create stable stream channels that conform to applicable policies (i.e., flood protection, maintenance access) while supporting desired ecosystems (i.e., in-channel habitat, riparian ecosystems, wetlands) following project implementation.

Key physical parameters for stream rehabilitation include active channel width, depth, slope, and planform, as well as overbank width, slope, and planform within the broader channel corridor. The approach focuses on developing these parameters based on the future flow and sediment regime, such that channels are designed to be adapted to the flow and sediment conditions currently present. The approach includes a goal of geomorphic stability within active channels, allowing for natural erosion, sedimentation, and channel migration to continue within limits, while also including engineered features within the active channel and overbank channel to protect property and provide for safe conveyance of peak flows.

The approach calls for the use of structures in locations where erosional forces will exceed the natural stability of the channel. To the extent possible, bank and channel bed protection features will be designed to mimic natural features using biotechnical (i.e., a combination of vegetative and structural methods) or structural methods to provide stream channels that are stable, attractive and support the desired habitat elements.

Given that hydrologic and sediment supply regimes have been greatly modified in many reaches, it is anticipated that biotechnical or structural grade control measures will be needed within the active channel to reduce stream energy. Additionally, given the relatively large peak flood conveyance flows that channels must convey (based on the OC Hydrology Manual), hardened limits on the overbank channel, and in some cases the active channel, may be necessary.

G-1.3 Applicability and Limitations

This Conceptual GRBoD Guideline is intended to be applied to stream reaches within urbanized corridors in South Orange County that (1) have been identified as geomorphically unstable (i.e., impacted by hydromodification) and (2) have been identified as potential rehabilitation projects. This Guideline is not intended to describe the process for project identification; factors outside of this Conceptual GRBoD Guideline will be the basis for identification of potential projects.

It is important to acknowledge that stream rehabilitation within existing urban areas may be constrained by a number of factors, including space and topographical limitations, modified hydrology and sediment supply, maintenance access, channel crossings, property ownership, and other factors. An underlying goal of this GRBoD is to improve and support desired ecosystems within these channels to the extent possible. However, there may be instances where traditional hardened engineered approaches are necessary in a constrained urban setting in order to reliably protect life and property from peak event flooding and scour.

G-2. PERFORMANCE STANDARDS

G-2.1 Hierarchy of Performance Standards

This section describes performance standards associated with geomorphically-referenced channel rehabilitation. The underlying goal of rehabilitation is to create stable stream channels adapted to future hydrologic and sediment supply conditions that conform to applicable policies (i.e., flood protection, maintenance access) while supporting desired ecosystems (i.e., in-channel habitat, riparian ecosystems, wetlands), where feasible. As introduced in Section G.1, urban channel corridors may not support this full suite of rehabilitation goals. In the preparation of alternatives analyses, feasibility studies, and subsequent phases of project development, a hierarchy of performance standards must be considered where constraints prevent all goals from being achieved (Table G-1).

Table G-1: Hierarchy and Role of Performance Standards for Rehabilitation Projects

Performance Standard	Role in Meeting Rehabilitation Goals
1. Provide design conveyance capacity for peak storm events	• Meet flood control policies to protects life and property • Protects against water quality impacts associated with flooding and infrastructure damage
2. Resist scour and excess erosion in peak storm events	• Protect life and property • Limit O&M needs • Protect habitat from degradation • Protect downstream reaches from excess sedimentation
3. Provide an active channel that is geomorphically stable	• Provide a stable physical setting to support riparian ecosystems • Limit O&M needs • Maintain sediment conveyance • Protect downstream reaches from excess sedimentation
4. Improve physical habitat	• Maximize natural channel form within the active channel • Minimize the need for hardened structures • Limit O&M needs • Maximize extent of suitable physical habitat created through rehabilitation • Maintain sediment conveyance
5. Effectively manage low flows	• Provide water quality improvement during dry weather conditions • Avoid introducing dry weather nuisance issues, such as standing water near grade control structures

G-2.2 Flood Protection

Consistent with the Orange County Flood Control District (OCFCD) Design Manual, all channel rehabilitation projects must, "provide 100-year protection for residences and other non- flood proof structures" (County of Orange, 2000). Design flowrates for flood conveyance shall be per the Orange County Hydrology Manual (1986 with 1996 addendum).

G-2.3 Peak Flow Scour Control

Channel rehabilitation projects must be designed to resist scour for the 100-year peak design discharge. While the Orange County Public Works design manuals do not have criteria for soft bed channel design, proper outlet scour protection per the OCEMA Local Drainage Manual (page 5-87), (County of Orange, 1996) will reduce the potential for in-channel knickpoint migration resulting from the formation of scour holes caused by concentrated flow. Proper energy dissipation is also a required step in the South Orange County HMP (County of Orange, 2015). Additionally, any buried lateral setback stabilization and grade control structures shall be designed: (1) deep enough to prevent undermining of those structures from the calculated toe-down scour associated with the 100-year peak discharge; and (2) of material that will withstand the calculated 100-year peak flow velocity and shear stress.

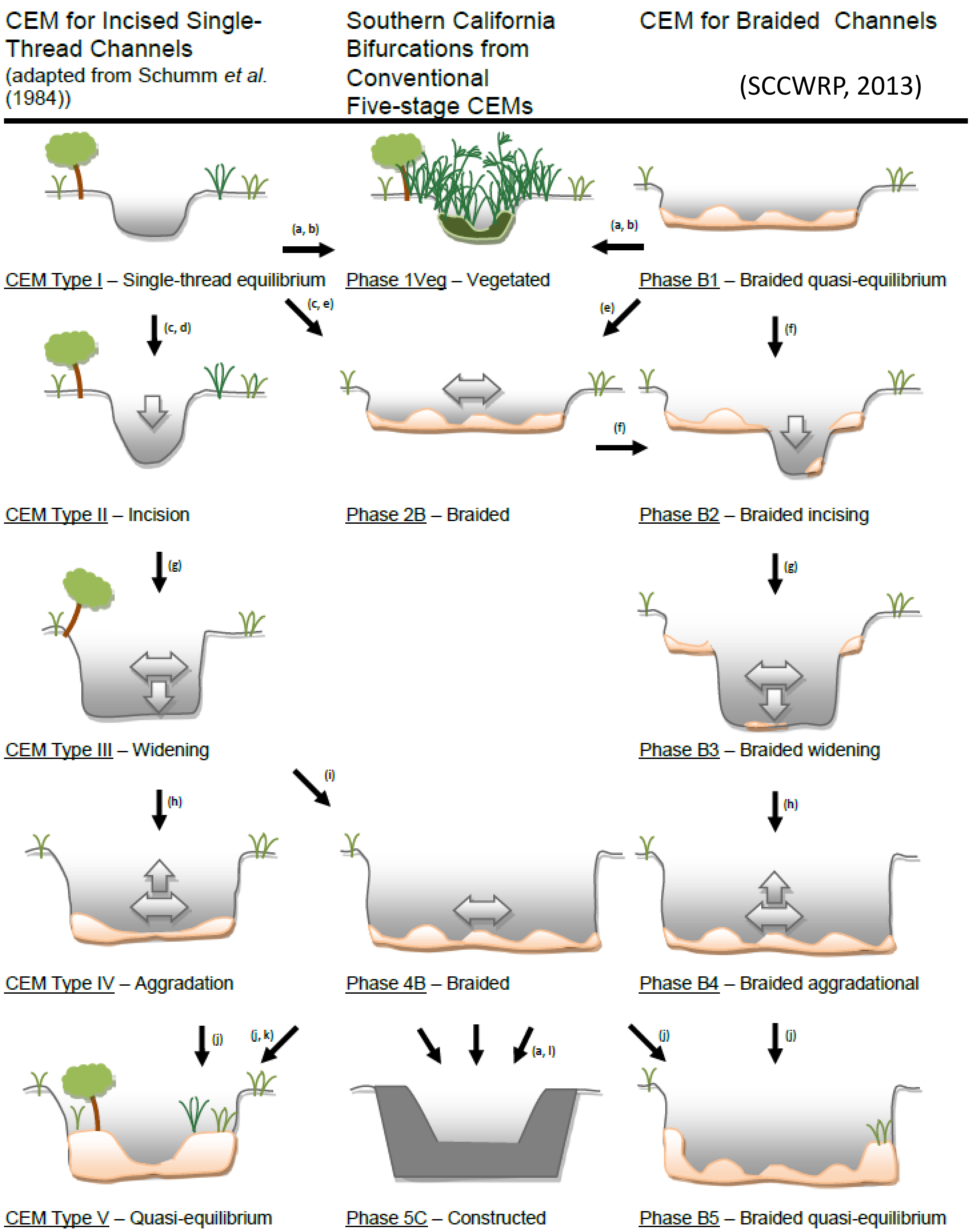
G-2.4 Geomorphic Stability

The physical channel parameters (including channel width, depth, slope, and planform) shall be selected using a preponderance of evidence approach to achieve dynamic equilibrium or geomorphic stability given the current and future flow and sediment regimes. Geomorphic stability is a geomorphic term defined as a condition in which channel form[1] is maintained over time within a natural range of variance. True stability never exists in natural streams because they are frequently undergoing channel form adjustments in order to convey a range of discharges and sediment loads. However, fluvial systems can become relatively stable in the sense that, if disturbed, they will tend to return approximately to their previous state and perturbation is damped down (Knighton 1998). A large scale event, like a flood, forest fire or landslide, can cause dramatic changes in channel form, but the channel will often re-established its equilibrium form over time. However, a persistent alteration to the controls on channel form can cause the channel to begin an evolutionary change in morphology, leading to degradation and instability until it reaches a new equilibrium state. This evolution change can take up to several hundred years before the new equilibrium is reached. For the purpose of this

[1] The components of channel form include: (1) bed and bank configuration (i.e. grain size, resistance to movement, and sequence of bed forms); (2) cross-sectional geometry (i.e. depth and width); (3) planimetric geometry (i.e. form of the channel when viewed from above); and (4) longitudinal geometry or slope (i.e. form of the channel when viewed in profile).

GRBoD guidance document, stream stability is assumed as the ability of a fluvial system to return to an equilibrium channel form when disturbed by external forces. Instability, thus, occurs when the controls on channel form are perturbed to a point that the fluvial system must adjust to a new equilibrium channel form. Per the Southern California Channel Evolution Model (CEM) (SCCWRP, 2013), Type I and Type V channels on the top and bottom rows of Figure G-1 are considered to be in dynamic equilibrium.

Figure G-1: Southern California Channel Evolution Model (CEM)



The development of design parameters to achieve geomorphic stability shall be based on multiple lines of evidence, include some or all of the following, as determined to be applicable for the reach of interest:

- Historical context of the channel of concern;
- Reference reach approaches;
- Dominant discharge analysis;
- Erosion Potential (Ep) analysis[2];
- Empirical bankfull width and depth relationships determined to be applicable to the reach of interest, and
- Lessons learned from past channel rehabilitation successes and failures in the region.

Each method may have different design inputs such as hydrologic and sediment supply estimates. In contrast to peak event flood and scour protection, estimates should generally be based on best estimates of actual long term conditions rather than conservative design assumptions. For example, monitored flow records or continuous simulation models (or a combination of these) are appropriate for estimating flows with an actual return interval in the 2- to 10-year range that are most relevant for normal geomorphic processes

Where possible, channel rehabilitation will be selected and designed to maintain the Ep ratio within 10 percent of the target value in the receiving waters. The target Ep will be adjusted to account for changes in bed sediment supply which is consistent with the Erosion Potential Performance Standard stated in the South Orange County HMP (County of Orange, 2015). It should be noted that the Erosion Potential method has limitations in the context of existing degraded channels (SCCWRP, 2013). This method involves comparing future conditions to a natural reference condition of the reach of interest. For channel design where the existing condition is unstable, as is the case for geomorphically impacted channels, the baseline used for comparison is more appropriately based on documented stable conditions from the past or reference reach(es) in the same region than the existing condition of the impacted reach of interest. Establishing a baseline stable condition that is appropriate for the reach of interest is an uncertain exercise. Therefore, this Conceptual GRBoD Guideline relies on other lines of evidence beyond the Ep criterion established in the HMP.

[2] Ep is the ratio of total long-term sediment transport capacity or effective work in the post-development condition versus the pre-development condition (post/pre).

G-2.5 Physical Habitat Improvement

Beyond geomorphic stability, channel rehabilitation projects should give specific consideration to improving physical habitat, including:

- Spacing and height of grade control structures and associated disruption to streambed;
- Tree canopy effects on the leaf litter budget and water temperature;
- Longitudinal connectivity for fauna to adequately move up and downstream without obstruction;
- Lateral floodplain connectivity; and
- Vertical connectivity with the groundwater table to support riparian vegetation

These elements are not mandatory elements of rehabilitation to address excess channel erosion and scour, however should be included opportunistically.

Clear habitat goals and quantifiable metric(s) which relate to habitat success should be identified for each channel rehabilitation project. These habitat goals and metrics of success should consider the appropriate levels of riparian connectivity necessary to support the targeted habitat and wildlife. The habitat goals and metrics should also be consistent with applicable California Department of Fish and Wildlife (CDFW) Natural Community Conservation Plan / Habitat Conservation Plan (NCCP/HCP) programs.

Channel rehabilitation projects may require the following permits:

- California Department of Fish and Wildlife – 1602 Streambed Alteration Agreement.
- US Fish and Wildlife Service – Authorization under the Endangered Species Act.
- US Army Corps of Engineers – Clean Water Act Section 404 Permit.
- Regional Water Quality Control Board – Clean Water Act Section 401 Water Quality Certification.
- Local Grading Permit

G-2.6 Low Flow Management

Channel rehabilitation projects should consider dry weather conditions, in addition to wet weather and peak flow conditions in the development and integration of design features. These elements are not mandatory elements of rehabilitation to address excess channel erosion and scour, however should be included opportunistically. Designs should be developed to provide treatment processes for flow during dry weather, where applicable, and provide vertical connectivity with groundwater to promote natural gain/loss dynamics. Movement of flow during dry weather conditions should be maintained to prevent stagnant water and resulting nuisance conditions.

G-3. REHABILITATION DESIGN ELEMENTS

An important aspect of watercourse rehabilitation is to provide peak event flood and scour control and mitigate geomorphic impacts, while providing a channel form that is conducive to riparian ecosystems. This can be conceptually achieved through the use of "softer" approaches in the active channel coupled with more engineered approaches at periodic points in the active channel (e.g., grade control structures) and on the outer channel limits (e.g., buried bank stabilization). Approaches for reducing stream energy (and associated erosion) or reinforcing the channel so it can withstand elevated stream energy include:

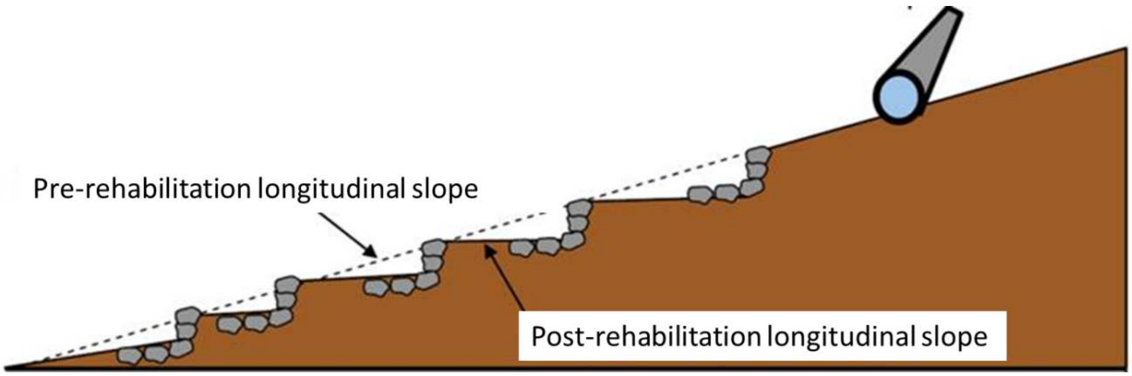
- Grade control/drop structures to result in an effectively flatter slope in the active channel
- Increase in channel sinuosity to result in a flatter slope in the active channel
- Channel widening to reduce stream energy and associated shear stress per unit area
- Bed and bank reinforcement to improve resistance to elevated shear stresses
- Reduction in hydrologic load through upland flow control or partial flow diversion.

This section introduces these design elements, which can be used individually or in combination to meet the performance standards provided in Section G.2. Section G.4 provides a conceptual design approach for developing a rehabilitation design that incorporates some or all of these elements.

G-3.1 Grade Control / Drop Structures

Drop structures have the effect of reducing the average channel slope, thereby reducing the shear stresses generated by stream flows. These controls can be incorporated as natural looking rock structures with a step-pool design which allows drop energy to be dissipated into the pools while providing a reduced longitudinal slope between structures. Figure G-2 provides a schematic of a series of drop structures in profile view.

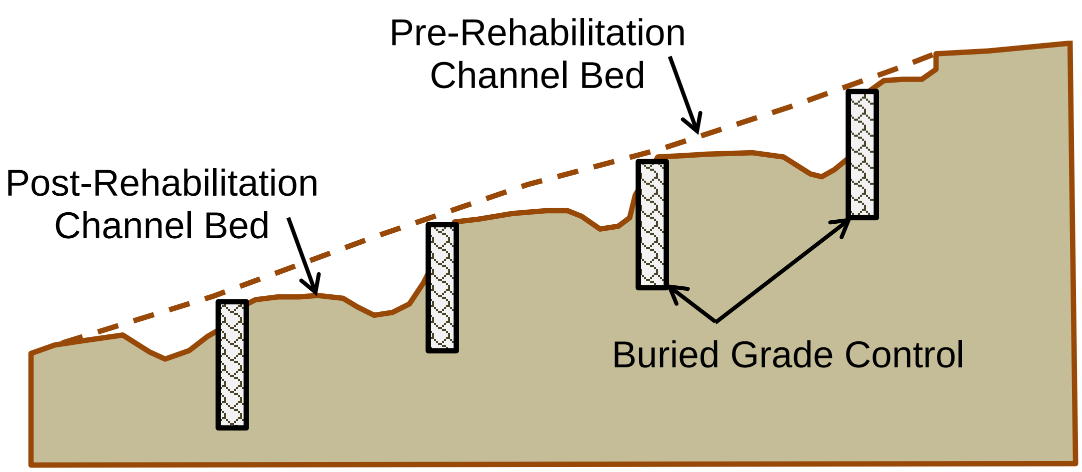
Figure G-2: Drop Structure Schematic



(County of San Diego HMP, 2011)

Grade control structures are designed to maintain a desired channel slope while allowing for minor amounts of local scour. These control measures are often buried and entail a narrow trench across the width of the stream backfilled with soil cement, larger stone, or concrete, as well as the creation of a "plunge pool" feature on the downstream side of the sill by placing boulders and vegetation. A grade control structure provides a reduced footprint and impact as compared to drop structures, which are designed to alter the channel slope. Figure G-3 provides a schematic of a series of grade control structure in profile view.

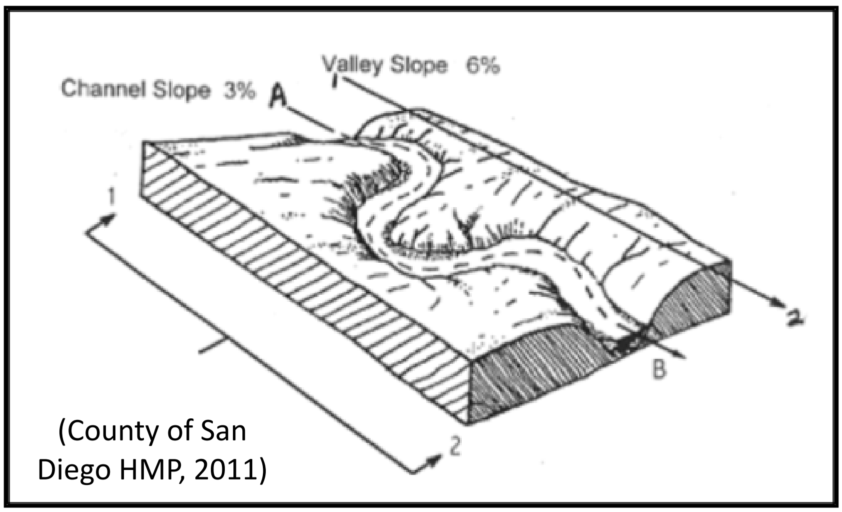
Figure G-3: Grade Control Structure Schematic



G-3.2 Channel Sinuosity

Increasing channel sinuosity (meandering) can serve to reduce the channel slope, thereby reducing the shear stresses and flow velocity generated by stream flows. However, forcing a channel to be too sinuous is likely to lead to subsequent channel avulsion (cutting a new stream path) to a straighter course. Channel sinuosity needs to be supported by a basis that shows the proposed form and gradient to be appropriate for the valley slope and sediment and water regime. This may take the form of reference reaches in similar watersheds that have supported the proposed morphology over a significant period of time, or comparison between the proposed form and typical literature values (County of San Diego, 2011). Figure G-4 provides a schematic of how channel sinuosity can result in a shallower active channel slope than the overall valley slope.

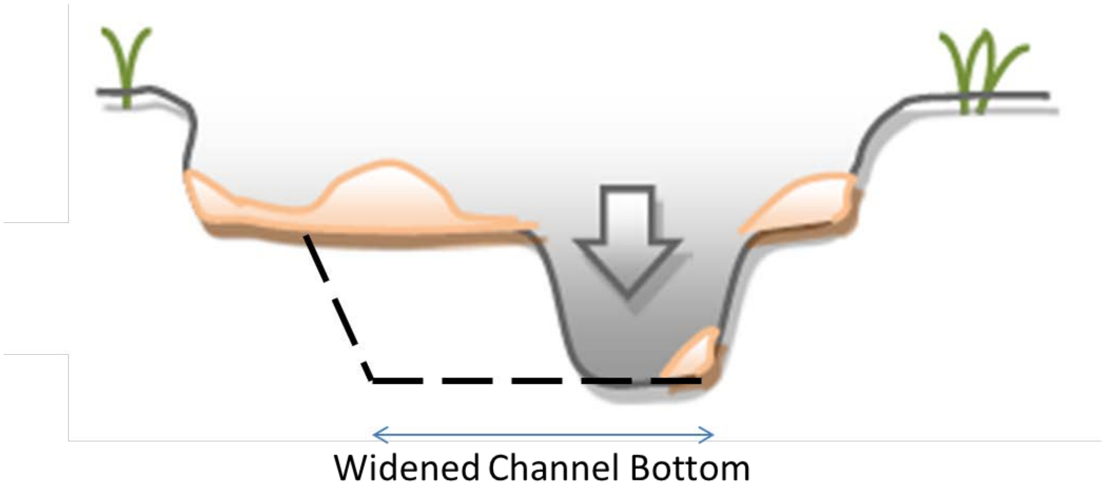
Figure G-4: Channel Sinuosity Schematic



G-3.3 Channel Widening

Increasing the width-to-depth ratio of a stream's cross section is meant to spread flows out over a wider cross section with lower depths, thereby reducing shear stress for a given flow rate. This approach can be a useful management strategy in incised creeks to bring them back to equilibrium conditions. As with sinuosity, it is important to develop a robust geomorphic basis that shows the increase in width-to-depth ratio to be sustainable, meaning the channel would not continue downcutting into the channel bottom once widened (County of San Diego, 2011). Figure G-5 provides a schematic of channel widening.

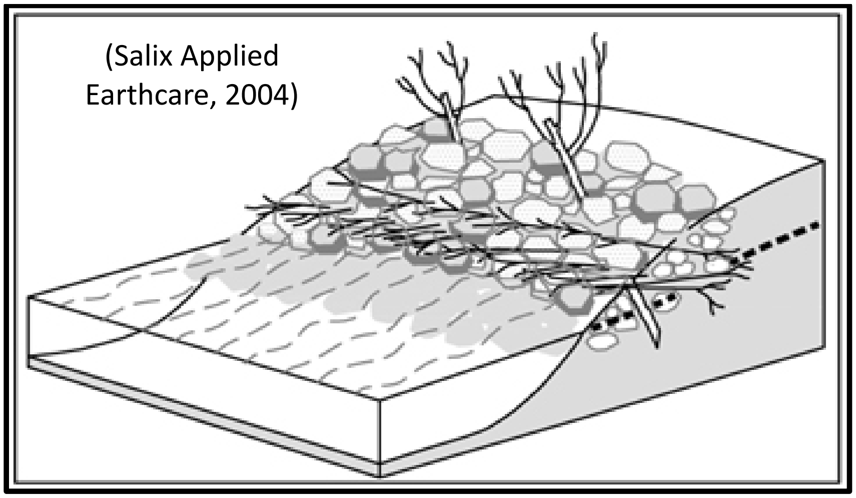
Figure G-5: Channel Widening Schematic



G-3.4 Bed and Bank Reinforcement / Buried Lateral Setback Stabilization

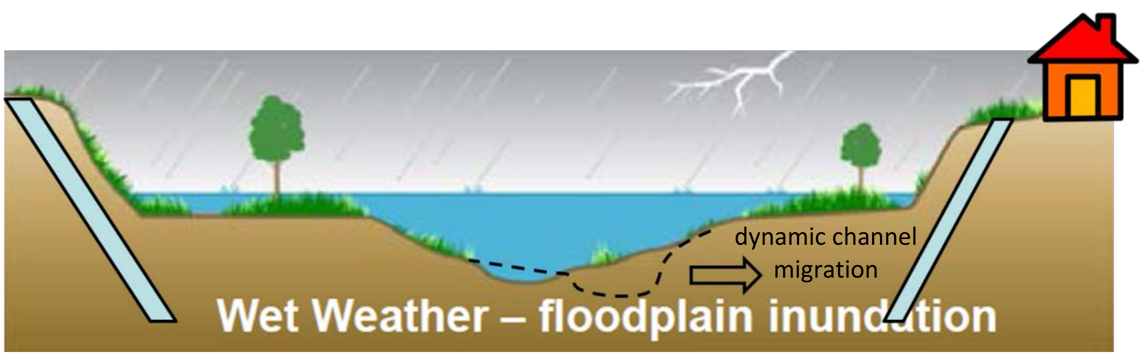
Channel reinforcement serves to increase bed and bank resistance to shear stress. Biotechnical approaches include large woody debris, live crib walls, vegetated mechanically stabilized earth, live siltation, live brushlayering, willow posts and poles, live staking, live fascine, rootwad revetment, live brush mattresses, and vegetated reinforcement mats. These technologies provide erosion control that stabilizes bed and bank surfaces and allows for re-establishment of native plants, which serves to further increase channel stability. Conventional channel lining and toe revetment such as rip rap is a form of bed and bank reinforcement. Figure G-6 provides a schematic of one type of bank reinforcement.

Figure G-6: Example Bank Reinforcement Schematic



Buried lateral setback stabilization acts as a barrier to withstand and eliminate the potential for redirection of the active channel into development or infrastructure. When installed it is hidden from view so that it looks like a natural channel. Buried lateral setback stabilization allows a channel to dynamically adjust, but within set limits so that bank migration halts when it is exposed. Material used includes soil cement, stacked boulders, or grouted riprap. Figure G-7 provides a schematic of buried lateral setback stabilization.

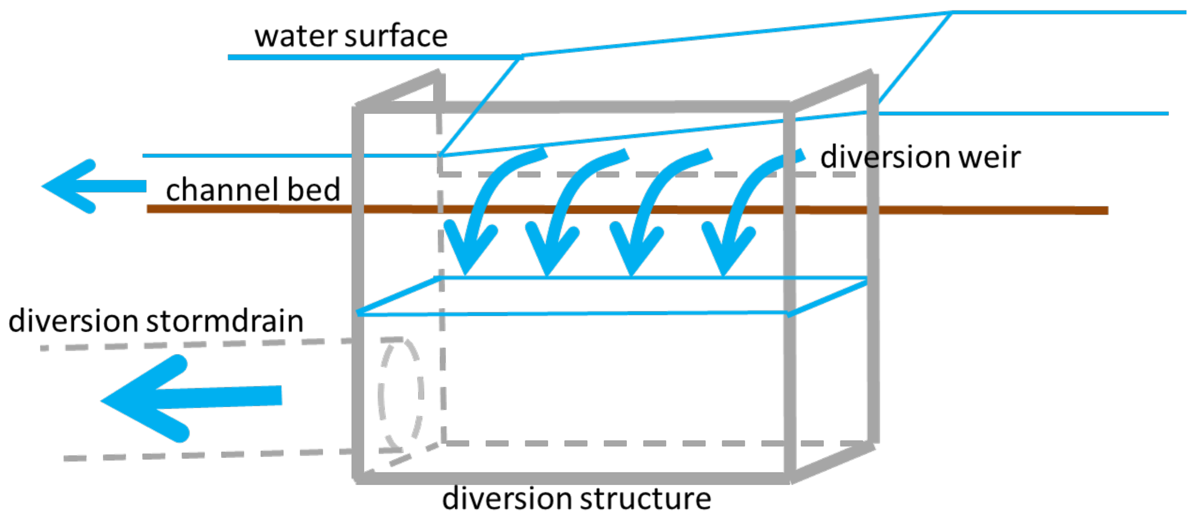
Figure G-7: Buried Lateral Setback Schematic



G-3.5 <u>Partial Flow Diversion</u>

Partial flow diversion includes re-routing of excess flow and/or volume to an engineered stormdrain so that it can be routed downstream to a less erodible channel reach. This strategy reduces erosion potential by reducing the flow volumes, durations, and/or magnitudes that a channel experiences. The diversion occurs over a side weir or riser pipe structure that has a crest elevated above the channel bed. Partial flow diversion is more practical for managing the duration and volume of small to mid-storm flows, given that design of a diversion system to handle peak storm flows is typically cost prohibitive. Figure G-8 provides a schematic of partial flow diversion.

Figure G-8: Partial Flow Diversion Schematic



G-3.6 Upland Flow Control

As part of channel rehabilitation, opportunities for enhanced flow control of runoff from urbanized areas should be considered. Control of geomorphically-significant discharges (above the critical flowrate for incipient motion or in-channel erosion), should be the primary focus of upland flow control improvements. Approaches could include:

- Expansion of the storage volume of existing facilities to provide a "dead storage" for increased volume reduction or flow duration control.
- Operational improvements of existing flow controls facilities, potentially with active/adaptive outlet control systems (for example solutions provided by OptiRTC www.optirtc.com) to allow operation as a flow duration control facility during more frequent storm events when peak event flood control functions are not needed.
- Diversion of small storm flows or extended detention discharges to sanitary sewer to harvest water for recycling and reduce flow volume in stream
- New retrofit facilities

- New purposes or operations of water storage facilities
- Addition of regional stormwater detention/retention basins within former floodplain, which is no longer laterally connected to an impacted channel reach

The effect of upland flow controls should be reflected in the estimates of hydrology used for design.

G-4. CONCEPTUAL DESIGN GUIDANCE

The sequence for conceptual design includes the following steps, which are described in the sections below.

1. Characterize Reach Morphology
2. Establish Conceptual Channel Geometry
3. Configure Design Elements
4. Analyze Peak Event Hydraulics
5. Reference to Past Channel Rehabilitation

G-4.1 Characterize Reach Morphology

This section provides instruction on how to characterize the geomorphic setting of a project reach and its tributary watershed to evaluate past and present watershed and channel conditions and determine root causes of known geomorphic impacts. This characterization focuses on assessing the four key factors that govern channel form (hydrology, sediment supply, channel geometry, and bed/bank material) and changes to these four factors caused by land use alteration. The characterization is essential for the population of input parameters necessary for subsequent design analysis.

If a channel is currently geomorphically impacted, then characterization of the existing condition is still worthwhile to understand which of the four factors have been modified by land use alteration. It is crucial to understand the current state of an unstable channel's form and processes in order to best understand what can be done to rehabilitate the impacted channel.

G-4.1.1 Hydrology

Hydrology is a key factor because a channel's basic function is to convey water discharge. Hydrology is characterized by defining the watershed's area, impervious cover, percent development, design discharges (Q2 through Q100), and runoff coefficient, if available, for relevant historical current and future land use conditions. Additional watershed information about land cover, geology, soils, terrain steepness, climate, and groundwater conditions is helpful as well. Flow gage records are the ideal source of hydrologic data, but hydrologic models can be applied to simulate the hydrologic response of catchments under pre- and post-disturbance conditions for specific design storm events or a continuous period of record.

Hydrologic calculations or modeling for peak design events (i.e., the 100-year return period) shall be performed per the Orange County Hydrology Manual (County of Orange, 1986). Intermediate peak discharges (i.e., 2- to 25-year return period) shall be calculated using empirically derived formulae for the region (i.e., USGS SIR 2012-5113 South Coast Region 5; Hawley and Bledsoe, 2011; and Waananen and Crippen, 1977). Modeling software appropriate for long-term continuous simulation includes USEPA's Storm Water Management Model (SWMM), USGS's Hydrological Simulation Program – Fortran (HSPF), and the US Army Corps of Engineers' Hydrologic Modeling System (HMS). Input parameters for these continuous simulations are hourly precipitation data for a long-term (>30 years) record, sub-catchment delineation, impervious cover, soil type, vegetative cover, terrain steepness, lag time, and monthly evapotranspiration rate. The primary output is a discharge record associated with the stream location of concern. Traditionally, a hydrograph is the primary means for graphically comparing discharge records; however, a hydrograph is not ideal for long-term flow records because the period of interest spans several decades. Instead, a more effective means for comparing long-term continuous discharge records is to create flow duration curves and histograms.

G-4.1.2 Channel Geometry

Channel shape is an integral factor of stream stability because it serves as the basis of key hydraulic properties (specifically flow stage, velocity, and shear stress) that drive the conveyance of water and sediment. Channel geometry is characterized in plan form, cross-section, and longitudinal profile. Cross-sections and longitudinal profiles of the active channel are surveyed at strategic locations. Methods of collecting topographic survey data can range from simply using an autolevel, cloth tape, and survey rod to conducting a detailed ground-based LiDAR survey. If the natural channel geometry has been modified and can no longer be surveyed, then either historical survey data should be obtained or an undisturbed reach, having similar drainage area and valley slope, should be surveyed to approximate the pre-disturbance condition. Plan form can be characterized with historical imagery review and topographic maps. Localized channel geometry modifications, such as at a storm drain outfall, should be considered as well because concentrated flow can form scour holes which result in potential for in-channel knickpoint migration.

G-4.1.3 Bed and Bank Material

Bed and bank material properties (as well as vegetation type and density) define the channel's susceptibility to the forces of flowing water. The characteristic of bed and bank material that is most important to channel form is its resistance to movement (often expressed as critical shear stress or velocity). As the size and weight of non-consolidated bed material increases, or the cohesive strength of consolidated bank and bed material increases, the channel form becomes more resistant to erosive forces and thus more stable. Bed and bank material is characterized during a geomorphic field assessment. For each stream location analyzed, a measure of critical shear stress is obtained that depends on the material type. For non-cohesive material, a Wolman pebble count or sieve analysis is used to obtain a grain size distribution, which is converted to a critical shear stress using an empirical relationship. For cohesive material, an in-situ jet test or a reference table is used, such as that provided in *Stability Thresholds for Stream Restoration Material* by Fischenich (2001). For banks reinforced with vegetation, reference tables are used. Localized bed and bank modifications, such as at a storm drain outfall, should be considered as well because changes in material type (i.e., from hard to soft) are a hot spot for vortex shedding which can result in knickpoint migration.

G-4.1.4 Sediment Supply

Sediment supply is a key factor because a channel's basic function is to convey sediment. While accounting for changes in bed sediment supply is necessary for quantifying geomorphic impacts in live-bed alluvial stream systems, where the bed is made up of materials that are generated from upstream sources, it is not considered as essential for channels that have no significant exchange of material between the sediment carried by the stream and the bed (NRCS, 2007). Sediment supply changes can be characterized at a preliminary screening-level with calculations of area and stream length in the watershed that have been or will be eliminated by development in the watershed. These reductions in area and stream length are compared to the totals by watershed. Sediment supply rates can also be estimated using regional erosion rates found in the literature, accumulated sediment deposited in sediment sinks (such as dams or debris basins, if they exist), or models such as MUSLE, RUSLE, or GeoWEPP. SCCWRP has promoted the use of mapping Geomorphic Landscape Units (GLUs) to identify relative magnitudes of sediment supply from hillslope processes based on classifications of terrain steepness, geology, and land cover (SCCWRP, 2010). A similar categorization can be done for sediment supply generated by in-stream erosion processes by mapping Geomorphic Channel Units (GCUs) (PACE et al, 2013).

G-4.2 Establish Conceptual Channel Geometry

The next step in channel design is to establish the basic geometric characteristics in cross-section (width and depth) and longitudinal profile (slope) with consideration to past changes in hydrology and bed sediment supply. While channel width and depth can initially be established independently of longitudinal slope, as described in the following paragraph, the three parameters are integrally related to one another and need to be addressed iteratively and in combination with one another. Additionally, any proposed reductions in hydrologic loading (e.g., via partial flow diversion or upland flow control) should be considered in the derivation of the basic channel geometry.

Initially, an empirical relationship developed by Coleman et al (2005), modified by Stein (County of San Diego, 2011), can be used to express representative bankfull channel dimensions (width, depth,) as a function of dominant discharge. Other empirical bankfull geometry equations for the region can be used as well. Historical aerial image review can also help to determine a reference channel width, however this may not necessarily be the most appropriate future design condition given changes in hydrology.

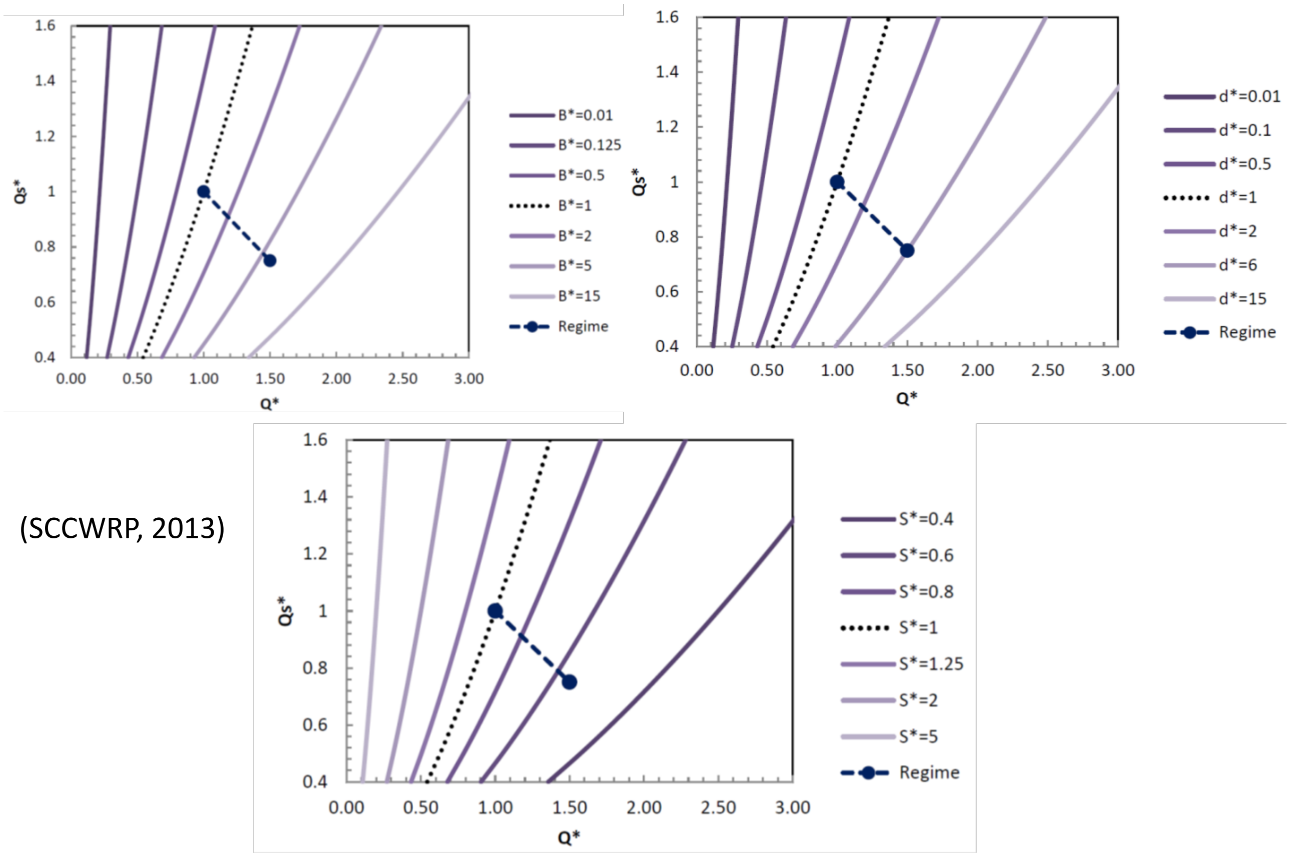
Channel slope, adjustments to width and depth, and optional partial flow diversion is evaluated using a preponderance of evidence, including the results of the dominant discharge method, field geomorphic data method, Erosion Potential (Ep) method, and/or other approaches as applicable. The preponderance of evidence approach is meant to ensure that hydraulic and sediment transport results are reasonable and the channel is likely to remain geomorphically stable over the longer term.

G-4.2.1 Dominant Discharge Method

This method is based on applying a sediment transport equation for the dominant discharge (Q2, Q5, or Q10) in the baseline and post-disturbance conditions and iteratively adjusting channel slope, cross-section geometry, and/or partial flow diversion until post-development sediment transport is equal to the baseline. The method requires selection of the most suitable sediment transport equation(s) based on the type of channel. It also requires identification of a baseline reference channel that is considered to be stable and of similar type.

SCCWRP (2013) has provided a set of channel response diagrams, using the Bagnold (1980) sediment-transport function, that can be used to evaluate potential maximum changes in channel width, depth, and slope based on relative changes in dominant discharge and sediment flux. While these generic diagrams, provided in Figure G-9, are not appropriate to inform detailed designs, they can help produce a general target to aim for.

Figure G-9: Maximum Channel Response Diagrams for Channel Width (B), Depth (d), and Slope (S)



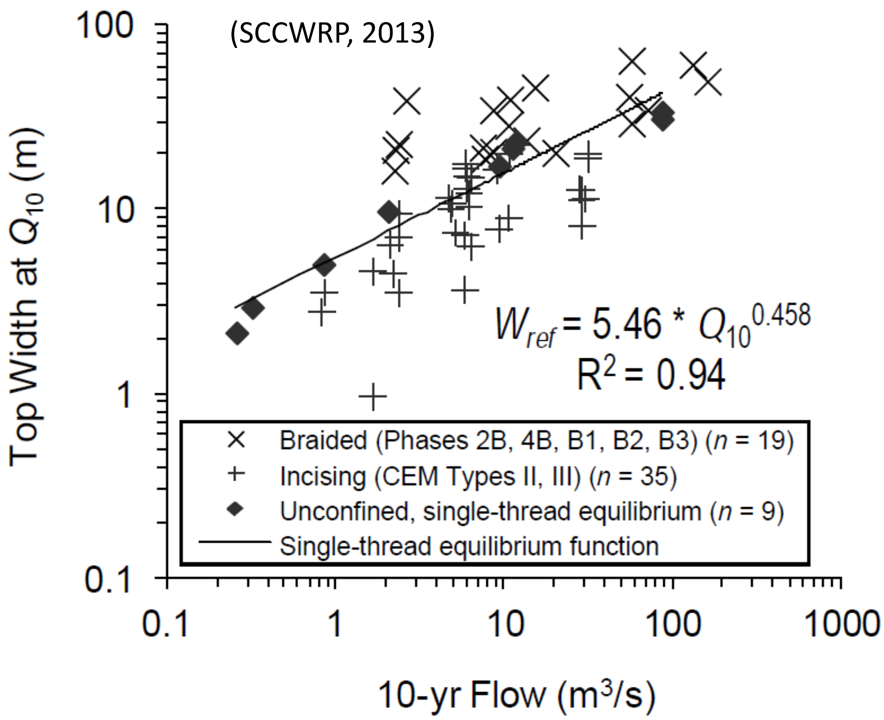
(SCCWRP, 2013)

G-4.2.2 Field Data Method

Data on stable longitudinal slope can be collected in South Orange County by measuring channel gradient in stable channel reaches and comparing them to watershed area or dominant discharge. The scatter plot will provide an envelope of actual observed field conditions. While this envelope of data should not be, and is not, the sole basis for design, it is an important line of supportive evidence with which to verify the estimates provided by sediment transport models. A measure of stable channel gradient under post-development conditions can be determined by looking at the channel gradient of watersheds with the same runoff as the post development watershed. For example, as a first step approximation, a 1 square mile watershed in which post-development runoff is tripled will lead channel slopes to adjust to a gradient more appropriate to a 3 square mile watershed, assuming the same sediment delivery.

SCCWRP (2013) has provided a plot of top width vs. 10-year flow at unconfined, unconstructed single-thread equilibrium, braided, and incising sites. This field-based plot, provided in Figure G-10, can be a useful tool to evaluate appropriate channel widths based on the type of channel desired (e.g., single-thread or braided).

Figure G-10: Field Data Plot of Channel Top Width Versus 10-Year Flow



G-4.2.3 Erosion Potential Method

Erosion potential (Ep) is a measure of the change in the long-term, cumulative effective work done on the channel by hydraulic forces between a baseline (reference stable condition) and future, post-rehabilitation condition, which represents the change in sediment transport capacity. 'Effective work' is calculated based on the difference between the applied boundary shear stress and the critical shear stress of the boundary materials or bed sediments represented by the complete grain size distribution. The ratio between baseline and future post-rehabilitation effective work or sediment transport capacity (Ep) is used to evaluate whether the designed channels will be stable under future flow conditions. The methodology should be based on continuous hydrographs (measure or modeled) for 20+ years (30+ years preferred). The resulting flow time series are applied to an effective work or sediment transport model to calculate Ep for a series of baseline condition and post-rehabilitation cross sections.

For channel design where the existing condition is unstable, the baseline used for comparison is based on stable reference reach(es). When reduction in sediment supply is an important physical element in stable channel conditions, the target Ep is adjusted accordingly. When reductions in sediment supply are not important, the target ratio of existing and proposed Ep is set to 1.0. That is, the proposed design attempts to match the baseline conditions (i.e., the future sediment transport condition is equal to the existing sediment transport condition). When reduction in sediment supply is important, an equivalent reduction in the transport capacity is needed. For example, if sediment supply is reduced to 40% of its baseline (reference) level, the transport capacity should also be reduced to 40% of its baseline condition.

G-4.3 Configure Design Elements

Once the basic channel geometry is established, the next step is to configure rehabilitation design elements, described in Section G-3, such that the established width, depth, slope, and any desired partial flow diversion can be accommodated.

G-4.3.1 Slope Reduction

Where the slope estimation methods utilized predict that the proposed channel gradient will be considerably flatter than the existing gradient, drop structures, grade controls, increased channel sinuousity, and/or other methods will be required to take up the elevation difference between the existing and proposed stable slopes. To maximize vegetation, aquatic, and wildlife habitat and maintain a natural channel appearance, a range of types of step-pool structures and armored riffles can be developed to accommodate drops in channel elevation. Construction of these structures may include large boulders, soil cement or concrete and will mimic natural step-pool function and morphology (as identified in reference reaches) in appearance and hydraulic function.

G-4.3.2 Channel Migration Allowance

Where feasible, rehabilitation channels should have some degree of natural geomorphic dynamic function, including a limited ability to laterally and vertically migrate within prescribed limits. Buried lateral setback stabilization can be incorporated to limit the potential for lateral channel migration into the toe of the valley side, without putting adjacent property, utilities, other infrastructure, or sensitive habitat at risk from bank erosion. Similarly, grade control structures can be incorporated to limit the potential for the rehabilitated channel to migrate vertically, without undermining roadway or bridge crossings or exposing buried utilities.

G-4.3.3 Bank Toe Protection

Bank toe protection should be located at banks to be rehabilitated, areas where infrastructure, homes, structures, are proposed or already exist, and areas where significant lateral channel movement is expected. Toe protection should be a permanent, continuous treatment that protects from cut-bank scalloping, under-cutting, or bank failure caused by the lateral migration of the low flow channel or localized scour. Rock placement along the toe of slope should be wide enough to provide maximum protection from migration of the low flow channel and should be designed to launch as needed to protect the bank from localized scour.

G-4.4 Analyze Peak Event Hydraulics

Once the channel design elements are situated, the channel configuration should be evaluated for stability and hydraulic performance under peak design flow conditions using HEC-RAS, or more sophisticated 2-dimensional hydraulic or hydrodynamic models. HEC-RAS is used to assess the channel, floodplain, and engineered features at a range of flow conditions to determine: final design of engineered structures; engineered material selection or rock sizing; compliance with flood control freeboard requirements; compliance with established peak event hydraulic criteria; sufficient dissipation of energy by step structures during high flow events; and non-erosive velocities on floodplain and along constructed slopes. Initially, individual engineered structures (e.g., step pools) are modeled through a range of flows to optimize hydraulic design. Sequences of engineered structures are then added to the model to simulate proposed conditions throughout the project reach.

G-4.5 Reference to Past Channel Rehabilitation Projects

Channel rehabilitation requires empirical inputs and groundtruthing. As part of alternatives analysis and feasibility studies, consideration should be given to lessons learned from past rehabilitation projects in the Southern California region that have similar characteristics. Comparison of proposed design parameters to similar parameters used in past successful and unsuccessful projects can be used as a line of evidence for the likelihood of projects. Post rehabilitation project appraisals should be compiled to provide a resource library to support adaptation of design approaches.

G-5. REFERENCES

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