Geosyntec consultants

1111 Broadway, 6th Floor
Oakland, California 94607
PH 510.836.3034
FAX 510.836.3036
www.geosyntec.com

Technical Memorandum

Date:	28 May 2015
To:	Geoff Brosseau, Bay Area Stormwater Management Agencies Association (BASMAA) and Jill Bicknell, Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP)
Cc:	Dan Cloak, Dan Cloak Environmental Consulting, and Tony Dubin, Dubin Environmental Consulting
From:	Judd Goodman P.E., Project Engineer and Lisa Austin P.E., Associate
Subject:	Preliminary Erosion Potential Modeling Analysis Geosyntec Project Number: WW1963

1 INTRODUCTION

This technical memorandum documents the preliminary Erosion Potential (Ep) modeling analysis for a generic one-acre project catchment and a bioretention control measure designed per the standard Bay Area specifications. The purpose of this modeling analysis was to preliminarily evaluate the suitability of alternative hydromodification control standards, compared to the current flow duration curve matching criteria included in the Municipal Regional Stormwater NPDES Permit (MRP) Provision C.3.g.ii.(2) (SFRWQCB, 2009).

This memorandum is organized as follows:

- Section 2 describes the methodology and assumptions used in the Ep analysis.
- Section 3 summarizes the results of the Ep analysis.
- Section 4 provides conclusions of the Ep analysis, including an opinion as to whether the preliminary results warrant further evaluation of alternative flow duration curve matching criterion proposed by Dan Cloak and Tony Dubin, representing the Contra Costa Clean Water Program (CCCWP).

2 METHODOLOGY AND ASSUMPTIONS

Erosion Potential (Ep) is expressed as the ratio of post-project to pre-project (post/pre) long-term "work done" on the stream (SCVURPPP, 2005). The Ep ratio is a commonly used metric in the field of fluvial geomorphology to quantitatively predict hydromodification impacts while taking into account the hydrology, channel geometry, and bed and bank material of streams and how these factors change as a result of altered land use (e.g., urbanization). For each of the following hydromodification numeric control standards, the Ep and BMP sizing factor (i.e., ratio of BMP footprint to catchment area) were calculated.

- **Current Flow Duration Standard** = flow duration control per the goodness of fit criteria in the current MRP Provision C.3.g.ii.(2) (SFRWQCB, 2009) [1]:

  The post-project flow duration curve shall not deviate above the pre-project flow duration curve by more than 10 percent over 10 percent of the length of the curve corresponding to the range of flows to control.

- **Alternative Flow Duration Standard** = per the flow duration control goodness of fit criteria proposed in the Contra Costa Clean Water Program (CCCWP) Hydromodification Management (HM) Facility Sizing Study (Dubin, 2014):

  The net deviation above the post-project flow duration curve from the pre-project flow duration curve shall not be more than 10% over more than 10% of the length of the curve corresponding to the range of flows to control.

- **Alternative Flow Duration Standard + Peak Flow Frequency Matching** = Alternative Flow Duration Standard provided above plus Peak Flow Matching, per the Contra Costa Clean Water Program's Final Hydromodification Management Plan (HMP) (CCCWP, 2006):

  For flow rates from [the low flow threshold] to Q_2, the post-project peak flows shall not exceed pre-project peak flows. For flow rates from Q_2 to Q_{10}, post-project peak flows may exceed pre-project flows by up to 10% for a 1- year frequency interval. For example,

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[1] The current hydromodification control standard for Contra Costa Permittees includes a peak flow frequency curve matching standard, which is not included for the Alameda, Fairfield-Suisun, San Mateo, Santa Clara, and Vallejo Permittees. However, the current flow duration curve matching standard is almost always more restrictive than the peak flow frequency curve matching standard. For the rain gauge and soil conditions included in this study, all sizing factors that achieve the current flow duration control standard also meet the peak flow frequency standard (Dubin, 2014).

post-project flows could exceed pre-project flows by up to 10% for the interval from Q_9 *to* Q_{10} *or from* $Q_{5.5}$ *to* $Q_{6.5}$*, but not from* Q_8 *to* Q_{10}*.*

- **Erosion Potential (Ep) Control** = consistent with the SCVURPPP HMP management objective (section 5.2) (SCVURPPP, 2005), the Vallejo HMP performance standard (section 4.1) (City of Vallejo, 2013), and the first sentence of the HM Standard in the current MRP (provision C.3.g.ii.) (SFRWQCB, 2009):

  Stormwater discharges from HM Projects shall not cause an increase in the erosion potential of the receiving stream over the pre-project (existing) condition.

  Erosion potential (Ep) is expressed as the ratio of post-project to pre-project "work done" on the creek. A target Ep equal to 1.0 is the basis for Ep Control.

The Ep analysis relied on continuous hydrologic simulations and geomorphic calculations to compare long-term changes in cumulative work in the pre- and post-project conditions. This approach is consistent with the steps provided in Appendix D of the Vallejo HMP (2013). The input assumptions used for the Ep analysis are provided below and are organized according to three of the key factors that control stream stability: (1) hydrology, (2) channel geometry, and (3) bed and bank material.

2.1 Hydrology Assumptions

Continuous hydrologic analyses were performed on a one-acre representative catchment to produce flow duration histograms necessary for the Ep analysis. Continuous hydrologic simulations were performed using HSPF by Dubin Environmental Consulting with the parameters listed below. Documentation of these continuous hydrologic simulations and others is provided in a technical memorandum (Dubin, 2014).

- Precipitation = Martinez gage
- Mean Annual Precipitation = 20.2 inches
- Catchment soil type = Hydrologic Soil Group D
- Catchment tributary area = 1 acre
- post-project imperviousness = 100%
- BMP type = bioretention facility with 12-inch gravel depth
- BMP infiltration rate = 0.25 in/hr

- BMP sizing factors modeled = 0.04 to 0.06 (at increments of 0.002)
- Catchment Pre-Project Q_2 = 0.362 cfs

Project catchment flow rates derived from HSPF for the one-acre catchment were multiplied by a ratio of the pre-development 2-year peak discharge for the watershed and project catchment (i.e., Q_2 watershed / Q_2 project catchment) so that hydraulic and effective work calculations could be performed for a representative receiving stream with a tributary area of one-square mile. This scaling translated the runoff from the one-acre project catchment to erosivity in its downgradient receiving stream. A conceptual illustration of the one-acre project catchment delineated in relation to the receiving stream and one-square mile watershed is provided in Figure 1. Assumptions for the scaling from the one-acre catchment to the one-square mile watershed are as follows:

- Receiving channel tributary area = 1 square mile
- Channel Q_2 = 34.93 cfs (per empirical equation in USGS SIR 2012-5113)
- Channel Q_2 / Project Q2 = 34.93 cfs / 0.362 cfs = 96.5

2.2 <u>Channel Geometry Assumptions</u>

Empirical curves developed by Dunn and Leopold (1978) for the San Francisco Bay Region were used to express representative receiving channel bankfull discharge, cross-sectional area, width, and depth for the one-square mile watershed area. Results are as follows:

- Bankfull Cross-Sectional Area = 23.45 sq ft
- Bankfull Width = 16.34 ft
- Bankfull Depth = 1.52 ft
- Bankfull Discharge = 51.45 cfs

Manning's equation was used to iteratively find the longitudinal slope for the assumed receiving channel, such that the wetted cross sectional area at bankfull conveys the bankfull discharge of 51.45 cfs, per the Dunn and Leopold (1978) regional curve. The hydraulic analysis assumed a Manning roughness value for the main channel, corresponding to a non-vegetated, straight channel with no riffles and pools. A separate Manning's roughness was used for the over bank floodplain with an assumed side slope. The "n" values used are consistent with those requested of the San Diego Regional Water Board in the development of the San Diego HMP (County of San Diego, 2011). The parameters used for Manning's equation include:

- Mid-Channel Manning's n = 0.035

- Overbank Manning's n = 0.070
- Overbank Side-Slope = 10 horizontal to 1 vertical
- Longitudinal Channel Slope = 0.19%

2.3 Bed and Bank Material Assumptions

A default critical low flow threshold of 10% of the pre-development Q_2 was used for this analysis. This corresponds to 0.036 cfs for the one-acre project catchment and 3.49 cfs for the one-square mile watershed tributary to the representative receiving stream. Flow rates below these values were assumed to contribute no work on the channel. The resulting in-stream critical shear stress was 0.034 lb/ft^2.

2.4 Erosion Potential Calculation

Ep was calculated using the factors characterized above as inputs to the following methodology. This process is described in the following steps, consistent with Appendix D of the Vallejo HMP (2013).

Step 1: Continuous Hydrologic Analysis

The project-scale continuous HSPF simulations, described in Section 2.1 above, were used to develop long-term simulated flow records for the pre-project condition, post-project condition without BMP, and post-project conditions with BMP (11 total scenarios with BMP sizing factors ranging between 0.04 and 0.06). Project flow rates derived from HSPF for the one-acre catchment were multiplied by the ratio of the pre-development two-year peak discharge (i.e., Q_2 watershed / Q_2 project catchment = 34.93 cfs / 0.362 cfs = 96.5) to create a flow histogram for a representative receiving stream with tributary area of one-square mile. This scaling translated the runoff from the one-acre project catchment to that of a downgradient receiving stream with a larger tributary area.

Step 2: Hydraulic Analysis

Hydraulic analysis was performed using HEC-RAS to calculate stage, mid-channel flow velocity, and effective shear stress for the range of simulated flow output using the channel geometry and roughness parameters provided in Section 2.2.

Step 3: Work Analysis

The hydraulic output (Step 2) and critical low flow threshold, provided in Section 2.3, were used to produce a work rating curve using the following effective work equation.

$$W = (\tau - \tau_c)^{1.5}\ V$$

Where:

W = Work [dimensionless];

τ = Effective Shear Stress [lb/ft^2];

τ_c = Critical Shear Stress [lb/ft^2];

V = Mid-Channel Flow Velocity [ft/s]

Step 4: Cumulative Work Analysis

The work rating curve (Step 3) and the flow histograms (Step 1) were integrated to calculate long term total work for the pre-development condition and each post-development scenario.

Step 5: Erosion Potential Analysis

Ep was calculated for each of the 12 post-project scenarios (one without a BMP and 11 with a BMP) by dividing the total work of the post-project condition by that of the pre-project condition (post/pre).

3. RESULTS

Ep results and BMP sizing factors associated with each of the four hydromodification control numeric control standards of interest, and that for the unmanaged scenario, are provided in Table 1. To calculate the BMP footprint size necessary to achieve Ep Control (i.e., a target Ep of 1.0): first, the 12 BMP sizing factors were plotted against their resulting Ep values; then, a best fit trendline was generated for the data; and finally, an Ep value of 1.0 was entered into the trendline equation to calculate the resulting BMP sizing factor. Figure 2 provides the plot of Ep versus BMP sizing factor.

Of the three flow duration standards evaluated, the Alternative Flow Duration Standard + Peak Flow Frequency Matching standard produced results closest to Ep Control. The Current Flow Duration Standard was overly conservative (Ep < 1.0) meaning the BMP size is larger than what is necessary to "*not cause an increase in the erosion potential of the receiving stream over the pre-project (existing) condition*", per the MRP HM Standard (SFRWQCB, 2009). The Alternative Flow Duration Standard was not sufficiently conservative (Ep > 1.0) meaning the BMP size is not large enough to meet the erosion potential management objective included in the MRP HM Standard.

4. CONCLUSIONS

The following are Geosyntec's conclusions of the preliminary Ep modeling analysis presented herein and possible next steps:

- Preliminary results warrant further evaluation (i.e., additional sensitivity analysis) of the Alternative Flow Duration Standard + Peak Flow Frequency Matching standard because it produced similar sizing factors as Ep Control.
- Further evaluation of sizing factors to achieve an Ep Control standard is warranted because Ep is the most direct measure of the geomorphic processes associated with hydromodification and is consistent with the erosion potential management objective included in the MRP HM Standard.
- Additional sensitivity analysis is necessary to comprehensively evaluate the utility of the Alternative Flow Duration Standard + Peak Flow Frequency Matching and Ep Control standards. Such a sensitivity analysis would model a range of input parameters associated with hydrology, channel geometry, and bed/bank material. Possible parameters to evaluate include: precipitation gage, project catchment soil type, catchment area, BMP type, BMP infiltration rate, watershed area, bankfull width, bankfull depth, bankfull discharge, channel roughness, longitudinal slope, critical low flow threshold, and effective work equation.

  It is anticipated that BMP infiltration rate, project catchment soil type, and critical low flow threshold will be the most sensitive parameters to the calculations of Ep and unit BMP storage volume requirements. It is suggested that these parameters be included, as a minimum, if an additional sensitivity analysis is conducted.
- In developing the Ep input parameters for this study, it was assumed that the one-square mile watershed is undeveloped in the existing baseline condition and could potentially be fully developed in the future build-out condition. However, if a portion of the watershed were designated as protected open space (i.e., not to be developed at build-out), then the continuous hydrologic analysis performed could be adjusted to represent such land planning and the resulting BMP sizing would decrease for Ep Control. Likewise, if a portion of the watershed is already developed in the existing baseline condition (as of the HMP effective date), then the continuous hydrologic analysis could be adjusted to represent this existing land use condition and the resulting BMP sizing would decrease as well for Ep Control. An additional Ep and BMP sizing sensitivity analysis, which takes into account existing and buildout land uses, may be of interest to the Bay Area Copermittees if the Ep Control standard is adopted for use.

5. REFERENCES

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US Geological Survey (USGS). 2012. Methods for Determining Magnitude and Frequency of Floods in California, Based on Data through Water Year 2006. Scientific Investigation Report 2012-5113.

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Enclosures:

Table 1: Summary of Numeric Control Standards, BMP Sizing Factors, and Ep Results

Figure 1: Illustration of Project Catchment in Relation to the Receiving Stream and Watershed

Figure 2: Plot of Erosion Potential versus BMP Sizing Factor

Table 1: Summary of Numeric Control Standards, BMP Sizing Factors, and Ep Results

Numeric Control Standard	BMP Sizing Factor	Ep
Unmanaged	0	4.42
Alternative Flow Duration Standard	0.040	1.31
Erosion Potential (Ep) Control	0.0504	1.00
Alternative Flow Duration Standard + Peak Flow Frequency Matching	0.052	0.96
Current Flow Duration Standard	0.056	0.87

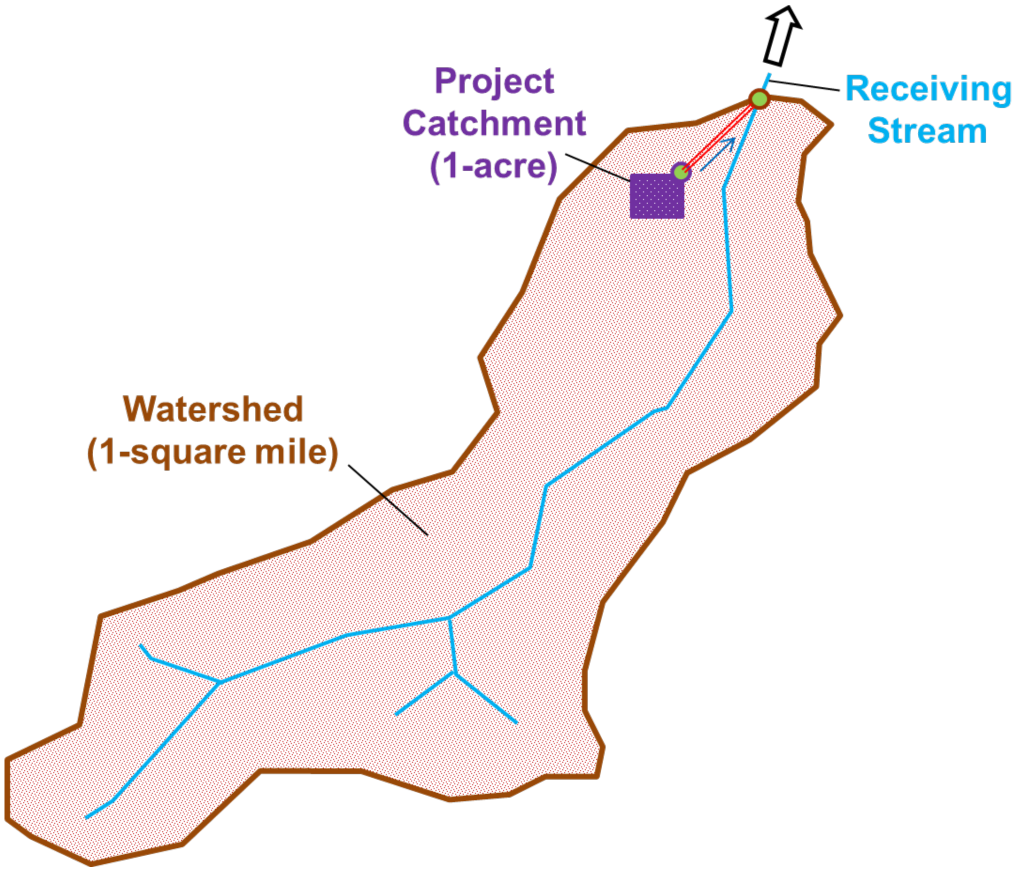

Figure 1: Illustration of Project Catchment in Relation to the Receiving Stream and Watershed

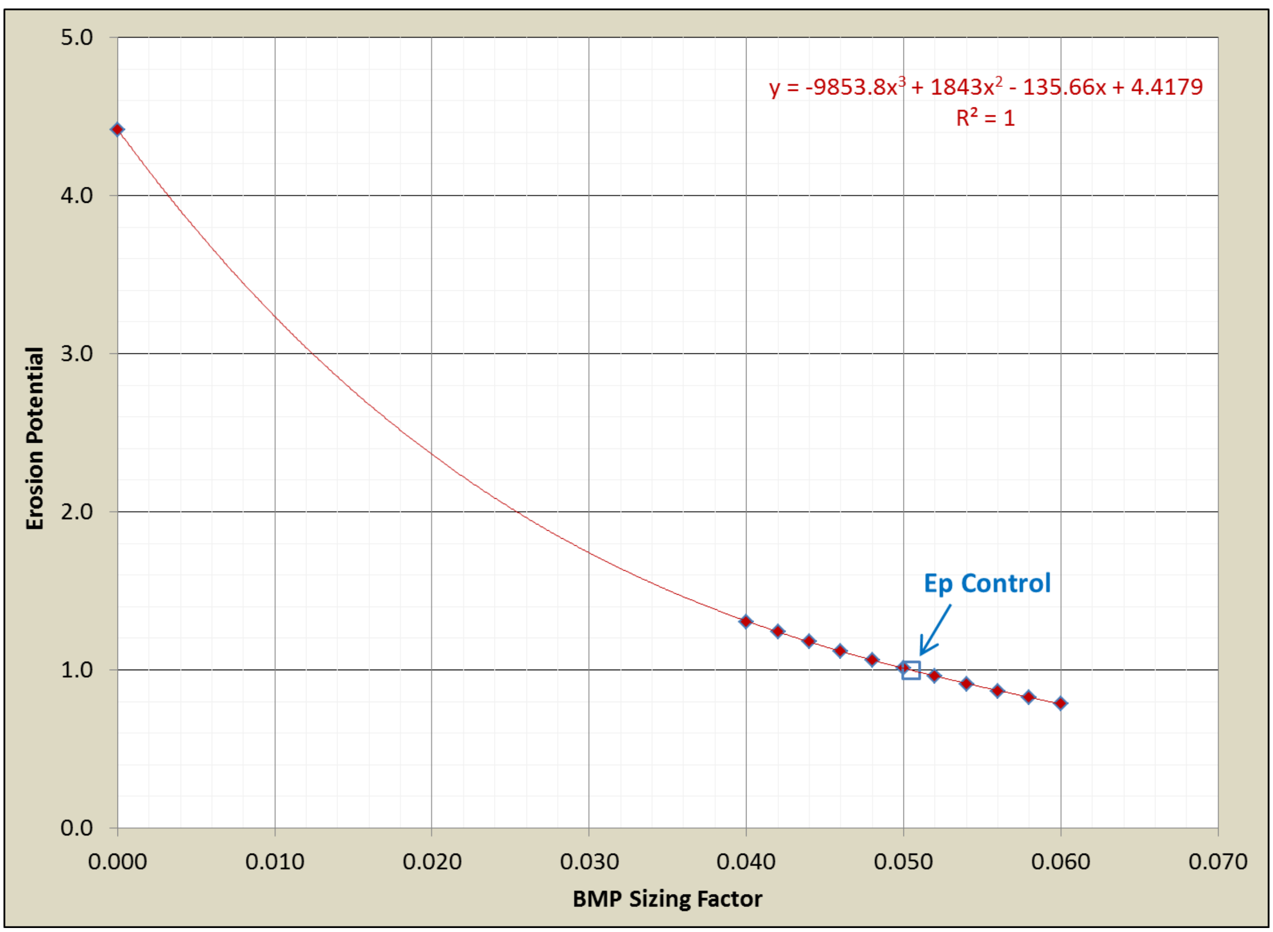

Figure 2: Plot of Erosion Potential versus BMP Sizing Factor