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Water Boards

EDMUND G. BROWN JR.
GOVERNOR

MATTHEW RODRIQUEZ
SECRETARY FOR
ENVIRONMENTAL PROTECTION

San Francisco Bay Regional Water Quality Control Board

Sent via electronic mail: No hard copy to follow

July 7, 2017
Reg. Measure 413707
CIWQS Plase ID 835732

Santa Clara Valley Water District
5750 Almaden Expressway
San Jose, CA 95118
Email: SFerranti@valleywater.org

Subject: Incomplete Application for Water Quality Certification Application for the Sunnyvale East and West Channels Flood Protection Project, City of Sunnyvale, Santa Clara County

Dear Mr. Ferranti:

San Francisco Bay Regional Water Quality Control Board (Water Board) staff has reviewed the federal Clean Water Act (CWA) water quality certification application materials submitted by the Santa Clara Valley Water District (District) for the Sunnvale East and West Channel , which we received on June 7, 2017 (Application). The Project purpose is to convey the one percent annual chance exceedance flood event in the Sunnyvale East Channel for 6.5 miles, and the Sunnyvale West Channel, for 3 miles. Both channels are in the City of Sunnyvale.

This letter is being sent to inform you that the Application does not provide all the information and items needed to be complete (23 CCR § 3856), nor does it provide sufficient information to determine whether the Project complies with State water quality standards. Accordingly, this letter outlines the information needed to complete the Application and certify that the Project will not violate State water quality standards.

Comment 1. Technically Accurate Project Description (Beneficial Uses)

The Application is incomplete because it does not recognize any beneficial uses of the Sunnyvale East and West channels. Thus, the description of Project's impacts to waters of the State are not accurately described in the Application. To complete the Application, we need to be provided with a technically accurate Project description that recognizes the beneficial uses of the Sunnyvale East and West Channels. We are providing further comments below to assists with this.

To issue a water quality certification, we need to determine that a Project will comply with all State water quality standards including, but not limited to, water quality standards in the *San Francisco Bay Basin Water Quality Control Plan* (Basin Plan). The water quality standards in the Basin Plan include beneficial uses, water quality objectives, and the State's Anti-Degradation Policy. Further, as indicated in Chapter 2 of the Basin Plan, beneficial uses designated for a water body generally apply to all of its tributaries, and beneficial uses are protected regardless of whether the Basin Plan identifies and designates beneficial uses for a water body.

Accordingly, the Sunnyvale East Channel has the beneficial uses of the Guadalupe Slough because it is tributary to the Guadalupe Slough[1]. Likewise, the Sunnyvale West Channel is tributary to Moffett Channel because it is tributary to the Moffett Channel[2]. Please note, however, that the Estuarine Habitat beneficial use and Preservation of Rare and Endangered Species beneficial use only apply to the tidally-influence channel sections. The Project should be designed to avoid and minimize impacts to beneficial uses, particularly in the tidally-influenced portions of the site (see Comment 4 pertaining to requirements for avoiding and minimizing impacts).

Comment 2. Full, Technically Accurate, and Complete Project Description (Permanent Impacts and Sediment Transport Analysis)

We appreciate the Application shows impacts in jurisdictional waters due placement of rock slope protection (RSP) Application, Tables 4A, 4B, and 4C). However, we disagree that the RSP is a temporary impact in this Project, but instead, we consider RSP a permanent impact. This is because the rock will replace existing earthen substrate, thereby permanently degrading the functions inherent in soft-earthen substrates, which include nutrient cycling; adsorption and breakdown of some pollutants in stormwater runoff; and substrate for benthic invertebrate communities. As a result, the Project will permanently impact beneficial uses and has the potential to cause or contribute to degradation of water quality within the channels. Furthermore, the linear feet of these impacts is not included in the Application. To complete the Application, we need to be provided with the linear feet and acres of permanent impacts associated with placement of RSP, and the linear feet and acres of temporary impacts in portions of the channels where RSP will not be placed (see Comment 4, Avoidance of Impacts, below).

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[1] The Basin Plan designates the following beneficial uses for the Guadalupe Slough: Estuarine Habitat (EST); Water Contact Recreation (REC-1); Non-Water Contact Recreation (REC-2); Wildlife Habitat (WILD); and Preservation of Rare and Endangered Species (RARE).

[2] The Basin Plan designates the following beneficial uses for the Moffett Channel: EST; REC-1; REC-2; and WILD.

The technical hydraulic information presented in the Application does not justify the proposed light class RSP, the concrete slurry sealant, or the new concrete channel segment. Specifically, Application, pg. 28, indicates that RSP design velocities for the 100-year storm event (Table A in Appendix A) were used to limit the areas of the proposed RSP; the text on this page also states that RSP was limited to locations that were currently eroding or would experience increased velocities during flood events. The majority of the 100-year storm event’s velocities through these reaches are well within the stability thresholds found to work for soil bioengineering bank stabilization methods (Fischenich, 2001 (Attachment A)). In the Fischenich report, live brush mattressing and brush layering both had a stability threshold of 12 ft/s when grown, vegetated coir mats had a stability threshold of 9.5 ft/s, and live willow stakes had a stability threshold ranging from 3 to 10 ft/s. These soil bioengineering bank stabilization techniques would provide substantially greater habitat than the light class riprap or concrete and improve water quality and beneficial uses. The concrete lined segment and concrete slurry sealant are not necessary given the stated velocities. In addition, there was no information provided about expected channel velocities during more frequently occurring storm events (i.e., 1.5-year, 2-year, 5-year, 10-year storm events). Due to their likelihood of occurrence, the velocities during these more frequently occurring storm events should be considered when evaluating the need for RSP. Finally, the bank shear stress values for these reaches were not provided even though it was stated in Section 4.4 of the Alternatives Analysis that, “The SCVWD performed a hydraulic analysis of erosion potential based on discharge, flow velocities, and shear stress to identify the locations and sizing of rock placement.” To complete the Application, we need to be provided with the shear stress values and the calculations to evaluate whether the Project design is the least environmentally damaging practicable alternative (see Comment 4, Avoidance of Impacts below).

Comment 3 – Full and Technically Accurate Project Description (Reduced Maintenance and Sediment Transport)

The Application indicates that reducing sediment maintenance is an objective of the Project. The information on the proposed Project design, however, does not demonstrate that existing geomorphic processes within the channel will be altered in a manner that would reduce sediment deposition. As a result, we do not expect sediment maintenance to be reduced by the Project. Accordingly, to complete the Application, we need to be provided with a sediment transport analysis that clarifies how the Project design is expected to reduce sediment maintenance by reducing sediment deposition. To assist with the development of a sediment transport analysis that will meet Water board requirements, we offer the further comments and suggestions below.

The Project design focuses on addressing water surface elevation for the 100-year flow event by raising levee heights and constructing floodwalls without considering sediment transport and deposition processes during the more frequent flow events that have a greater influence channel geomorphology (i.e., 1.5-year, 2-year, 5-year, 10-year storm events). In addition, the Application states that backwaters from Guadalupe Slough and Calabazas Creek enter the Project channels, which suggests that incoming tidal flows contribute to the sediment loads in the system. The Application, however, does not address provide information on this potential sediment source. Such considerations will need to be incorporated into the sediment transport analysis to demonstrate that the objective to minimize sediment maintenance will be achieved. We also note that for the Island Ponds Project, which included breaching Ponds A19, A20, and A21, the ponds are filling in with Bay sediment, despite the computer modeling results that predicted fluvial sediment would exceed the Bay source. The Application should be revised to address sediment transport with a focus on how incorporating a geomorphically functional design in the Project in order to meet the objective of reducing sediment maintenance. An example of how this can be done in a tidally influenced channel can be found on-line at http://www.marinwatersheds.org/documents/201611GWPFinalReport.pdf.

Further, we noted that a small section in the East channel will have the levee laid back and a rock bench constructed to create a low flow channel that will transport sediment more efficiently downstream. It's not clear why this approach is not used more extensively throughout the Project when the right-of-way is 40 to 80 feet wide. Further, the Application states that the channel banks are the soure of sediment in the Project, though all of the photographs in the Application show stable banks. In addition, if the banks are eroding, we would expect the channel cross section to be increasing. The Application should be revised to include more details with respect to the location and extent of channel erosion.

Comment 4. Avoidance of Impacts (Clean Water Act, Section 404(b)(1) Analysis)

We appreciate the analysis included as Appendix G intended to demonstrate how the Project avoids and mimimizes impacts to waters of the State. However the information provided is not sufficient for us to determine that impacts have been avoided to the maximum extent practicable. As a result, the Application does not include a complete description of avoidance measures necessary for it to be complete.

This refers to our requirement that for the Water Board to permit the proposed Project pursuant to the Clean Water Act, Section 401, we require a project proponent to conduct an alternatives analysis consistent with the U.S. Environmental Protection Agency's 404(b)(1) Guidelines (Guidelines). The Basin Plan incorporates Guidelines by reference to determine the circumstances under which filling of wetlands, streams, or other waters of the U.S. and/or the State may be permitted. In accordance with the Basin Plan, filling, dredging, excavating and discharging into a wetland or water of the state is prohibited unless the project meets the least environmentally damaging practicable alternative (LEDPA) standard as determined through the 404(b)(1) alternatives analysis. Although the LEDPA analysis is not required by CEQA, a project proponent may tailor their alternative analysis to fulfill both the CEQA and 404(b)(1) requirements to help expedite the Water Board's issuance of a 401 Certification and/or waste discharge requirements under Porter-Cologne.

The Guidelines sequence the order in which proposals should be approached: 1) Avoid - avoid impacts to waters; 2) Minimize - modify project to minimize impacts to waters; and, 3) Compensate – once impacts have been fully minimized, compensate for unavoidable impacts to waters. When it is not possible to avoid impacts to water bodies, disturbance should be minimized. Compensatory mitigation for lost water body acreage and functions through enhancement, restoration, and/or creation should only be considered after disturbance has been minimized. Where impacts cannot be avoided, the enhancement, restoration, and/or creation of adequate mitigation habitat to compensate for the loss of water body acreage, functions and values must be provided pursuant to the California Wetland Conservation Policy (also known as the "no net loss" policy; Executive Order W-59-93).

However, the LEDPA analysis provided as Appendix G is not sufficient for us to determine that impacts have been avoided and minimized to the maximum extent practicable. For example, the three-phase screening process in the LEDPA analysis resulted in only two of the 14 alternatives receiving the “Pass” score for all three phases. As a result, only those two alternatives are fully described and evaluated. For instance, Alternatve M-Bioengineering, was screened out at the second screening step due to cost, without providing any information for costs. Given that about 49,000 cubic yards of rock are proposed for the Project, it seems the cost of rock would have also been screened out since based on our experience, rock is more expensive than bioengineering methods. Accordingly, the analysis lacks the details necessary to show that the proposed RSP avoids and minimizes impacts to the maximum extent practicable.

In addition, the LEDPA analysis stated that use of Pond A4 as a detention basin was rejected due to the potential loss of wetlands, potential loss of sensitive species habitat, and water quality. However, there was not enough information provided about the potential water quality threat for Water Board staff to evaluate this potential threat. Similarly, the potential changes to existing habitat and salt marsh species habitat were not fully explained. For instance, the following questions, while not exhaustive, could have been addressed:

1. How much freshwater inflow would it take to change the existing habitat?
2. Could the Sunnyvale East Channel be diverted to Pond A4 without potentially changing the habitat?
3. Would changing the Project design upstream of Pond A4 result in a preferred alternative?
4. Could islands be installed within Pond A4 to provide refugia for salt marsh species?

Alternative M-Bioengineering was removed from further evaluation after a determination that this alternative was financially and logistically infeasible. However, no information about Alternative M's design, cost, and logistics was provided in the Alternatives Analysis. The only description about this alternative was that it used biotechnical bank stabilization with native vegetation plantings to stabilize the eroding channel banks instead of the proposed RSP. The Water Board supports the biotechnical bank stabilization approach, but there was insufficient detail and information about this alternative to assess it accurately and completely.

In the LEDPA analysis, additional details are needed to explain whether the District has evaluated the incremental benefits of flood detention for flows that are less than the 100-year event. Although Braly Field and Pond A4 were considered individually in the context of the 100-year event, those sites were rejected due to infeasibility and cost. We recommend the District seek detention options that are higher in the watershed where incremental benefits of smaller detention measures may be more significant.

With the exception of Alternative M, we noted that the alternatives screened for the LEDPA analysis only uses those same alternatives that were screened for purposes under CEQA, despite our comment on the Draft Environmental Impact Report stating that those alternatives would not meet the LEDPA requirements (February 21, 2014). Nevertheless, the proposed Project is not different from the CEQA preferred alternative, and the LEDPA does not provide the justification for rejecting Measure M or even a blend of bioengineering methods with other design solutions. For the LEDPA analysis, we need additional information and data for the District demonstrate the viability of bioengineering solutions for the Project.

We require the LEDPA analysis to be revised to address, at a minimum, the following issues:

- Alternatives that utilizes natural channel geometry with a low-flow channel and floodplain bench;

- More information about the water quality impact associated with using Pond A4 as a detention basin; and

- Alternatives that reduce the amount of impacts to waters of the State, including RSP amounts. For example, Alternative D could be revised to exclude the RSP, or other alternatives that reduce the hardscape and incorporate habitat enhancement features. In addition, in a small section of the East channel south of Interstate 101, the levee will be laid back and a bench will be constructed to construct a low-flow channel that will more efficiently transport sediment downstream. We support this approach but the Application shows no indicate this was considered throughout the Project.

Water Board staff has experience with similar flood control projects that incorporated natural habitat enhancement features into 100-year flood conveyance designs. For example, 100-year flood channel conveyance can be achieved with channel geometry that is based on natural floodplain features in-lieu of standard trapezoidal and rectangular channels, even with limited channel width. A low flow meandering channel with a floodplain bench could achieve the same design flood conveyance as the currently proposed Project, but this alternative was not considered in the Alternative Analysis. The use of this natural flood protection alternative could reduce the Project’s impacts to the channels and on-site wetlands while reducing sediment maintenance. In order for Water Board staff to determine the LEDPA, an alternative that uses channel geometry that is based on natural flood plain features needs to be fully evaluated. A geomorphic approach (see Comment 3) with bioengineering measures for bank stability is more aligned with the District’s “Natural Flood Protection” under the 2002 and 2012 bond measures for clean, safe, water and natural flood protection referenced in the LEDPA analysis.

Comment 5 - Proposed Mitigation is not Sufficient or Appropriate

The proposed mitigation to purchase mitigation credits in the mitigation bank located 15 miles away from the Project’s impacts is not acceptable. Since the impacts need to be reevaluated (see above), the compensatory mitigation plan should also be revised. The current proposal only addresses a portion of the Project’s impacts. To develop an appropriate mitigation plan, we recommend the District undertake the following:

1. Identify and quantify any unavaoidable impacts based on the degradation of beneficial uses and water quality resulting from permanently hardscaping existing channel substrate;

2. Identify and quantify mitigation opportunities that are within or as close as possible to the Project (within same drainage area is preferred); and

3. Identify mitigation opportunities that are the same kind of habitat as will be impacted waters, specifically the mitigation will need to address linear impacts as well as aerial impacts (Note: the proposed mitigation bank does not provide linear credits and is therefore unacceptable).

Comment 6 – Impervious Surfaces
The Project includes thousands of linear feet of impervious surfaces for maintenance roads and/or pedestrian uses. The Application must include a plan to demonstrate the Project includes measures to capture and detain or retain first-flush flows to prevent erosive flows from stormwater runoff from damaging the channel banks.

Comment 7 – Consultations with Federal Agencies
The Application indicates that the District has consulted with the U.S. Fish and Wildlife Service for a consultation under the Endangered Species Act (ESA), Section 7. The District must also coordinate with the National Marine Fisheries Service to consult under the ESA, Section 7. For a complete Application, the Water Board requires both federal agencies to determine whether incidental take permits are necessary for the project and/or any conservation measures to avoid take and/or jeopardy to federal threatened and endangered species.

Comment 8 – Full, Technically Accurate Project Description and Avoidance Measures (Volume and Reuse of Excavated Soil)
The Application indicates that a substantial amount of excavated soil will be reused onsite, but does not include the anticipated volume that will be reused on-site nor the measures that will be undertaken to ensure that the soil quality is appropriate for reuse on-site. As a result, the Application does not include a full and technically accurate Project description and is missing avoidance measures.

To complete the application, the District needs to provide us with a soil management plan that it will implement to ensure that the quality excavated sediment and soil is appropriate for on-site beneficial reuse. The plan must show the steps the District will take to implement the requirements of the Water Board May 2000 staff report, Beneficial Reuse of Dredged Materials: Sediment Screening and Testing Guidelines, or the most current revised version. Regional Water Board staff shall review and approve data characterizing the quality of all sediment and soil fill proposed for reuse onsite, and imported soil fill for the Project, prior to placement of fill at any of the levee, marsh, or channel areas at the Project site. Modifications to these procedures may be approved on a case-by-case basis, pending the District’s ability to demonstrate that the soil proposed for reuse and any imported soil fill material is unlikely to adversely impact beneficial uses.

Conclusion

As submitted, the Application is not yet complete. We recommend the District coordinate with us and other agency staff for a site inspection to help inform any revisions necessary for the Application.

Please contact me at (510) 622-2462 or susan.glendening@waterboards.ca.gov if you have any questions. All future correspondence regarding this Project should reference CIWQS Place ID No. 835732.

Sincerely,

Digitally signed by
Xavier Fernandez
Date: 2017.07.07
17:02:43 -07'00'

Xavier Fernandez
Senior Environmental
Scientist/Section Leader
Watershed Division

Enc.: Stability Thresholds for Stream Restoration Materials (Fischenich 2001)

Cc: SCVWD:
    Bill Sanchez, Bsanchez@valleywater.org
    Katherine Oven, Koven@valleywater.org
    Collette Frawley, Cfrawley@valleywater.org
  CDFW:
    Mayra Molina, Mayra.Molina@Wildlife.ca.gov
    Brenda Blinn, Brenda.Blinn@wildlife.ca.gov
  Corps, SF Regulatory Branch:
    Keith Hess, Keith.D.Hess@usace.army.mil
    Katerina Galacatos, katerina.galacatos@usace.army.mil
  Horizon Water and Environment, LLC, info@horizonh2o.com

Stability Thresholds for Stream Restoration Materials

by Craig Fischenich[1]

May 2001

Complexity	***Value as a Planning Tool***	***Cost***
🟥🟥🟥🟥⬜	🟥🟥🟥🟥⬜	🟥⬜⬜⬜⬜
Low Moderate High	Low Moderate High	Low Moderate High

OVERVIEW

Stream restoration projects usually involve some modification to the channel or the banks. Designers of stabilization or restoration projects must ensure that the materials placed within the channel or on the banks will be stable for the full range of conditions expected during the design life of the project. Unfortunately, techniques to characterize stability thresholds are limited. Theoretical approaches do not exist and empirical data mainly consist of velocity limits, which are of limited value.

Empirical data for shear stress or stream power are generally lacking, but the existing body of information is summarized in this technical note. Whereas shear thresholds for soils found in channel beds and banks are quite low (generally < 0.25 lb/sf), those for vegetated soils (0.5 – 4 lb/sf), erosion control materials and bioengineering techniques (0.5 – 8 lb/sf), and hard armoring (< 13 lb/sf) offer options to provide stability.

STABILITY CRITERIA

The stability of a stream refers to how it accommodates itself to the inflowing water and sediment load. In general, stable streams may adjust their boundaries but do not exhibit trends in changes to their geometric character. One form of instability occurs when a stream is unable to transport its sediment load (i.e., sediments deposited within the channel), leading to the condition referred to as aggradation.

When the ability of the stream to transport sediment exceeds the availability of sediments within the incoming flow, and stability thresholds for the material forming the boundary of the channel are exceeded, erosion occurs. This technical note deals with the latter case of instability and distinguishes the presence or absence of erosion (threshold condition) from the magnitude of erosion (volume).

Erosion occurs when the hydraulic forces in the flow exceed the resisting forces of the channel boundary. The amount of erosion is a function of the relative magnitude of these forces and the time over which they are applied. The interaction of flow with the boundary of open channels is only imperfectly understood. Adequate analytical expressions describing this interaction have not yet been developed for conditions associated with natural channels. Thus, means of characterizing erosion potential must rely heavily upon empiricism.

Traditional approaches for characterizing erosion potential can be placed in one of two categories: maximum permissible velocity, and tractive force (or critical shear stress). The former approach is advantageous in that velocity is a parameter that can be measured within the flow. Shear stress cannot be directly measured – it must be computed from other flow parameters. Shear stress is a better measure of the fluid force on the channel boundary than is velocity. Moreover, conventional guidelines, including ASTM standards, rely upon the shear stress as a

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[1] USAE Research and Development Center, Environmental Laboratory, 3909 Halls Ferry Rd., Vicksburg MS 39180

means of assessing the stability of erosion control materials. Both approaches are presented in this paper.

Incipient Motion (Threshold Condition)

As flow over the bed and banks of a stream increases, a condition referred to as the threshold state is reached when the forces tending to move materials on the channel boundary are in balance with those resisting motion. The forces acting on a noncohesive soil particle lying on the bed of a flowing stream include hydrodynamic lift, hydrodynamic drag, submerged weight ($F_w – F_b$), and a resisting force F_r. as seen in Figure 1. The drag is in the direction of the flow and the lift and weight are normal to the flow. The resisting force depends on the geometry of the particles. At the threshold of movement, the resultant of the forces in each direction is zero. Two approaches for defining the threshold state are discussed herein, initial movement being specified in terms of either a critical velocity (v_{cr}) or a critical shear stress (τ_{cr}).

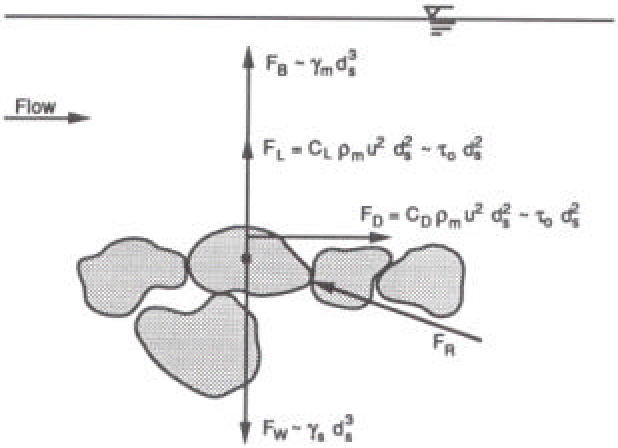

Figure 1. Forces acting on the boundary of a channel (adapted from Julien (1995)).

Critical Velocity

Figure 1 shows that both the lift and the drag force are directly related to the velocity squared. Thus, small changes in the velocity could result in large changes in these forces. The permissible velocity is defined as the maximum velocity of the channel that will not cause erosion of the channel boundary. It is often called the critical velocity because it refers to the condition for the initiation of motion. Early works in canal design and in evaluating the stability of waterways relied upon this method. Considerable empirical data exist relating maximum velocities to various soil and vegetation conditions.

However, this simple method for design does not consider the channel shape or flow depth. At the same mean velocity, channels of different shapes or depths may have quite different forces acting on the boundaries. Critical velocity is depth-dependent, and a correction factor for depth must be applied in this application. Despite these limitations, maximum permissible velocity can be a useful tool in evaluating the stability of various waterways. It is most frequently applied as a cursory analysis when screening alternatives.

Critical Shear Stress

The forces shown in Figure 1 can also be expressed in terms of the shear stress. Shear stress is the force per unit area in the flow direction. Its distribution in steady, uniform, two-dimensional flow in the channel can be reasonably described. An estimate of the average boundary shear stress (τ_o) exerted by the fluid on the bed is:

$$\tau_o = \gamma D S_f \qquad (1)$$

where γ is the specific weight of water, D is the flow depth (~ hydraulic radius), and S_f is the friction slope. Derived from consideration of the conservation of linear momentum, this quantity is a spatial average and may not provide a good estimate of bed shear at a point.

Critical shear stress (τ_{cr}) can be defined by equating the applied forces to the resisting forces. Shields (1936) determined the threshold condition by measuring sediment transport for values of shear at least twice the critical value and then extrapolating to the point vanishing sediment transport. His laboratory experiments have since served as a basis for defining critical shear stress. For soil grains of diameter d and angle of repose ϕ on a flat bed, the following relations can approximate the critical shear for various sizes of sediment:

$$\tau_{cr} = 0.5(\gamma_s - \gamma_w) d \, Tan \phi \qquad \text{For clays} \qquad (2)$$

$$\tau_{cr} = 0.25 d_*^{-0.6} (\gamma_s - \gamma_w) d \, Tan \phi \qquad \text{For silts and sands} \qquad (3)$$

$t_{cr} = 0.06(l_s - l_w)d\ Tan f$ For gravels and cobbles (4)

Where

$$d_* = d\left[\frac{(G-1)g}{n^2}\right]^{1/3} \quad (5)$$

γ_s = the unit weight of the sediment
γ_w = the unit weight of the water/sediment mixture
G = the specific gravity of the sediment
G = gravitational acceleration
ν = the kinematic viscosity of the water/sediment mixture

The angle of repose ϕ for noncohesive sediments is presented in Table 1 (Julien 1995), as are values for critical shear stress. The critical condition can be defined in terms of shear velocity rather than shear stress (note that shear velocity and channel velocity are different). Table 1 also provides limiting shear velocity as a function of sediment size. The V_{*c} term is the critical shear velocity and is equal to

$$V_{*c} = \sqrt{gR_hS_f} \quad (6)$$

Table 1. Limiting Shear Stress and Velocity for Uniform Noncohesive Sediments

Class name	*d_s (in)*	*f (deg)*	*t_{*c}*	*t_{cr} (lb/sf)*	*V_{*c} (ft/s)*
Boulder					
Very large	>80	42	0.054	37.4	4.36
Large	>40	42	0.054	18.7	3.08
Medium	>20	42	0.054	9.3	2.20
Small	>10	42	0.054	4.7	1.54
Cobble					
Large	>5	42	0.054	2.3	1.08
Small	>2.5	41	0.052	1.1	0.75
Gravel					
Very coarse	>1.3	40	0.050	0.54	0.52
Coarse	>0.6	38	0.047	0.25	0.36
Medium	>0.3	36	0.044	0.12	0.24
Fine	>0.16	35	0.042	0.06	0.17
Very fine	>0.08	33	0.039	0.03	0.12
Sands					
Very coarse	>0.04	32	0.029	0.01	0.070
Coarse	>0.02	31	0.033	0.006	0.055
Medium	>0.01	30	0.048	0.004	0.045
Fine	>0.005	30	0.072	0.003	0.040
Very fine	>0.003	30	0.109	0.002	0.035
Silts					
Coarse	>0.002	30	0.165	0.001	0.030
Medium	>0.001	30	0.25	0.001	0.025

Table 1 provides limits best applied when evaluating idealized conditions, or the stability of sediments in the bed. Mixtures of sediments tend to behave differently from uniform sediments. Within a mixture, coarse sediments are generally entrained at lower shear stress values than presented in Table 1. Conversely, larger shear stresses than those presented in the table are required to entrain finer sediments within a mixture.

Cohesive soils, vegetation, and other armor materials can be similarly evaluated to determine empirical shear stress thresholds. Cohesive soils are usually eroded by the detachment and entrainment of soil aggregates. Motivating forces are the same as those for noncohesive banks; however, the resisting forces are primarily the result of cohesive bonds between particles. The bonding strength, and hence the soil erosion resistance, depends on the physio-chemical properties of the soil and the chemistry of the fluids. Field and laboratory experiments show that intact, undisturbed cohesive soils are much less susceptible to flow erosion than are non-cohesive soils.

Vegetation, which has a profound effect on the stability of both cohesive and noncohesive soils, serves as an effective buffer between the water and the underlying soil. It increases the effective roughness height of the boundary, increasing flow resistance and displacing the velocity upwards away from the soil, which has the effect of reducing the forces of drag and lift acting on the soil surface. As the boundary shear stress is proportional to the square of the near-bank velocity, a reduction in this velocity produces a much greater reduction in the forces responsible for erosion.

Vegetation armors the soil surface, but the roots and rhizomes of plants also bind the soil and introduce extra cohesion over and above any intrinsic cohesion that the bank material may have. The presence of vegetation does not render underlying soils immune from erosion, but the critical condition for erosion of a vegetated bank is usually the threshold of failure of the plant stands by snapping, stem scour, or uprooting, rather than for detachment and entrainment of the soils themselves. Vegetation failure usually occurs at much higher levels of flow intensity than for soil erosion.

Both rigid and flexible armor systems can be used in waterways to protect the channel bed from erosion and to stabilize side slopes. A wide array of differing armor materials are available to accomplish this. Many manufactured products have been evaluated to determine their failure threshold. Products are frequently selected using design graphs that present the flow depth on one axis and the slope of the channel on the other axis. Thus, the design is based on the depth/slope product (i.e., the shear stress). In other cases, the thresholds are expressed explicitly in terms of shear stress. Notable among the latter group are the field performance testing results of erosion control products conducted by the TXDOT/TTI Hydraulics and Erosion Control Laboratory (TXDOT 1999).

Table 2 presents limiting values for shear stress and velocity for a number of different channel lining materials. Included are soils, various types of vegetation, and number of different commonly applied stabilization techniques. Information presented in the table was derived from a number of different sources. Ranges of values presented in the table reflect various measures presented within the literature. In the case of manufactured products, the designer should consult the manufacturer’s guidelines to determine thresholds for a specific product.

Uncertainty and Variability

The values presented in Table 2 generally relate to average values of shear stress or velocity. Velocity and shear stress are neither uniform nor steady in natural channels. Short-term pulses in the flow can give rise to instantaneous velocities or stresses of two to three times the average; thus, erosion may occur at stresses much lower than predicted. Because limits presented in Table 2 were developed empirically, they implicitly include some off this variability. However, natural channels typically exhibit much more variability than the flumes from which these data were developed.

Sediment load can also profoundly influence the ability of flow to erode underlying soils. Sediments in suspension have the effect of damping turbulence within the flow. Turbulence is an important factor in entraining materials from the channel boundaries. Thus, velocity and shear stress thresholds are 1.5 to 3 times that presented in the table for flows carrying high sediment loads.

In addition to variability of flow conditions, variation in the channel lining characteristics can influence erosion predictions. Natural bed material is neither spherical nor of uniform size. Larger particles may shield smaller ones from direct impact so that the latter fail to move until higher stresses are attained. For a given grain size, the true threshold criterion may vary by nearly an order of magnitude depending on the bed gradation. Variation in the installation of erosion control measures can reduce the threshold necessary to cause erosion.

Table 2. Permissible Shear and Velocity for Selected Lining Materials[1]

Boundary Category	Boundary Type	Permissible Shear Stress (lb/sq ft)	Permissible Velocity (ft/sec)	Citation(s)
Soils	Fine colloidal sand	0.02 - 0.03	1.5	A
	Sandy loam (noncolloidal)	0.03 - 0.04	1.75	A
	Alluvial silt (noncolloidal)	0.045 - 0.05	2	A
	Silty loam (noncolloidal)	0.045 - 0.05	1.75 – 2.25	A
	Firm loam	0.075	2.5	A
	Fine gravels	0.075	2.5	A
	Stiff clay	0.26	3 – 4.5	A, F
	Alluvial silt (colloidal)	0.26	3.75	A
	Graded loam to cobbles	0.38	3.75	A
	Graded silts to cobbles	0.43	4	A
	Shales and hardpan	0.67	6	A
Gravel/Cobble	1-in.	0.33	2.5 – 5	A
	2-in.	0.67	3 – 6	A
	6-in.	2.0	4 – 7.5	A
	12-in.	4.0	5.5 – 12	A
Vegetation	Class A turf	3.7	6 – 8	E, N
	Class B turf	2.1	4 - 7	E, N
	Class C turf	1.0	3.5	E, N
	Long native grasses	1.2 – 1.7	4 – 6	G, H, L, N
	Short native and bunch grass	0.7 - 0.95	3 – 4	G, H, L, N
	Reed plantings	0.1-0.6	N/A	E, N
	Hardwood tree plantings	0.41-2.5	N/A	E, N
Temporary Degradable RECPs	Jute net	0.45	1 – 2.5	E, H, M
	Straw with net	1.5 – 1.65	1 – 3	E, H, M
	Coconut fiber with net	2.25	3 – 4	E, M
	Fiberglass roving	2.00	2.5 – 7	E, H, M
Non-Degradable RECPs	Unvegetated	3.00	5 – 7	E, G, M
	Partially established	4.0-6.0	7.5 – 15	E, G, M
	Fully vegetated	8.00	8 – 21	F, L, M
Riprap	6 – in. d_{50}	2.5	5 – 10	H
	9 – in. d_{50}	3.8	7 – 11	H
	12 – in. d_{50}	5.1	10 – 13	H
	18 – in. d_{50}	7.6	12 – 16	H
	24 – in. d_{50}	10.1	14 – 18	E
Soil Bioengineering	Wattles	0.2 – 1.0	3	C, I, J, N
	Reed fascine	0.6-1.25	5	E
	Coir roll	3 - 5	8	E, M, N
	Vegetated coir mat	4 - 8	9.5	E, M, N
	Live brush mattress (initial)	0.4 – 4.1	4	B, E, I
	Live brush mattress (grown)	3.90-8.2	12	B, C, E, I, N
	Brush layering (initial/grown)	0.4 – 6.25	12	E, I, N
	Live fascine	1.25-3.10	6 – 8	C, E, I, J
	Live willow stakes	2.10-3.10	3 – 10	E, N, O
Hard Surfacing	Gabions	10	14 – 19	D
	Concrete	12.5	>18	H

[1] Ranges of values generally reflect multiple sources of data or different testing conditions.

A. Chang, H.H. (1988).
B. Florineth. (1982)
C. Gerstgraser, C. (1998).
D. Goff, K. (1999).
E. Gray, D.H., and Sotir, R.B. (1996).
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J. Schoklitsch, A. (1937).
K. Sprague, C.J. (1999).
L. Temple, D.M. (1980).
M. TXDOT (1999)
N. Data from Author (2001)
O. USACE (1997).

Changes in the density or vigor of vegetation can either increase or decrease erosion threshold. Even differences between the growing and dormant seasons can lead to one- to twofold changes in erosion thresholds.

To address uncertainty and variability, the designer should adjust the predicted velocity or shear stress by applying a factor of safety or by computing local and instantaneous values for these parameters. Guidance for making these adjustments is presented in the section titled “Application” below.

EROSION MAGNITUDE

The preceding discussion dealt with the presence or absence of erosion, but did not address the extent to which erosion might occur for a given flow. If the thresholds presented in Table 2 are exceeded, erosion should be expected to occur. In reality, even when those thresholds are not exceeded, some erosion in a few select locations may occur. The extent to which this minor erosion could become a significant concern depends in large measure on the duration of the flow, and upon the ability of the stream to transport those eroded sediments.

Flow Duration

Although not stated, limits regarding erosion potential published by manufacturers for various products are typically developed from studies using short flow durations. They do not reflect the potential for severe erosion damage that can result from moderate flow events over several hours. Studies have shown that duration of flow reduces erosion resistance of many types of erosion control products, as shown in Figures 2 - 4. A factor of safety should be applied when flow duration exceeds a couple of hours.

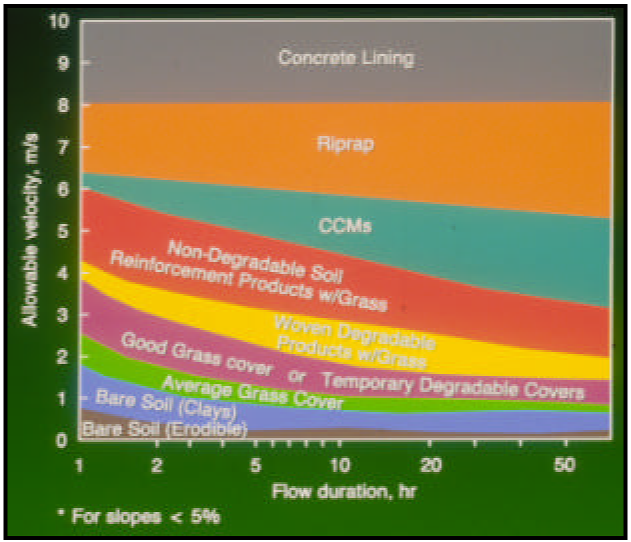

Figure 2. Erosion limits as a function of flow duration (from Fischenich and Allen (2000)).

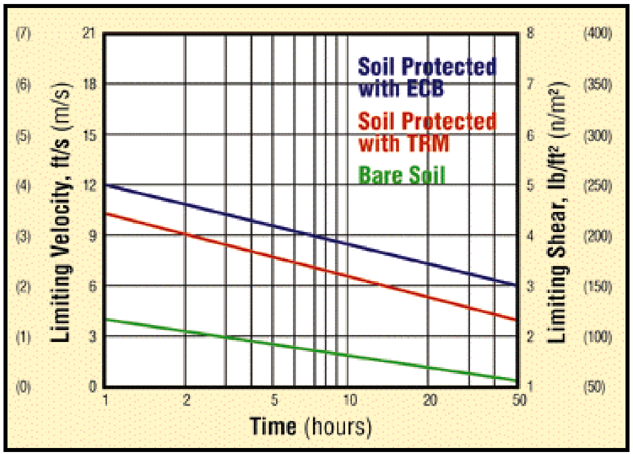

Figure 3. Limiting values for bare and TRM protected soils (from Sprague (1999))

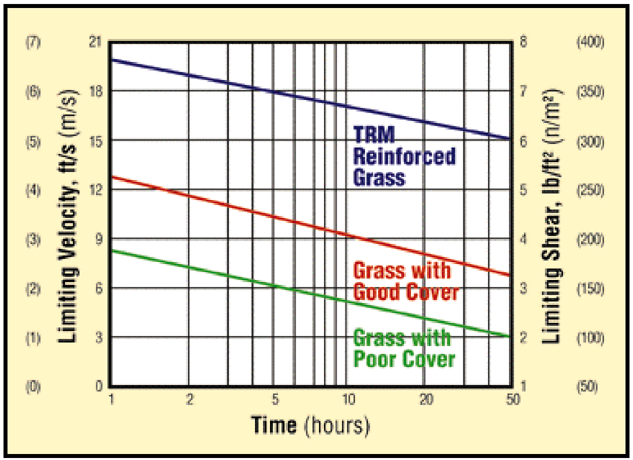

Figure 4. Limiting values for plain and TRM reinforced grass (from Sprague (1999))

Correlations between flow volume and amount of erosion tend to be poor. Multi-peaked flows may be more effective than single flows of comparable or greater magnitude because of the increased incidence of wetting. Flows with long durations often have a more significant effect on erosion than short-lived flows of higher magnitude. Sediment transport analysis can be used to gauge the magnitude of erosion potential in the channel design, but predictive capability is limited.

Sediment Transport

A number of flow measures can be used to assess the ability of a stream to transport sediment. The unit stream power (P_m) is one common approach, and is related to the earlier discussion in that stream power includes both velocity and shear stress as components. Sediment transport (Q_s) increases when the unit stream power (P_m) increases. Unit stream power in turn is controlled by both tractive stress and flow velocity:

$$P_m = v \cdot \tau = v \cdot \gamma_w \cdot D \cdot S_f \qquad (7)$$

The total power (P_t) is the product of the unit power times the channel width (W):

$$P_t = P_m \cdot W = v \cdot W \cdot D \cdot \gamma_w \cdot S_f = v \cdot A \cdot \gamma_w \cdot S_f = Q_w \cdot \gamma_w \cdot S_f \qquad (8)$$

Stream power assessments can be useful in evaluating sediment discharge within a stream channel and the deposition or erosion of sediments from the streambed. However, their utility for evaluating the stability of measures applied to prevent erosion is limited because of the lack of empirical data relating stream power to stability. The analysis of general streambank erosion is not a simple extension of the noncohesive bed case with an added downslope gravity component. Complication is added by other influencing variables, such as vegetation, whose root system can reinforce bank material and increase erosion resistance. Factors influencing bank erosion are summarized in Table 3.

Table 3. Factors Influencing Erosion

actor	***elevant characteristics***
low properties	agnitude, frequency and variability of stream discharge; Magnitude and distribution of elocity and shear stress; Degree of turbulence
ediment composition	ediment size, gradation, cohesion and stratification
limate	ainfall amount, intensity and duration; Frequency and duration of freezing
ubsurface conditions	eepage forces; Piping; Soil moisture levels
hannel geometry	idth and depth of channel; Height and angle of bank; Bend curvature
iology	egetation type, density and root character; Burrows
nthropogenic factors	rbanization, flood control, boating, irrigation

APPLICATION

The stability of a waterway or the suitability of various channel linings can be determined by first calculating both the mean velocity and tractive stress (by the previous equations). These values can then be compared with allowable velocity and tractive stress for a particular ground cover or lining system under consideration (e.g., existing vegetation cover, an erosion control blanket, or bioengineering treatment). Allowable tractive stresses for various types of soil, linings, ground covers, and stabilization measures including soil bioengineering treatments, are listed in Table 2. Additionally, manufacturers' product literature can provide allowable tractive stresses or velocities for various types of erosion control products.

An iterative procedure may be required when evaluating channel stability because various linings will affect the resistance coefficient, which in turn may change the estimated flow conditions. A general procedure for the application of information presented in this paper is outlined in the following paragraphs.

Step 1-Estimate Mean Hydraulic Conditions.

Flow of water in a channel is governed by the discharge, hydraulic gradient, channel geometry, and roughness coefficient. This functional relationship is most frequently evaluated using normal depth or backwater computations that take into account principles of conservation of linear momentum. The latter is preferable because it accounts for variations in momentum slope, which is directly related to shear stress. Several models are available to aid the hydraulic engineer in assessing hydraulic conditions. Notable examples include HEC-2, HEC-RAS, and WSP2. Channel cross sections, slopes, and Manning's coefficients should be determined based upon surveyed data and observed or predicted channel boundary conditions. Output from the model should be used to compute main channel velocity and shear stress at each cross section.

Step 2- Estimate Local/Instantaneous Flow Conditions.

The computed values for velocity and shear stress may be adjusted to account for local variability and instantaneous values higher than mean. A number of procedures exist for this purpose. Most commonly applied are empirical methods based upon channel form and irregularity. Several references at the end of this paper present procedures to make these adjustments. Chang (1988) is a good example. For straight channels, the local maximum shear stress can be assumed from the following simple equation:

$$t_{\max} = 1.5t \qquad (9)$$

for sinuous channels, the maximum shear stress should be determined as a function of the planform characteristics using Equation 10:

$$t_{\max} = 2.65\, t \left(\frac{R_c}{W}\right)^{-0.5} \qquad (10)$$

where R_c is the radius of curvature and W is the top width of the channel. Equations 9 and 10 adjust for the spatial distribution of shear stress; however, temporal maximums in turbulent flows can be 10 – 20 percent higher, so an adjustment to account for instantaneous maximums should be added as well. A factor of 1.15 is usually applied.

Step 3- Determine Existing Stability.

Existing stability should be assessed by comparing estimates of local and instantaneous shear and velocity to values presented in Table 2. Both the underlying soil and the soil/vegetation condition should be assessed. If the existing conditions are deemed stable and are in consonance with other project objectives, then no further action is required. Otherwise, proceed to step 4.

Step 4- Select Channel Lining Material.

If existing conditions are unstable, or if a different material is needed along the channel perimeter to meet project objectives, a lining material or stabilization measure should be selected from Table 2, using the threshold values as a guideline in the selection. Only material with a threshold exceeding the predicted value should be selected. The other project objectives can also be used at this point to help select from among the available alternatives. Fischenich and Allen (2000) characterize attributes of various protection measures to help in the selection.

Step 5- Recompute Flow Values.

Resistance values in the hydraulic computations should be adjusted to reflect the selected channel lining, and hydraulic condition should be recalculated for the channel. At this point, reach- or section-averaged hydraulic conditions should be adjusted to account for local and instantaneous extremes.

Table 4 presents velocity limits for various channel boundaries conditions. This table is useful in screening alternatives, or as an alternative to the shear stress analysis presented in the preceding sections.

Table 4. Stability of Channel Linings for Given Velocity Ranges

Lining	0 – 2 fps	2 – 4 fps	4 – 6 fps	6 – 8 fps	> 8 fps
Sandy Soils	🟨	🟥	🟥	🟥	🟥
Firm Loam	🟨	🟨	🟥	🟥	🟥
Mixed Gravel and Cobbles	🟩	🟨	🟨	🟥	🟥
Average Turf	🟩	🟨	🟨	🟥	🟥
Degradable RECPs	🟩	🟨	🟨	🟨	🟥
Stabilizing Bioengineering	🟩	🟨	🟨	🟨	🟥
Good Turf	🟩	🟩	🟨	🟨	🟨
Permanent RECPs	🟩	🟩	🟩	🟩	🟨
Armoring Bioengineering	🟩	🟩	🟩	🟩	🟨
CCMs & Gabions	🟩	🟩	🟩	🟩	🟨
Riprap	🟩	🟩	🟩	🟩	🟩
Concrete	🟩	🟩	🟩	🟩	🟩

Key:

🟩	**Appropriate**
🟨	**Use Caution**
🟥	**Not Appropriate**

Step 6– Confirm Lining Stability.
The stability of the proposed lining should be assessed by comparing the threshold values in Table 2 to the newly computed hydraulic conditions. These values can be adjusted to account for flow duration using Figures 2-4 as a guide. If computed values exceed thresholds, step 4 should be repeated. If the threshold is not exceeded, a factor of safety for the project should be determined from the following equations:

$$FS = \frac{t_{\max}}{t_{est}} \quad or \quad FS = \frac{V_{\max}}{V_{est}} \qquad (11)$$

In general, factors of safety in excess of 1.2 or 1.3 should be acceptable. The preceding five steps should be conducted for every cross section used in the analysis for the project. In the event that computed hydraulic values exceed thresholds for any desirable lining or stabilization technique, measures must be undertaken to reduce the energy within the flow. Such measures might include the installation of low-head drop structures or other energy-dissipating devices along the channel. Alternatively, measures implemented within the watershed to reduce total discharge could be employed.

APPLICABILITY AND LIMITATIONS

Techniques described in this technical note are generally applicable to stream restoration projects that include revegetation of the riparian zone or bioengineering treatments.

ACKNOWLEDGEMENTS

Research presented in this technical note was developed under the U.S. Army Corps of Engineers Ecosystem Management and Restoration Research Program. Technical reviews were provided by Messrs. E.A. (Tony) Dardeau, Jr., (Ret.), and Jerry L. Miller, both of the Environmental Laboratory.

POINTS OF CONTACT

For additional information, contact the author, Dr. Craig Fischenich, (601-634-3449, fischec@wes.army.mil), or the manager of the Ecosystem Management and Restoration Research Program, Dr. Russell F. Theriot (601-634-2733, therior@wes.army.mil). This technical note should be cited as follows:

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USACE TR EL 97-8