9665 Chesapeake Drive, Suite 201
San Diego, CA. 92123
Tel: 858-514-8822
Fax: 858-514-8833

PWA
PHILIP WILLIAMS & ASSOCIATES, LTD
ENVIRONMENTAL HYDROLOGY
550 Kearny Street, Suite 900
San Francisco, California 94108-2404
TEL 415.262.2300 FAX 415.262.2303
www.pwa-ltd.com

Project No: 133904

San Diego County Hydromodification Management Plan (HMP)

Subject: Lower Flow Threshold Alternatives

Date: April 30, 2009

To: Sara Agahi – County of San Diego
San Diego NPDES Copermittees
Hydromodification Technical Advisory Committee (TAC)

From: Eric Mosolgo – Brown and Caldwell
Christie Beeman – PWA
Andy Collison – PWA

Copy to: Nancy Gardiner – Brown and Caldwell

This Technical Memorandum details criteria for the determination of flow control limits to mitigate the effects of hydromodification, as mandated by Regional Water Quality Control Board (RWQCB) Order R9-2007-0001 Provision D.1.g. The purpose of the hydromodification criteria is to prevent development-related changes in storm water runoff from causing, or further accelerating, stream channel erosion or other adverse impacts to beneficial stream uses.

Per the RWQCB Permit, the lower flow control limit shall be based on flows corresponding to shear stresses which cause initiation of sediment movement in the channel bed or side slopes. The consultant team has conducted extensive sediment transport modeling to estimate anticipated critical shear stresses, which would cause initiation of sediment movement, using a wide array of parameter values representative of local conditions.

Results of these analyses have been provided to the Technical Advisory Committee and Copermittees for review. The resultant feedback provided by experienced local hydraulic engineering experts such as Marty Teal, Dennis Bowling, Tory Walker, Dr. Howard Chang and others provides a practical reference check to the sediment transport modeling since the expert group collectively provides decades of local experience with regard to sediment transport processes.

In an attempt to simplify implementation, the consultant team made an effort to identify a single countywide lower flow control standard. This approach required the assumption of conservative values for a variety of channel conditions, including the channel particle size (D50), and channel slope. Values assumed in the analysis include the following:

- Channel width to depth ratios of 3, 6, 10, and 20 were modeled. Channel dimensions were scaled for flows of 10 cfs and 20 cfs.
- Sediment sizes of 0.5 mm and 2 mm were modeled
- Channel slopes of 0.005, 0.015 and 0.025 were modeled.

Based on the comprehensive assessment of a wide range of potential receiving channel conditions using sediment transport modeling and equations, the consultant team identified 0.1Q2 as the potential lower flow threshold.

The consensus amongst the consultant team and the independent Technical Advisory Committee, however, is that the singular use of channel critical shear stress for the lower flow threshold (as calculated using sediment transport equations) has limitations and that the lower flow threshold of 0.1Q2, which was derived using a collection of conservative assumptions, is too conservative and restrictive. The consultant team and the County of San Diego concluded that further analysis should be conducted to identify alternative lower flow thresholds in certain situations, including the following:

- Erosion-resistant channel bed - alternate lower flow threshold based on shear stress nomograph
- Very low runoff (e.g. small project) - alternate lower flow threshold based on minimum flow rate
- Discharge to very large channel - alternate lower flow thresholds based on watershed position

Therefore, based on the consultant team's analysis and input from the Technical Advisory Committee, the consultant team recommended providing alternate low flow thresholds for certain conditions. These alternative thresholds are discussed in more detail below. The applicability and use of alternate thresholds will be incorporated into a decision matrix to assist with implementation of the final Hydromodification Management Plan (HMP). This decision matrix will be a flow chart based tool to guide project applicants through the HMP compliance process. It will recommend a suite of mitigation options, appropriate flow thresholds, and the required level of analysis for specific receiving stream susceptibilities and proposed project impacts.

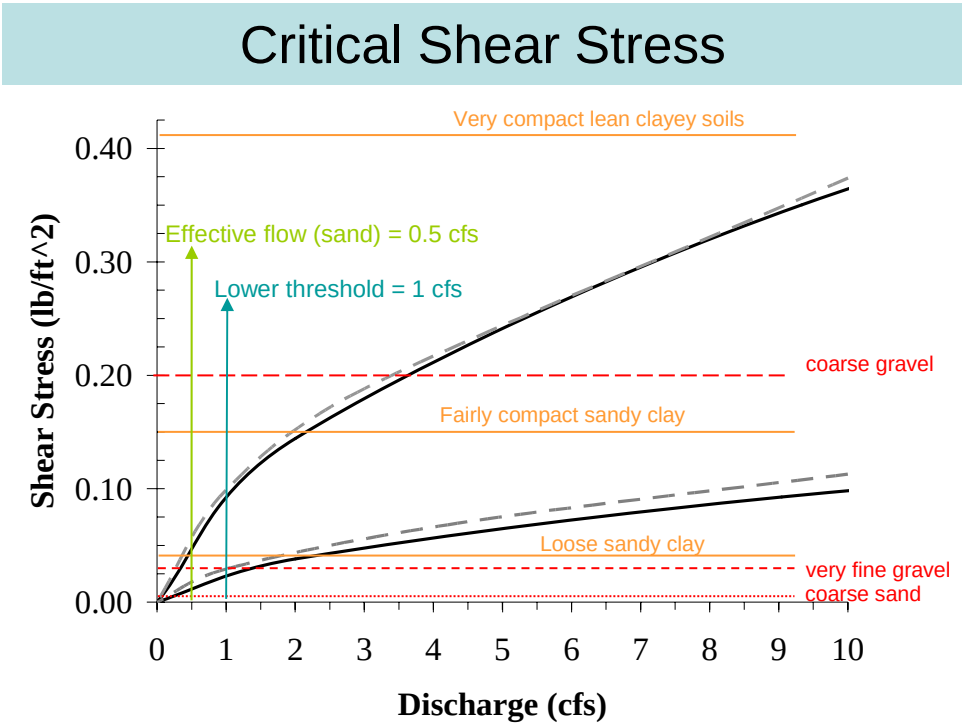
Identification of Alternate Lower Flow Thresholds for Erosion-Resistant Channels

While the single lower flow control threshold ($0.1Q_2$) may be appropriate for less resistant channel bed materials such as unconsolidated sand, an alternate standard is recommended when the receiving channel is comprised of consolidated channel materials, gravel or cobbles. This is because the critical shear stress increases dramatically in such conditions as compared to the unconsolidated sediment assumptions from which the lower flow threshold of $0.1Q_2$ was derived. Additionally, multiple other channel factors, such as bed armoring, bed consolidation, vegetation, etc. have the cumulative effect of increasing critical shear stress above levels predicted by standard sediment transport equations.

The consultant team's subsequent analysis regarding alternatives to the lower flow threshold included the following approaches:

- Bed infiltration losses estimated for unconsolidated channel materials such as sand. These losses include runoff that infiltrates through the channel floor into the groundwater system and is thus lost to the receiving streamflow system within the domain of analysis.
- Evaluated relationship between *applied shear stress* that could cause erosion and discharge (Q) for a range of typical channel configurations (varying channel width to depth ratios, roughnesses, slopes)
- Compared these values to *critical shear stress* for larger range of bed material types (grain size, degree of consolidation). For values where the applied shear stress exceeds the critical shear stress, sediment movement is predicted.

As a result of the analysis, the consultant team has developed preliminary nomographs to identify potential alternate lower flow thresholds for a range of channel conditions. A range of channel scenarios, from steep/rough/incised to flat/smooth/shallow, were evaluated with respect to both shear stress and discharge. Channel dimensions were scaled for bankfull flow conditions of 10 cfs and 20 cfs. The nomographs relate shear stress to discharge and identify nomograph zones for various channel bed conditions including compact clayey soils, coarse gravel, compact sandy clay, unconsolidated sandy clay, and coarse sand. An example lower flow threshold nomograph is presented below.



Critical shear stress varies from 0.006 lb/ft² for sand to 1.107 lb/ft² for cobbles – this variability of critical shear stress provides a clear basis for identifying alternate lower thresholds based on channel characteristics. A standardized protocol will be provided to allow the applicant to demonstrate that the appropriate channel conditions are met. Such a protocol could include the development of a critical shear stress calculator which would be dependent on the user-defined value of D_{50} for the receiving channel segment. Protocols would

also be developed for situations where the receiving channel segment contains a mixture of channel bed materials within the domain of analysis.

Identification of a Minimum Flow Rate as an Alternate Lower Flow Threshold

It is the consensus of the independent Technical Advisory Committee that under field conditions, erosion would not actually occur at the lowest flows predicted by the sediment transport modeling. The following discussion details the reasons why the consultant team agrees with the Technical Advisory Committee's opinion regarding this issue.

The majority of published critical shear stress data results and empirical sediment transport equations used in numerical models were derived from laboratory flume experiments. In these experiments, clean, unconsolidated sediment is placed in the flume. Simulated flow is then initiated until particles begin to move. These flume conditions omit many field conditions that would increase resistance to sediment movement.

While these differences between flume and field conditions are less relevant at the medium to high flows which are generally modeled in sediment transport evaluations, they are more significant around the threshold of sediment motion, which is the focus of hydromodification management programs. These factors include channel bed armoring by coarser sediment, bed consolidation, the presence of fine sediment that increases cohesion, the presence of vegetation, bed form roughness, etc. Additionally, the potential for channel bed infiltration becomes significant at lower flow rates, thus reducing the effective flow in the channel. These factors are site specific and difficult to quantify, but have the cumulative effect of increasing critical shear stress above the levels predicted in sediment transport equations.

The consultant team and the Technical Advisory Committee thus agree that a minimum flow rate should be applied to the lower flow control threshold. Preliminary sediment rating curve calculations, prepared by PWA using spreadsheets and incorporating sediment transport equations, indicate that the implementation of a minimum flow rate of roughly 1 cfs would provide adequate protection for most small creek systems (with the exception of unconsolidated sand channels). It is recommended that the determined minimum flow rate (specific value still to be finalized pending approval by the TAC) be used as the lower flow control threshold in cases where $0.1Q_2$ is less than the minimum flow rate.

- The consultant team's preliminary calculations show that a lower flow threshold of 1 cfs would be protective for most channels (i.e. lower flow threshold = the higher of $0.1Q_2$ or 1 cfs)
- It is difficult to identify a lower flow boundary for an unconsolidated sand bed channel.

It is noted that the lower flow threshold above may require adjustment in relation to the size of the proposed project site. For instance, smaller sites (<10 acres) may require a lower flow threshold as compared to larger sites. These determinations will be made pending approval by the TAC and be incorporated into the final decision matrix.

To mitigate flows from small systems, flow control devices may require small outflow orifices. A minimum orifice size or a list of standard orifice sizes will be developed for both unprotected and protected outlet orifice scenarios. To prevent orifice clogging and potential subsequent safety and vector issues, it is imperative that operation and maintenance protocols be followed in the design and maintenance of these flow control facilities.

The consultant team and the County of San Diego have requested information regarding detention basin and BMP maintenance from operation and maintenance staff in all San Diego municipalities. These responses will be consolidated in a comprehensive summary of practical design and maintenance considerations, which will be detailed in a separate technical memorandum.

Alternate Lower Flow Threshold Based on Watershed Position

The final decision matrix will include provisions regarding the determination of alternate lower flow thresholds in the following situations.

- Where the project site is very small as compared to the contributing watershed area to the receiving channel.
- Where the project site directly discharges runoff to a large receiving channel
- Where the potential for cumulative impacts in the watershed are minimal

Pending approval by the TAC and Copermittee Workgroup, policy decisions will be made regarding alternate lower flow limits and thresholds correlating to the following ratios.

- Project discharge / receiving channel discharge
- Project impervious area / receiving watershed impervious area
- Project impervious area / future planned impervious area in watershed

Finally, a listing of erosion-resistant receiving water bodies may be developed. These could include hardened and armored channels, large rivers, lakes, and lagoon systems.

Summary

Based on the opinions of both the consultant team and the Technical Advisory Committee, the consultant team will develop a decision matrix detailing application of the lower flow threshold standard to assist with implementation of the final HMP. Elements of the decision process include evaluation of alternate lower flow thresholds for erosion-resistant channels, determination of alternate lower thresholds based on a minimum flow rate, and determination of alternate lower thresholds based on watershed position.