HYDROMODIFICATION MANAGEMENT and MONITORING PLAN

for the

SANTA ANA RIVER WATERSHED REGION

within the

COUNTY of SAN BERNARDINO

MAY 2013

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ACRONYMS

ACCCMP	Alameda Countywide Clean Water Program
BAHM	Bay Area Hydrology Model
BEHI	Bank Erosion Hazard Index
BMI	Benthic Macroinvertebrates Index
BMP	Best Management Practice
CASQA	California Stormwater Quality Association
CCCWP	Contra Costa Clean Water Program
CEM	Channel Evolution Model
CEQA	California Environmental Quality Act
CRP	Controlled Release Points
D_{50}	Median grain size diameter
Ep	Erosion potential index
ET	Evapotranspiration
FSURMP	Fairfield-Suisun Urban Runoff Management Program
GIS	Geographical Information System
HEC-HMS	Hydrologic Modeling System; distributed by the US Army Corps of Engineers Hydrologic Engineering Center
HMP	Hydromodification Management Plan
HMoP	Hydromodification Monitoring Plan
HR	Hydraulic Radius
HSPF	Hydrologic Simulation Program FORTRAN, distributed by USEPA
IBI	Index of Biotic Integrity
IMP	Integrated Management Practices
LEED	Leadership in Energy and Environmental Design
LID	Low Impact Development
LSPC	Loading Simulation Program in C++
MHHW	Mean Higher High Water
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resource Conservation Service
OCHM	Orange County Hydrology Manual
PDP	Priority Development Project
PLS	Pervious Land Surface
PWA	Philip Williams & Associates
S	Slope in Lane’s equation
Q or Qw	Flow
Qcrit - Qc	Critical flow
Qcp	Geomorphically critical flow – 10 percent of the 2-year flow
Qs	Sediment discharge in Lane’s equation
RWQCB	Regional Water Quality Control Board
SCCWRP	Southern California Coastal Water Research Project
SCVURPPP	Santa Clara Valley Urban Runoff Pollution Prevention Program
SMCWPPP	San Mateo Countywide Water Pollution Prevention Program
STOPPP	San Mateo County Stormwater Pollution Prevention Program
SSMP	Standard Stormwater Mitigation Plan
SUSMP	Standard Urban Stormwater Mitigation Plan
SWM SWMM	Stanford Watershed Model Stormwater Management Model; distributed by USEPA
SWMP	Stormwater Management Plan
SWWM	Stormwater Management Model
TGD	Technical Guidance Document
TMDL	Total Maximum Daily Load
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey

1 Introduction

Hydromodification refers to changes in the magnitude and frequency of stream flows due to urbanization and the resulting impacts on receiving channels, such as erosion, sedimentation, and potentially degradation of in-stream habitat. The degree to which a channel will erode or aggrade is a function of the increase or decrease in work (shear stress), the resistance of the channel bed and bank materials – including vegetation (critical shear stress), the change in sediment delivery, and the geomorphic condition (soil lithology) of the channel. Critical shear stress is the shear stress threshold above which motion of bed material load is initiated. Not all flows cause significant movement of bed material—only those flows that generate shear stress in excess of the critical shear stress of the bank and bed materials. Urbanization increases the discharge rate, volume and timing of runoff, and associated shear stress exerted on the channel by stream flows, and can trigger erosion in the form of incision (channel downcutting), widening (bank erosion), or both.

The goal of this document is to fulfill specific requirements of Section XI.B.3.b.ii of the National Pollutant Discharge Elimination System (NPDES) Municipal Separate Storm Sewer (MS4) Permit No. CAS618036 and Santa Ana Regional Water Quality Control Board (RWQCB) Order R8-2010-0036 (Permit). Section XI.B.3.b.ii requires "…the Principal Permittee, in coordination with the Co-permittees, to [shall]… develop and implement a Hydromodification Monitoring Plan… to evaluate hydromodification impacts for the drainage channels deemed most susceptible to degradation. The HMP [will] identify[s] sites to be monitored, include an assessment methodology, and required follow-up actions based on monitoring results. Where applicable, monitoring sites may be used to evaluate the effectiveness of stormwater Best Management Practices (BMP) in preventing or reducing impacts from hydromodification. Section XI.B.3.b.iii of the Permit requires "…the Principal Permittee, in coordination with the Co-permittees, shall… develop and implement a Hydromodification Management Plan prioritized based on drainage feature/susceptibility/risk assessments and opportunities for restoration."

The RWQCB jurisdiction area covers the area of San Bernardino County within the Santa Ana River Watershed Region. MS4 Co-Permittees or dischargers directly or indirectly discharging runoff into waters of the United States and State of California within the Santa Ana Region include the Cities of Big Bear Lake, Chino, Chino Hills, Colton, Fontana, Grand Terrace, Highland, Loma Linda, Montclair, Ontario, Rancho Cucamonga, Redlands, Rialto, San Bernardino, Upland, Yucaipa, as well as the unincorporated area of San Bernardino County and the San Bernardino County Flood Control District.

The San Bernardino County Areawide Program (Program) Hydromodification Management Plan (HMP) is built upon the findings of the WAP development process and the methodologies of the South Orange County HMP. The aim of these HMP plans is to establish a regional consistency in hydromodification requirements. Like the South Orange County HMP, the Program HMP utilizes a flow control approach. A flow control approach includes defining a flow range that ensures geomorphic stability within a channel. Where receiving stream channels are already unstable, hydromodification monitoring and management can be a method to avoid accelerating or exacerbating existing problems. Where receiving stream channels are in a state of dynamic equilibrium, hydromodification management may prevent the onset of erosion, sedimentation, lateral bank migration, or impacts to in-stream vegetation.

While this HMP considers flow and sediment mobilization due to development, it does not consider the loss of sediment supply.

2 HMP Requirements and Standards for Projects

Section XI.D.4 of the Permit defines those projects that are considered as Priority Development or re-development Projects (PDP) and requires the implementation of a Water Quality Management Plan (WQMP). The project WQMP defines LID and hydromodification measures that will ensure that pre-development site hydrology are mimicked through the implementation of on-site hydrologic controls. Projects that have the potential to cause or contribute to Hydrologic Condition of Concerns (HCOC), are required to implement on-site hydrologic control measures and on-site management controls so that post-development runoff volume, velocity, duration, and time of concentration are not significantly different (less than or equal to 5% difference) from pre-development hydrology for a 2-year storm event.

The Program submitted a draft Technical Guidance Document (TGD) for WQMP to the RWQCB for public review in March 2013. The TGD provides direction to project proponents on the design and implementation of LID concepts and features and on-site hydrologic controls. In addition, the TGD requires project proponents to document on-site BMP infeasibility and proposes two alternative mitigation actions: 1) a project proponent constructed off-site regional or sub-regional LID BMP that provides the same level of hydrologic controls as an on-site system; or 2) a financial contribution to an in-lieu project fund (when available).

2.1 HMP Applicability Requirements

To determine if a proposed project must implement hydromodification controls, refer to the HMP Decision Matrix in Figure 2-1.

The HMP Decision Matrix can be used for all projects. It should be noted that all PDP are subject to the Permit's LID and water quality treatment requirements, even if hydromodification flow controls are not required.

Projects may be exempt from HMP criteria under the conditions spelled out in Section XI.E.5.d.ii of the Permit, or under the following conditions (as detailed in the Program's 2013 TGD for WQMP):

- If the project is an in-stream flood control or restoration project (See Section 2.4).
- If the project is not a PDP; as defined by Permit Sections XI.D.4.a- XI.D.4.i (Figure 2-1, Node 1);
- If the project discharges stormwater runoff directly to an exempt receiving water, a controlled release point (CRP), or an in-stream flood control restoration project (Figure 2-1, Node 3);
- If the project discharges stormwater runoff directly to an EHM conveyance system that extends to an exempt receiving water or a controlled release point (Figure 2-1, Nodes 4 & 5). Such engineered systems could include existing storm drain systems, existing hardened conveyance channels, stable engineered and maintained unlined conveyance channels that are part of the MS4 but that are not receiving waters. To qualify for this exemption, the existing hardened or rehabilitated conveyance system must continue uninterrupted to the exempt system. The engineered conveyance system cannot discharge to an unlined, non-engineered channel segment prior to discharge to the exempt system. Additionally, the project proponent must demonstrate that the engineered conveyance system has the capacity to convey the 10-year ultimate condition flow through the conveyance system. The 10-year flow should be calculated

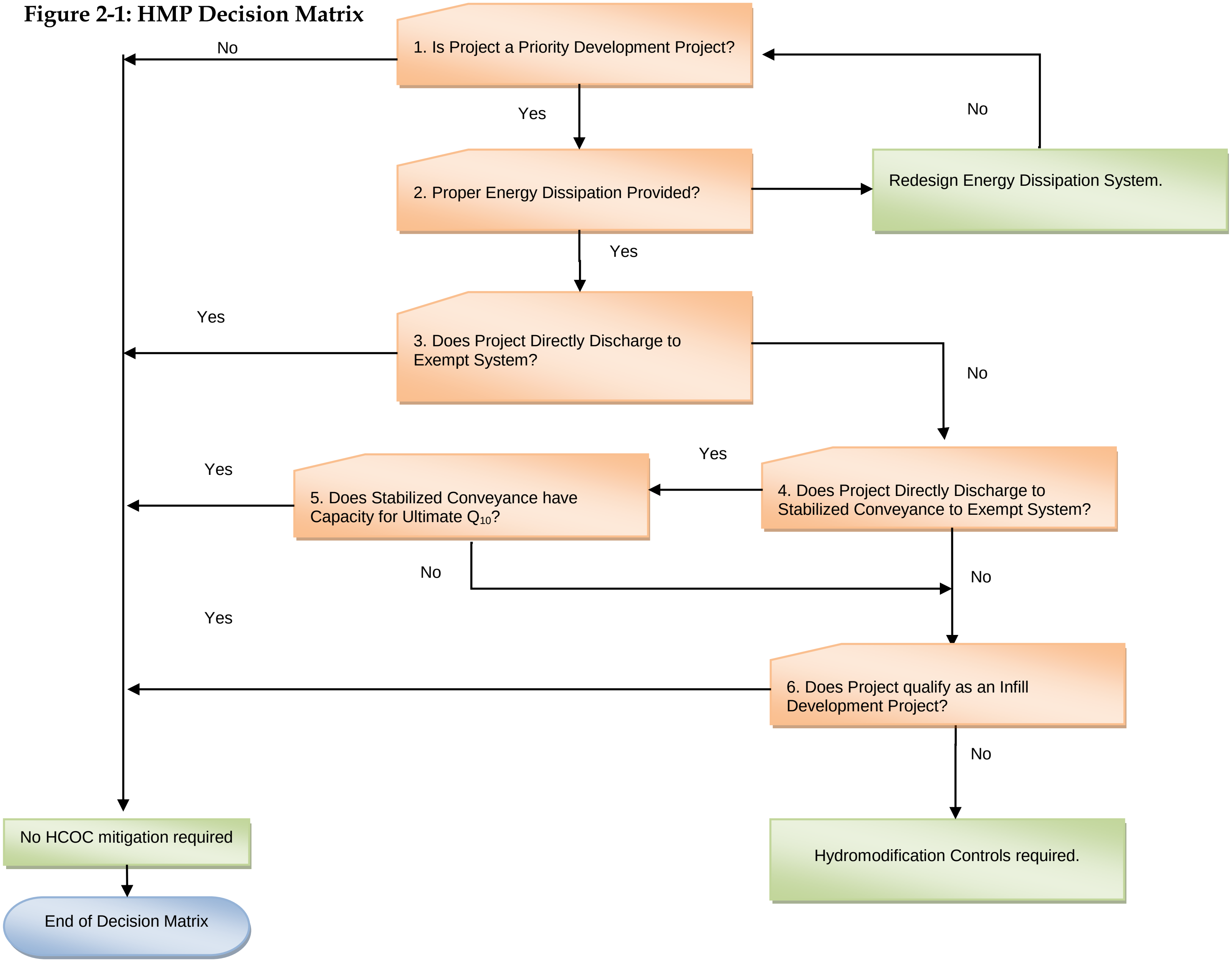
based upon single-event hydrologic criteria as detailed in the San Bernardino County Hydrology

- If the project is classified as an infill development project (Figure 2-1, Node 6).

A proposed PDP that does not meet exemption criteria must meet the full HCOC requirements defined in the TGD for WQMP and hydrologic control measures as well as on-site management controls in compliance with the Permit.

Alternatively, if on-site hydrologic control measures and management controls are not technically feasible due to site constraints, a technical study will be developed to demonstrate the infeasibility as detailed in Section 2.2.

Figure 2-1: HMP Decision Matrix



2.2 PDP Infeasibility and Alternative Compliance Plan

For some PDP, implementation of on-site hydromodification controls consistent with the TGD for WQMP may not be feasible due to site constraints. These projects require alternatives to on-site hydromodification controls. The LID requirements of the Permit require the implementation of LID techniques that effectively result in hydrologic processes that mimic the desired natural watershed conditions. There are two alternative compliance options for PDP that cannot implement on-site hydromodification controls. One option is for a PDP proponent to identify and construct regional or sub-regional mitigation systems to offset the inability to meet the HCOC criteria on-site. The second option is for the PDP proponent to contribute financially into an in-lieu fund, if available.

A technical study documenting the BMP infeasibility must be documented in the PDP WQMP. The study will identify why on-site hydromodification controls cannot be incorporated into the project. The study must include the project constraints and provide detailed technical justification as to why the project constraints prevent implementation of on-site controls. The study will be submitted to the jurisdiction of the location of the PDP for review as part of the Preliminary WQMP.

Selection and implementation of an off-site regional or sub-regional mitigation system shall require cooperation with, and, ultimately, approval from the jurisdiction in which the PDP is proposed. The project proponent and local jurisdiction should evaluate, identify and then prioritize regional or sub-regional mitigation opportunities existing within the same watershed as the PDP. The off-site mitigation project must be sized to mitigate the equivalent runoff volume as compared to implementing on-site hydromodification controls. The project proponent may also, with approval of the applicable jurisdiction investigate the potential for implementation of an in-stream restoration project for the receiving water of the project. It must be determined that the receiving water for the project has hydromodification impacts. Again, the project proponent and local jurisdiction should prioritize in-stream restoration projects located in the receiving water of the PDP.

Once the project conceptual plans have been approved by the PDP's jurisdiction, the project proponent must submit the appropriate permit applications to the appropriate regulatory agencies (e.g., RWQCB, California Department of Fish and Game, U.S. Army Corps of Engineers) for review and approval.

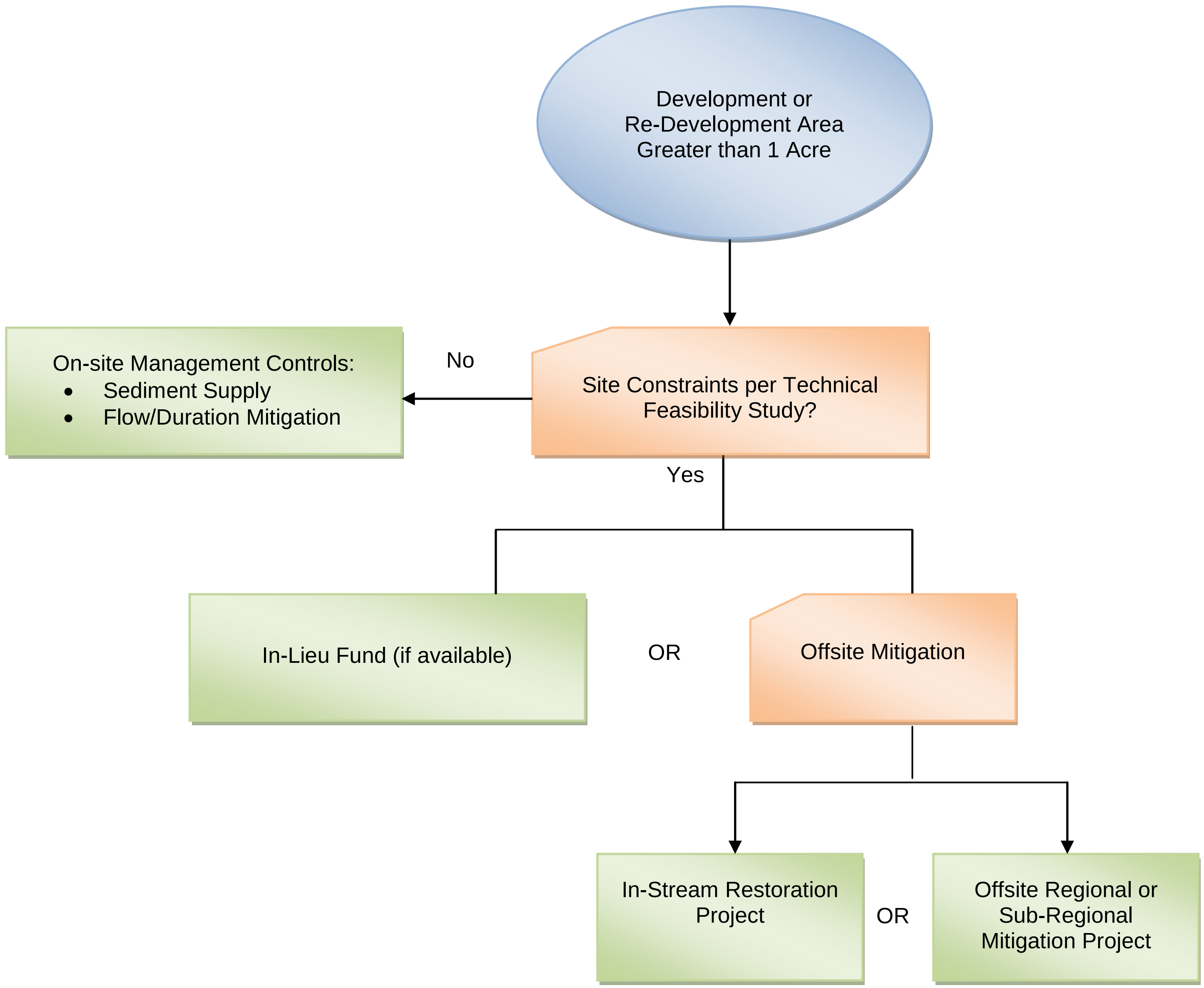
The Program will investigate development an in-lieu fund, with proceeds specifically allocated to restoration or rehabilitation projects. Ideally, the in-lieu fund would be able to develop regional HCOC mitigation projects where the PDP can buy HCOC mitigation credits if it is determined that implementing on-site hydromodification controls is infeasible. The development and operation of such a mitigation bank would require the identification of potential regional HCOC mitigation projects; the environmental clearance (CEQA), planning, design, permitting, construction, and maintenance of regional HCOC mitigation projects; the development of a fee structure for PDP participating in the in-lieu fund; and administration of the HCOC in-lieu fund. Regional HCOC mitigation projects may also be approved for use for off-site LID implementation if site conditions do not allow for implementation of LID-type projects.

A proposed PDP that does not meet exemption criteria must meet the full HCOC requirements defined in the TGD for WQMP. In addition, the project proponent shall verify and document the eligibility for exemption criteria as defined in Section 3.1.

Hydrologic control measures and on-site management controls to ensure compliance with the HMP criteria are described in Appendix A. Using this approach, mitigation of both flow and duration is achieved through on-site hydrologic control measures, and sediment loss is addressed through on-site management controls.

A flow chart indicating which HCOC mitigation should be pursued and implemented for PDPs is shown in Figure 2.2**Error! Reference source not found.**.

Figure 2-2: Priority Development or Re-Development Project HCOC Requirements- Decision Matrix



2.3 Summary of Transportation Project Feasibility Requirements

Municipal and public roadway projects constitute a standalone category based on their unique characteristics. Transportation projects are linear development or re-development projects to be completed within a limited right-of-way.

Generally, the accepted Santa Ana River watershed regional approach to WQMP development for managing transportation projects is to prepare a “functionally equivalent document” (Riverside County Transportation Guidance Document, November 2012) that incorporates site-specific engineering conditions into the BMP-selection analysis in order to manage project runoff to the MEP.

The MS4 Permit requires development of a standard design and post-development Best Management Practices (BMP) guidance to guide application of Low Impact Development (LID) BMPs to the maximum extent practicable (MEP) on transportation projects including public street, road, highway, freeway and bike/pedestrian path improvement projects to reduce the discharge of pollutants to receiving waters. The San Bernardino County MS4 Permittees prepared this Transportation Projects Guidance ("Guidance") to provide guidance to city engineers, planners, MS4 program staff, and transportation project proponents on how to address the MS4 Permit requirements within their jurisdictions. This guidance is largely based upon public street, road, highway, and freeway BMP techniques contained within USEPA's Municipal Handbook, *Managing Wet Weather with Green Infrastructure: Green Streets (*http://water.epa.gov/infrastructure/greeninfrastructure/upload/gi_munichandbook_green_sreets.pdf) and the *Low Impact Development Manual for Southern California* prepared for the Southern California Stormwater Monitoring Coalition, in cooperation with the State Water Resources Control Board, by the Low Impact Development Center. This Guidance also provides links and references to other sources of information regarding the application of LID-based BMPs to Transportation Projects (see Section 6: Resources).

2.4 Selection of Potential Rehabilitation and Restoration Projects

The Program will further investigate the potential rehabilitation and restoration projects that were identified during development of the WAP (Appendix F), as well as sites discovered during future hydromodification monitoring events. Rehabilitation projects are used for streams that require a modified morphology along with restored beneficial uses, while restoration projects are used for streams that are in geomorphic equilibrium and will not observe any altered flow and/or sediment regimes. Higher priority projects will be considered first for individual HCOC mitigation projects (to be constructed by PDP proponents) or Program stream restoration and/or rehabilitation projects. As detailed in Section 4.1.iii., individual HCOC mitigation projects may only be sought by PDP proponents who have demonstrated infeasibility for on-site HCOC mitigation and/or incorporation of LID features. In addition, individual HCOC projects shall receive permitting approval from the RWQCB, California Department of Fish and Wildlife, and U.S. Army Corps of Engineers prior to implementation.

As of the date of this document, an in-lieu Fund, incorporating mitigation fees has not been established by the Program. Should an in-lieu fund be established, the following criteria shall be considered:

- The HMP shall extend the availability of the mitigation fund to those projects not able to comply with HCOC requirements.
- The Program or Program members may allocate part or a majority of these funds to in-stream restoration projects. Stream restoration projects restore the beneficial uses of a stream and provide a healthy environment for biotic populations.

- A net benefit should be demonstrated through a quantitative cost-to-benefit analysis for all projects.
- Projects shall offset, in terms of beneficial uses and environmental benefits, the hypothetical on-site mitigation of the 2-year return frequency event;
- The stream classification system shall be used to assist in the prioritization of projects as follows: Non-EHM sections are more susceptible to hydromodification than EHM sections. Engineered, hardened, and maintained channels are by definition operated and maintained by the SBCFCD. These channels are designed to convey, at a minimum, the 10-year event. In addition, regular maintenance corrects any changes in stream morphology after out-of-range events (rarer than 10-year event). Within the Non-EHM sections, priority for projects should be gradually given to those segments identified as having high, medium, and low susceptibility risks. Susceptibility risks were evaluated in Appendix C of the WAP.
- The absence of CRPs, non-CRPs, or any type of retarding or sedimentation basin upstream of the project should be considered. As identified in Section 3, upstream basins modify the stresses on channel morphology of downstream waterbodies, most of which are still converging towards a morphologic equilibrium under modified sediment and flow regimes. Unless a combined geomorphic and hydrologic analysis demonstrates that the stream section has reached quasi-equilibrium, projects should not be considered in such cases. Projects without upstream basins will provide the most cost-effective and durable benefits.

An assessment of expected future developments in the drainage area tributary to the project will provide direction as to whether potential PDP proponents would be able to participate financially into these restoration projects. PDP proponents are directed to contribute to projects in the same watershed, thus offsetting the hydromodification created by the PDP. The second benefit of assessing expected future development is to understand the future sediment and flow regimes under which the stream section will be subject.

In addition to spatial and technical priorities presented above, local jurisdictions should consider the temporal priority of each project as part of the potential in-lieu fund. The temporal priority at the time of consideration of one restoration or rehabilitation project should be determined based on Figure 3-3. Projects temporal priority may be adjusted based on new evidence as it is acquired through channel surveys. Implementation, if required, should focus on those projects demonstrating combined high temporal, technical, and spatial priorities. Figure 2-3 presents a preliminary decision matrix to assist in the process of prioritizing in-lieu projects.

Figure 2-3, Node 1 – Evaluation of an identified restoration/rehabilitation project, identified in Appendix E and Appendix F of the WAP;

Figure 2-3, Node 2 – Identify if a flood control retarding basin or sedimentation basin is located upstream of the identified project.

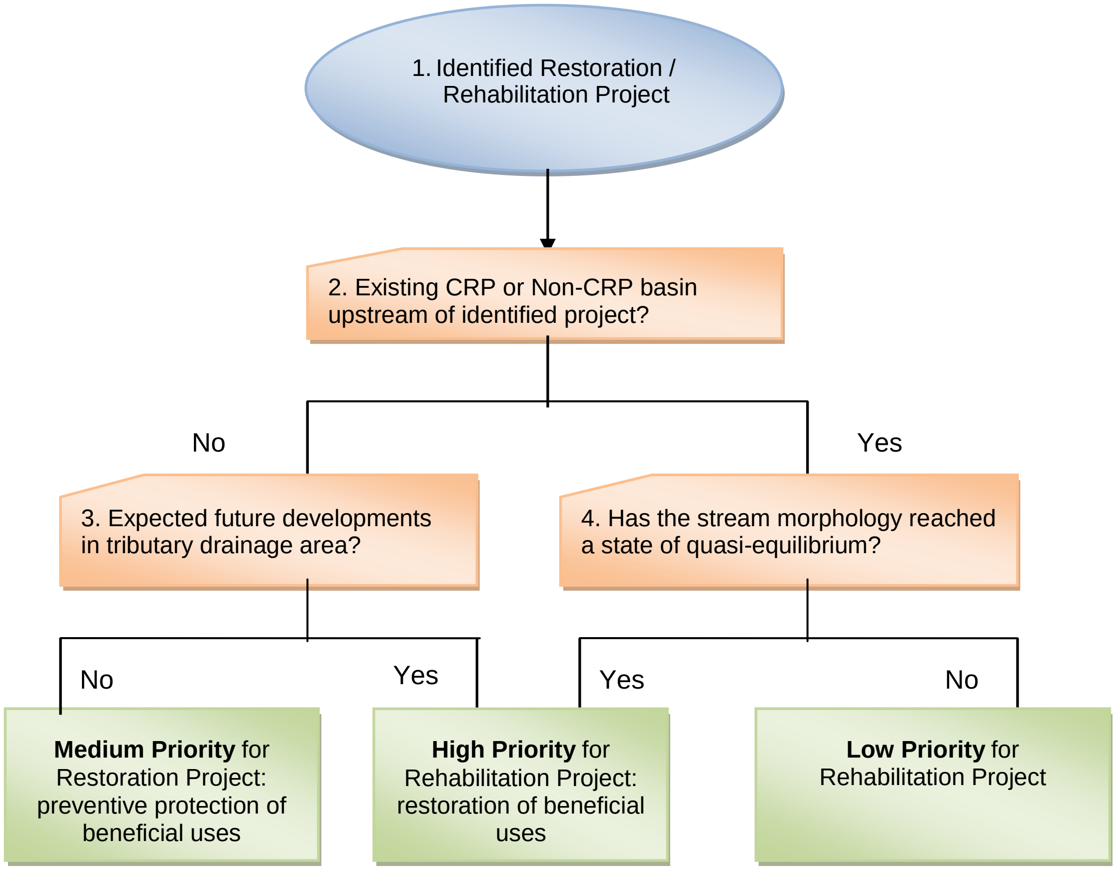
Figure 2-3, Node 3 – If there are no retarding basin upstream of the potential restoration project, the existence of future developments in the tributary drainage area should be investigated;

Figure 2-3, Node 4 – If there are identified upstream basins altering sediment and flow regimes in the stream, a combined geomorphic and hydrologic analysis should determine if the stream channel has reached a state of quasi-equilibrium at the location considered for restoration;

Figure 2-3, Priority Action Nodes – Two types of actions are considered: 1) rehabilitation for streams that require a modified morphology along with restored beneficial uses and 2) restoration for streams that are in geomorphic equilibrium and will not observe any altered flow and/or sediment regimes.

If an in-lieu fund is established, the Program will re-evaluate the above criteria.

Figure 3-3: Prioritization Matrix for Restoration and Rehabilitation Projects



3 Hydromodification Monitoring Plan (HMoP)

3.1 Susceptibility and Risk Classification

A methodology to determine the susceptibility of channels to hydromodification was developed as part of the WAP. Susceptibility risks were determined based on two methods: analysis of the SBCFCD System Index, also known as the Red Book; and conducting Rapid Stream Risk Classifications using the method created by WEST Consultants (2011). The SBCFCD System Index helped identify which channel facilities would be classified as Engineered, Hardened, and Maintained (EHM) or Non-Engineered, Hardened, and Maintained (non-EHM).

The Rapid Stream Risk Classification method was subsequently used to quantify the susceptibility risk of each existing drainage facility based on six criteria:

- Shear Ratio - an indicator of channel's bed shear stress sensitivity to increased discharge;
- Entrainment Ratio - represents the channel erosion potential;
- Geotechnical Stability Number - measures the lateral channel stability;
- Confinement Class – measure of the amount of room that exists for the channel to actively move laterally and is a useful indicator of a channel's vulnerability to erosion;
- Bank Conditions
- Streambed Condition

From utilization of these two methods, six classification categories were created and considered:

- EHM - Engineered, Hardened, and Maintained;
- Low Risk - Non-EHM with a low risk for Hydromodification;
- Medium Risk - Non-EHM with a medium risk for Hydromodification;
- High Risk - Non-EHM with a High risk for Hydromodification;
- Default High Risk – Non-EHM that was not evaluated;
- Santa Ana River

Existing drainages were then delineated and classified based on their susceptibility to hydromodification. The resultant spatial classifications of susceptibility risk for the stream channels in the Santa Ana River Watershed Region of San Bernardino County can be found in the Program's on-line WAP Geodatabase (*http://sbcounty.permitrack.com/wap/*). An in-depth methodology for classification is detailed in Appendix C of the WAP.

3.2 Monitoring Sites

Technical concepts and constraints specific to the Santa Ana River Watershed Region of San Bernardino County were taken into consideration when selecting the potential monitoring stations that would effectively provide information regarding the performance of hydromodification measures.

Several criteria were evaluated and weighted, including:

- Selected monitoring stations focus primarily on stream sections found to present a high susceptibility risk during WAP development investigations. In zones as defined by the San Bernardino County Flood Control District where opportunities to monitor streams of high susceptibility risks are not available, monitoring of streams of medium susceptibility risks representative of the local conditions were considered.
- The existence of historical records of Rapid Stream Risk Classification: only the sections of streams that were surveyed during development of the WAP were evaluated to facilitate the tracking of geomorphic evolution.
- The existence of upstream new developments and the potential for future developments in the tributary drainage area. The presence of future developments was determined based on the most recent release of the San Bernardino County General Plan maps with a particular emphasis on the land use zoning district maps. Establishing monitoring stations immediately downstream of development areas will help evaluate the effectiveness of on-site BMP in preventing and/or reducing impacts from hydromodification on directly affected downstream channels.
- Ensuring that the spatial distribution of the selected monitoring stations captures the different San Bernardino County Flood Control District (SBCFCD) zones.

The potential monitoring stations initially selected are listed in Table 4-1. The exact locations of these sites are still being determined based upon their accessibility, location near a flow gage station, and potential for bioassessment. These sites will be further evaluated for their effectiveness as a representative location. The Program will submit a revised list of monitoring stations to the RWQCB for approval prior to implementation of the HMoP which shall include: information for each monitoring station including: monitoring station type, watershed information related to the tributary area such as soil type, land use, imperviousness, rain gauge stations, and stream flow monitoring location. The majority of channels within SBCFCD zones 1 and 2 are EHM, and are deemed not susceptible to hydromodification. The determination of the exact locations of the selected monitoring stations will ensure that the domain of analysis, as defined by SCCWRP, is not influenced by the downstream confluence.

The concept of providing hydromodification effectiveness measurements in the watershed headwaters is supported by SCCWRP. Research by SCCWRP has shown that hydromodification effects of a development project become muted with increasing distance from the development site (defined by SCCWRP as the Domain of Effect). To the extent practicable, monitoring locations selected in this plan are distributed throughout the Santa Ana River Watershed Region of San Bernardino County to provide for geographic and climatic variability.

Table 4-1 – HMP Preliminary Monitoring Locations

Stream	Flood Zone	Coordinates	City	Susceptibility risk	Station Type
24th Street Storm Drain	1	TBD	Rancho Cucamonga	High	TBD
Demens Creek Channel	1	TBD	Rancho Cucamonga	High	TBD
English Canyon	1	TBD	Chino Hills	High (medium)	TBD
Mill Creek	3	TBD	Redlands	High	TBD
Wilson Creek[1]	3	TBD	Yucaipa	High	TBD
Oak Glen Creek	3	TBD	Yucaipa	High	TBD

Notes:

1) There are two proposed stations on Wilson Creek: one station will be located upstream of the sedimentation basin #3 to a point where the domain of analysis will not be influenced by these basins and will serve as a test station for the Live Oak watershed. The second station will be located at the boundary line with the San Bernardino National Forest and will serve as a reference station. Wilson Creek was characterized by the Rapid Stream Risk Classification as high risk. Based on the General Plan, future developments are scheduled to occur in the drainage area located between the Wilson Creek test and reference stations.

3.2.1 Temporal Variability of Monitoring Locations

The single most important factor affecting the temporal variability inherent to measuring stream degradation is variable inter-annual rainfall frequency and intensity. Droughts in California can last years, with little to no rainfall occurring in Southern California. During El Niño years, anomalously high storm frequencies and intensities can result in sudden geomorphic changes. Rainfall intensity also varies intra-annually. Accordingly, the value of the monitoring program will be derived only over the long-term. Significant trends will likely require many years to identify.

3.2.2 Spatial variability of Monitoring Locations

Sampling a representative set of streams is important to capture the range of watershed conditions present in the Permit coverage area. Other important factors that affect stream responses to hydromodification include channel grade, watershed area, vegetated cover, and stream sinuosity of the lower reaches. In addition to channel and watershed features, location within the watershed is an important consideration. Monitoring stations should be located in the watershed headwaters just downstream of a development project of sufficient size, so that hydromodification effects from the proposed development can be isolated for comparison purposes to the maximum extent practicable. Upper watershed sites provide more definitive measures of HMP effectiveness because they can more directly correlate effects to specific development projects.

3.3 Hydromodification Monitoring Parameters

The permit requires that PDP projects shall not cause adverse impacts to downstream natural channels or habitat integrity. Geomorphic, Hydrologic, and biological parameters will be monitored to ensure that implemented project hydrologic control measures are effectively mitigating any potential HCOC.

While the San Bernardino HMP is based upon the Orange County HMP, differences exist between the two landscapes which requires differences in approach to the Hydromodification Monitoring Plan (HMoP). These differences in approach are due mainly to the absence of coastal watersheds within San Bernardino County, the fact there is a higher proportion of stream reaches in the lower watersheds that are engineered, hardened, and maintained (EHM), and a lower annual rainfall due to the arid climate. Due to the arid climate, most streams demonstrate only an ephemeral flow in the spring with bank to bank flow occurring only during rain events. This combination of channel physical characteristics and ephemeral nature of flow is insufficient to provide adequate habitat for the WARM and COLD beneficial uses established for many streams. These beneficial uses do not have water currently put towards these uses due to the physical constraints in the watershed which also makes such future uses highly unlikely.

Due to the characteristics of the landscape, a majority of the focus of the HMoP will be on geomorphic and hydrologic parameters with biological parameters considered when the susceptibility and risk management category changes due to alterations of the channel morphology. Specific parameters that will be monitored for are detailed in the following sections.

3.3.1 Geomorphic Parameters

A physical measurement of the pre-project and post-project cross sections of the channel will be performed to determine if the channel is incising and/or widening over time. This will be accomplished by conducting geomorphic assessments and channel surveys at monitoring stations. In addition to physical measurements, comparison of current and historical photos, aerial photography, and site inspection for signs of channel degradation will be performed to provide additional supporting evidence.

In San Bernardino County, numerous CRP and sedimentation basins located at the toe of steep mountain slopes have significantly reduced the sediment supply to downstream waterbodies, resulting ultimately in channel instability. Therefore, reaches not influenced by CRPs will be selected for monitoring.

Geomorphic parameters that will be monitored include those necessary to perform a stream rapid assessment (Section 4.1) and those necessary to classify the channel per the simplified Rosgen system of channel classification (See Appendix B). These parameters include:

- Shear Ratio;
- Entrainment Ratio;
- Geotechnical Stability Number;
- Confinement Class;
- Bank Conditions;
- Streambed Condition;
- Channel Cross Sections;

- Floodprone width;
- Bankfull width;
- Bankfull depth;
- Longitudinal slope;

3.3.2 Hydrologic Parameters

The Hydrology of a watershed is determined by the intensity and duration of a storm event as well as the physical characteristics of the landscape in which the watershed resides. Hydrologic parameters that are influenced by an increase in urbanization and can lead to changes in channel morphology include:

- Flow Rate;
- Duration of Flow
- Runoff Volume
- Velocity;
- Peak Flow;
- Peak Flow duration;
- Time of concentration

These parameters shall be documented and evaluated in conjunction with regional storm event data to assess whether or not post-development site hydrology varies significantly from pre-development hydrology for a 2-year storm event.

3.3.3 Biological Parameters

Biological organisms provide information on the overall health of a stream. The evolution of benthic macroinvertebrate communities may be the precursor to either an impacted, or improved, stream. The geomorphologic evolution of a stream segment which results in a change in the susceptibility and risk classification category, if it occurs, will be the trigger for conducting a bioassessment. If the geomorphic survey indicates no re-classification of susceptibility and risk for the reach (using the Rapid Stream Risk Classification detailed in Section 4.1), no bioassessment will be conducted. If a re-classification is indicated, then a bioassessment shall be conducted. Bioassessments will be conducted in late spring at applicable monitoring station locations by computing the Index for Biotic Integrity (IBI) score and comparing it to historical levels in the same stream if available. However, historical data for comparison for the lower watershed in San Bernardino County does not appear to be available based on the California Environmental Data Exchange Network (CEDEN) queries. Based upon the physical characteristics of the lower watershed where the effects of potential HCOC may occur (see section 3.3), the absence of historical data, and the requirements of bioassessment protocols (See Appendix C), it may be infeasible to conduct benthic community monitoring in the lower watershed as a monitoring parameter in the HMoP. Monitoring stations potential for bioassessments is still being determined.

3.4 Assessment Methodology

The defined assessment methodology addresses the requirements of Permit Section XI.B.3.b.ii., including a description of inspections and maintenance of hydrologic controls, as well as a follow-up protocol to address potential hydromodification impacts.

Considering the parameters to be monitored at the reference site and monitoring sites detailed above, the following approaches are proposed for hydromodification monitoring:

3.4.1 Complete a stream channel geomorphic survey at each of the selected channel sections or monitoring locations on a semi-annual basis.

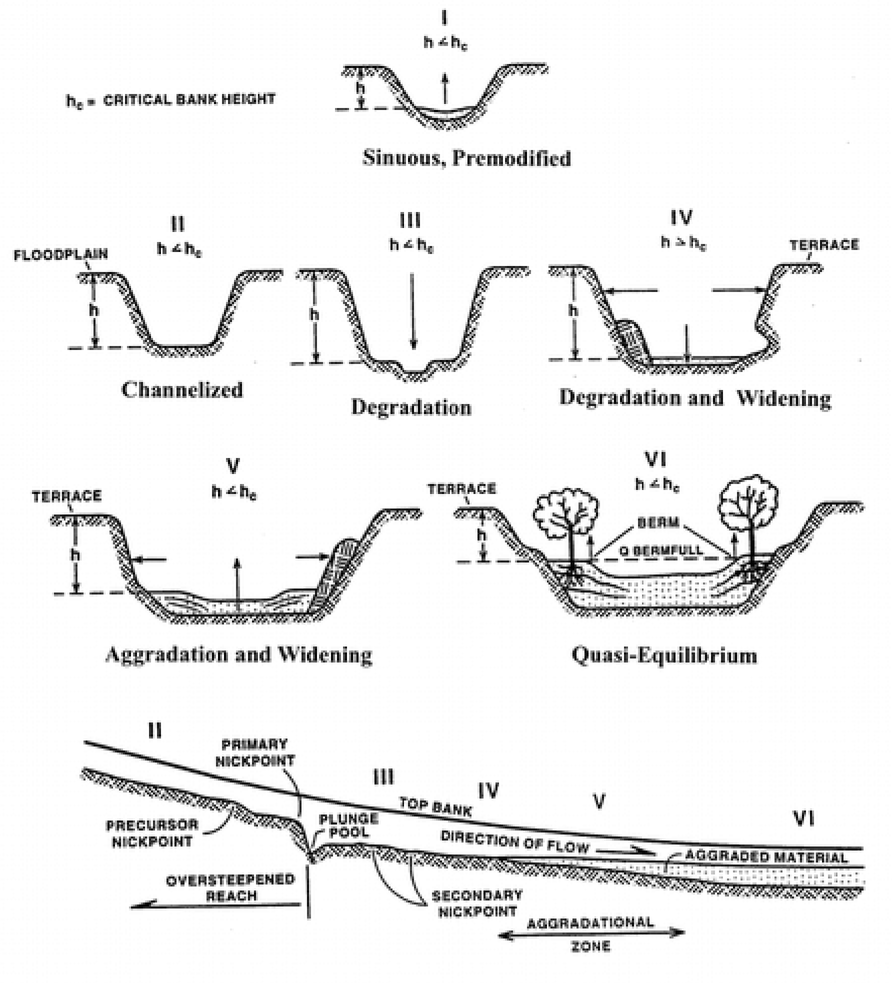
Only channels that were characterized as non-EHM will be assessed. The stream channel geomorphic survey will consist of collecting topographic and bathymetric measurements along each cross-section to characterize morphology and longitudinal slope of the stream segment. The collected measurements will include those necessary for the computation of a Rapid Stream Risk Classification (detailed in Section 4.1).

In addition, the following parameters will also be surveyed: the floodprone width, the bankfull width, the bankfull depth, and the longitudinal slope. Each surveyed stream segment will be subsequently classified per the simplified Rosgen system of channel classification (Rosgen, 1996). Figure B-2 shows the different types of channels per Rosgen channel classification (Rosgen, 1996).

The temporal evolution in geomorphology, if any, of the surveyed stream segment will be compared to the six-stage Channel Evolution Model defined by Simon, as well as the previous year cross section data, to correlate any potential impacts of urbanization to this change of stream channel geomorphology (Simon et al., 1992). Figure 4-2 illustrates the six-stage sequence of incised channel evolution (Simon et al., 1992). A stream segment will be considered stable over time if features of the stream segment (such as dimension, pattern, and profile) are maintained, and the stream system neither aggrades nor degrades. The channel classification procedure is described in more detail in Appendix B.

Channel geomorphic surveys will be conducted semi-annually, once at the end of the wet season and once at the end of the dry season and evaluated against storm event and flow data collected from gage stations.

Figure 4-2: Six-Stage Channel Evolution Model



(Simon et al, 1992)

3.4.2 Potentially evaluate the effectiveness of the HMP by monitoring benthic macroinvertebrate communities when the susceptibility and risk management classification of channel morphology changes.

An examination of benthic macroinvertebrate organisms is proposed to assess the change in biological health of the streams only if a channel's morphology is altered in a manner that would change the channels susceptibility and risk management classification as per section 3.1. An examination of these organisms is dependent upon identifying the availability of appropriate monitoring stations which contain the necessary physical characteristics described in the California Bioassessment Protocol (Appendix C).

Stream bioassessment for the purpose of determining HMP effectiveness may be coupled with the Urban Stream Bioassessment. Several bioassessment monitoring sites already exist for both the Surface Water Ambient Monitoring Program SWAMP, which is developed on a five-year cycle, and the annual Orange County Unified Program Effectiveness Assessment. At each of these existing sites, historical bioassessment data is readily available for the establishment of pre-project conditions. Several reference monitoring sites are available in the upper watershed including, but not limited to, three urban bioassessment sites. The ultimate selection of bioassessment sites should consider integrating one or several of these existing sites if consistent with the objectives of the HMoP Assessment Methodology.

3.4.3 BMP inspections and maintenance

Section 8 of the 2013 TGD for WQMP requires regular periodic inspections and maintenance of on-site post-construction BMP. Maintenance activities shall ensure that the systems are properly controlling runoff volume, velocity, duration, and time of concentration to meet the HCOC requirements defined in the Permit Section XI.E.5.d.(2).(c).

3.4.4 Performance & Follow-up Protocol

The objective of the performance protocol is to correct any performance deficiencies in the existing hydrologic controls. As defined in Section 3.4.1, channel cross-section surveys are to be performed on a semi-annual basis at representative locations in the Santa Ana River Watershed Region of San Bernardino County. If a significant degradation of a stream segment has been detected, it will be subjectively interpreted by the analyst as a rapid change of the morphology of the channel (cross-section) which may indicate that flow conditions have consequently changed. If the stream degradation was caused by flows outside the critical range (higher than a 10-year return frequency storm then no further investigation is needed. An investigation shall then be performed to determine the cause of the change.

The performance protocol is an iterative investigative process that consists of evaluating the tributary area of the impacted stream segment to identify the potential source(s). Hydrologic controls of priority projects will be examined to determine if they are under-performing due to a lack of maintenance or poor design.

If a lack of BMP maintenance is apparent, or if the BMP(s) is in a state of disrepair, the local jurisdiction shall, in compliance with WQMP post-construction maintenance requirements, direct the site owner to perform the appropriate maintenance and/or repair, as needed, in a timely manner. This lack of performance may then be assumed to be directly responsible for the drastic change in stream conditions (morphology), subject to verification by future monitoring.

If no evidence of priority project BMP deficiency is apparent, local jurisdictions will prioritize the tributary area when conducting their IC/ID program. If no obvious sources can be found, and continuing degradation occurs, it can be assumed that the cause of the rapid change of the morphology is due to existing conditions (urbanization, channel lithography, etc.) in the tributary area. Rehabilitation or restoration of the stream segment may then be required; and currently identified rehabilitation and restoration opportunities will be evaluated for their applicability. Once an appropriate site is identified, that site shall be reprioritized as a high priority project per section 2.4.

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APPENDIX A – LITERATURE REVIEW

This section provides the results of a literature review conducted to provide a basis for the development of the Hydromodification Management and Monitoring Plan.

Hydromodification, in the context of this Plan, refers to changes in the magnitude and frequency of stream flows due to urbanization and the resulting impacts on the receiving channels in terms of erosion, sedimentation, and degradation of in-stream habitat. The processes involved in aggradation and degradation are complex, but are caused by an alteration of the hydrologic regime of a watershed due to increases in impervious surfaces, more efficient storm drain networks, and a change in historic sediment supply sources. The study of hydromodification is an evolving field, and regulations to manage the impacts of hydromodification must be grounded in the latest science available.

HMP seek ways to mitigate erosion impacts by establishing requirements for controlling runoff from new and significant re-development. In order to establish appropriate regulations, it is important to understand 1) how land use changes alter stormwater runoff; and 2) how these changes can impact stream channels. These, and other issues central to HMP adopted in California, have been addressed in numerous journal articles, books, and reports. This report builds upon previous literature reviews developed for the South Orange County HMP and the San Diego County HMP, including recent studies or information relevant to Southern California.

Managing Hydromodification

There are many different approaches to managing hydromodification impacts from urbanization; and most HMP provide multiple options for achieving and documenting compliance with National Pollutant Discharge Elimination System (NPDES) permit requirements. In general, hydrograph management approaches focus on managing runoff from a developed area to not increase instability in a channel, and in-stream solutions focus on managing the receiving channel to accept an altered flow regime without becoming unstable. This section briefly summarizes various approaches for HMP compliance.

Hydrograph Management Solutions

Facilities that detain or infiltrate runoff to mitigate development impacts are the focus of most HMP implementation guidance. They work by either reducing the volume of runoff (infiltration facilities) or holding water and releasing it below Q_c (detention facilities). These facilities, also referred to as BMP, can range from regional detention basins designed solely for flow control, to bioretention facilities that serve a number of functions. A number of BMP, including swales, bioretention, flow-through planters, and extended detention basins have been developed to manage stormwater quality, and several resources describe the design of stormwater quality BMP (CASQA 2003; Richman et al. 2004). In many cases, these facilities can be designed to also meet hydromodification management requirements.

Many HMP also provide guidance for applying LID approaches to site design and land use planning to preserve the hydrologic cycle of a watershed and mitigate hydromodification impacts. These plans typically include decentralized stormwater management systems and protection of natural drainage features, such as wetlands and stream corridors. Runoff is typically directed toward infiltration-based BMP that slow and treat runoff. The following sections summarize how hydromodification management BMP developed for existing HMP have been designed and implemented.

Sizing Hydromodification BMP

Hydromodification BMP differ slightly from those used to meet water quality objectives in that they focus more on matching undeveloped flow-regimes than on removing potential pollutants, although these two functions can be combined into one facility. Various methods exist for sizing hydromodification BMP.

Hydrograph Matching uses an outflow hydrograph for a particular site that matches closely with the pre-project hydrograph for a design storm. This method is most traditionally used to design flood-detention facilities to mitigate for a particular storm recurrence interval (e.g., the 100-year storm). Although hydrograph matching can be employed for multiple storm recurrence intervals, this method does not typically take into account the smaller, more frequent storms where a majority of the erosive work in stream channel is done.

Volume Control matches the pre-project and post-construction runoff volume for a project site. Any increase in runoff volume is either infiltrated on site, or discharged to another location where streams will not be impacted. The magnitude of peak flows and time of concentration is not controlled, so while this method ensures there is no increase in total volume of runoff, it can result in higher erosive forces during storms.

Flow Duration Control matches both the duration and magnitude of a specified range of storms. The entire hydrologic record is taken into account, and pre-project and post-construction runoff magnitudes and volumes are matched as closely as possible. Excess runoff is either infiltrated on-site or discharged below Q_{cp} (Geomorphically critical flow – 10 percent of the 2-year flow).

Several agencies have adopted the flow duration control approach. The Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVUPPP) HMP reviewed each of these methods and concluded that a Flow Duration Control approach was the most effective in controlling erosive flows. Two examples were evaluated using this approach, one on the Thompson Creek subwatershed in Santa Clara Valley and one on the Gobernadora Creek watershed in Orange County. The evaluation approach used continuous simulation modeling to generate flow-duration curves, and then designed a test hydromodification management facility to match pre-project durations and flows.

In addition to the SCVURPP HMP, the flow duration control approach has been applied by the Alameda Countywide Clean Water Program (ACCWP), SMCWPPP, the Fairfield-Suisun Urban Runoff Management Program (FSURMP), Contra Costa Clean Water Program (CCCWP), San Diego County, and South Orange County. Among these agencies, different approaches have emerged on how to demonstrate that proposed BMP meet flow-duration control guidelines. Both methods employ continuous simulation to match flow-durations, but differences exist in how continuous simulation is used (site-specific simulation vs. unit area simulation). Differences also exist in the focus of the two approaches (regional detention facilities vs. on-site LID facilities). Both approaches were evaluated by the different RWQCBs and deemed valid (Butcher 2007).

BAHM Approach

The Bay Area Hydrology Model (BAHM) is a continuous simulation rainfall-runoff hydrology model developed for ACCWP, SMCWPPP, and SCVURPP. It was developed from the Western Washington Hydrology Model, which focuses primarily on meeting hydromodification management requirements using stormwater detention ponds alone or combined with LID facilities (Butcher 2007). The Western Washington Hydrology model is based on the Hydrologic Simulation Program – FORTRAN (HSPF) modeling platform, developed by the United States

Environmental Protection Agency (U.S. EPA), and uses HSPF parameters in modeling watersheds.

Project proponents who want to size a hydromodification BMP select the location of their project site from a map of the county and BAHM correlates the project location to the nearest rainfall gauge and applies an adjustment factor to the hourly rainfall for the nearest gauge, to produce a weighted hourly rainfall at the project site. The user then enters parameters for the proposed project site describing soil types, slope, and land uses. BAHM then runs the continuous rainfall-runoff simulation for both the pre-project and the post-construction conditions of the project site. Output is provided in the form of flow-duration curves that compare the magnitude and timing of storms between the pre-project and the post-construction modeling runs.

If an increase in flow durations is predicted, the user can select and size mitigation BMP from a list of modeling elements. An automatic sizing subroutine is available for sizing detention basins and outlet orifices that matches the flow duration curves between the pre-project scenario and a post-construction mitigation scenario. Manual sizing is necessary for other BMP included in the program, such as storage vaults, bioretention areas, and infiltration trenches. The program is designed so that, once a BMP is selected and sized, the modeling run can be transferred to the local agency for approval. The model reviewer at the local agency can launch the program and verify modeling parameters and sizing techniques.

Contra Costa Clean Water Program (CCCWP) Approach

The CCCWP developed a protocol for selecting and sizing hydromodification BMP, which are referred to as Integrated Management Practices (IMPs) in their guidebook. Instead of a project proponent running a site-specific continuous simulation to size hydromodification control facilities, the CCCWP provides sizing factors for designing site level IMPs. Sizing factors are based on the soil type of the project site and are adjusted for Mean Annual Precipitation. Sizing factors are provided for bioretention facilities, flow-through planters, dry wells and a combination cistern and bioretention facility.

Sizing factors were developed through continuous-simulation HSPF modeling runs for a variety of development scenarios. Flow-durations were developed for a range of soil types, vegetation and land use types, and rainfall patterns for development areas in Contra Costa County. Then, based on a unit area (one acre) of impervious surface, flow-durations were modeled using several IMP designs. These IMPs were then sized to achieve flow control for the range of storms required, (from 10 percent of the 2-year storm up to the 10-year storm). These sizing factors were then transferred to a spreadsheet form for use by project proponents.

The primary difference between the CCCWP approach and the BAHM approach is the level of modeling required. The CCCWP approach is simplified for the project proponent in that both hydromodification and water quality mitigation are incorporated into the IMP sizing factors. The BAHM allows for more flexibility in that regional BMP may be used for hydromodification, and if desired, water quality, in addition to site level approaches. The South Orange County NPDES Permit allows for regional mitigation of hydromodification impacts. Therefore, an approach that uses continuous simulation to assess regional or neighborhood level BMP implementation is preferred for this Plan.

Sediment Management Solutions

Sediment discharge is one of the fundamental independent variables impacting stream stability. Lane (1955) described alluvial channel stability in the relation:

$$Q_s \times D_{50} \propto Q_w \times S$$

Where:

Q_s = Sediment discharge

D_{50} = Median sediment size

Q_w = Flow

S = Channel Slope

As seen by Lane's relationship, if any of the four variables are altered, one or more of the remaining variables must change. In the case of urbanization, runoff usually is increased, causing a reduction in channel slope (S) through downcutting or increased channel meander. Urbanization may also result in a change in sediment discharge (Q_s). Streambed material is derived from the channel bed and banks. If channels are altered by development in such a way as to reduce or increase sediment discharge, instability may occur.

Only a portion of the total sediment load in a channel is important for stream stability. Total channel sediment load may be classified by size or transport mechanism. The wash load commonly refers to the portion of the total sediment load that remains continuously in suspension (based on particle size). The wash load has a nominal impact on channel stability. Bed material load refers to the material that moves along the channel bed via saltation, and is continuously in contact or exchange with the channel bed. Bed material load is the critical portion of total sediment discharge for channel stability.

Urbanization can reduce the mass of bed material transported through the elimination of alluvial channel sections. This occurs in site development when first order and particularly larger streams are lined or placed into underground conduits.

In-Stream Stabilization Solutions

In-stream solutions focus on managing the stream corridor to provide stability, modifying the stream channel to accept an altered flow regime. In cases where development is proposed in a watershed with an impacted stream it may be beneficial to focus on rehabilitating the stream channel to match the new independent variables of channel cross section, sediment discharge, flow discharge and channel slope rather than retrofitting the watershed or only controlling a percentage of the runoff with on-site controls. This type of approach can restore stream functions, beneficial uses, and values at a much more rapid pace, especially in locations that cannot physically be returned to their natural state due to changes in stream channel alignment and restrictions on the channel cross section due to adjacent development. In addition, in some cases where a master-planned watershed development plan is being implemented it may be more feasible to design a new channel to be stable under the proposed watershed land use rather than to construct distributed on-site facilities.

A stream channel that has devolved far enough down the evolution sequence, exhibiting surpassed planforms or bank height, should be allowed to continue progressing toward a new stable equilibrium condition (SCCWRP, 2012). This is specifically the case for channels with significantly altered flow or sediment discharge. In such cases, SCCWRP recommends determining the appropriate channel form that would provide equilibrium for expected future conditions per Lane's interpretation. Numerous publications have concluded that the natural state of channels in urban areas cannot longer be sustained under changed hydrologic conditions.

In-stream stabilization and restoration solutions are available to streams identified as highly susceptible to hydromodification. The WAP identified several opportunities for restoration along susceptible channels. Tiered benefits (benthic communities, morphology) of such in-stream restoration projects must offset the hydrologic and sediment changes induced by upstream urbanization.

Other Methods

A number of methods exist for managing channels to accept altered flow regimes and higher shear forces. These have been covered in detail in a number of sources available to watershed groups and public agencies. (A few helpful sources include Riley 1998, Watson and Annable 2003, and FISRWG 1998.)

Stream Susceptibility - Domain of Analysis

Southern California Coastal Water Research Project (SCCWRP) has developed a series of screening tools that evaluate the susceptibility of a stream to hydromodification impacts (SCCWRP, 2010). These screening tools allow a project proponent to rate the susceptibility of the evaluated stream to erosion for a variety of geomorphic scenarios including alluvial fans, broad valley bottoms, incised headwaters, etc.

The development of HMP in most Southern California counties is correlated to the ultimate findings of SCCWRP studies on hydromodification (SCCWRP, 2008 through 2011). It is generally acknowledged that SCCWRP's formulation of regional standards for hydromodification management may serve as a baseline for development of HMP for specific regions in Southern California.

When evaluating the stream susceptibility though the SCCWRP screening tools, a domain of analysis is defined. This domain of analysis corresponds to the reach lengths upstream and downstream from a project from which hydromodification assessment is required. The domain of analysis determination includes an assessment of the incremental flow accumulations downstream of the site, identification of grade control points in the downstream conveyance system, and quantification of downstream tributary influences. Extensive susceptibility mapping was performed during development of the WAP. The results of the investigations are detailed in Section 3.3.

The effects of hydromodification may propagate for significant distances downstream (and sometimes upstream) from a point of impact such as a stormwater outfall. Accordingly, the domain of analysis serves as a representative buffer domain across which the susceptibility of a stream should be evaluated. This representative domain spans multiple channel types/settings, and is defined as follows in this HMP (SCCWRP, 2010):

Proceed downstream until reaching the closest of the following:

- at least one reach downstream of the first grade-control point (but preferably the second downstream grade-control location)
- tidal backwater/lentic waterbody
- equal order tributary (Strahler 1952)
- a 2-fold increase in drainage area
- OR demonstrate sufficient flow attenuation through existing hydrologic modeling.

Proceed upstream to extend the domain: 1) upstream for a distance equal to 20 channel widths; OR 2) to grade control in good condition; whichever comes first. Within that reach, identify hard points that could check headward migration, evidence that head cutting is active or could propagate unchecked upstream

Within the analysis domain there may be several reaches that should be assessed independently based on either length or change in physical characteristics. In more urban settings, segments may be logically divided by road crossings (Chin and Gregory 2005), which may offer grade control, cause discontinuities in the conveyance of water or sediment, etc.

Hydrograph Matching Approach

The San Bernardino HMP adopts a hydrograph matching approach, as required per Permit condition XI.E.5.(ii).(c) for priority development or re-development project proponents. The Permit states that "post-development site hydrology (runoff volume, velocity, duration, time of concentration) must not significantly be different from pre-development hydrology for a 2-year return frequency storm. The selection of the 2-year storm event as a matching event may have been linked to the dominant discharge, as defined by Leopold (1964). Leopold (1964) introduced the concept of effective work, whereby the flow-frequency relationship of a channel is multiplied by sediment transport rate. This gives a mass-frequency relationship for erosion rates in a channel. Flows on the lower end of the relationship (e.g., two-year flows) may transport less material, but occur more frequently than higher flows, thereby having a greater overall effect on the work within the channel. Conversely, higher magnitude events, while transporting more material, occur infrequently so cause less effective work. Leopold found that the maximum point on the effective work curve occurred around the 1-to 2-year frequency range. This maximum point is commonly referred to as the dominant discharge. It corresponds roughly to a bankfull event (a flow that fills the active portion of the channel up to a well-defined break in the bank slope).

Previous Studies

Previous hydromodification literature reviews were conducted by Geosyntec Consultants (Mangarella and Palhegyi, 2002) for the Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP) and by the Contra Costa Clean Water Program (CCCWP, 2004). Mangarella and Palhegyi provide a detailed overview of the geomorphic and hydrologic processes involved in hydromodification (see Section **Error! Reference source not found.**) for additional details on the mechanics of stream erosion).

To date, six approved HMP have been published. These include HMP for SCVURPPP (2005), the CCCWP (2005), the Fairfield-Suisun Urban Runoff Management Program FSURMP (2005), the Alameda Countywide Clean Water Program (ACCCMP 2005), the San Mateo Countywide Stormwater Pollution Prevention Program (SMCWPPP [formerly STOPPP] 2005), and the San Diego County Hydromodification Plan (2009). In addition, the South Orange County HMP has been approved upon integration of the San Diego Regional Board comments. In addition, a number of HMP were implemented while agencies developed their final plans. Interim HMP are not detailed in this report because these plans have adopted findings from the above listed HMP.

Hydrograph Modification Processes

The effects of urbanization on channel response have been the focus of many studies (see Paul and Meyer, 2001 for a review), and the widely accepted consensus is that increases in impervious surfaces associated with urbanizing land uses can cause channel degradation. Urbanization generally leads to a change in the volume and timing of runoff in a watershed, which increases erosive forces on channel bank and bed material and can cause large-scale channel enlargement, general scour, stream bank failure, loss of aquatic habitat and degradation of water quality.

Channel erosion, like most physical processes, is a complex system based on a variety of influences. Channel erosion is non-linear (Philips 2003), meaning the response of streams is not directly proportional to changes in land use and flow regimes. Small changes or temporary disturbances in a watershed may lead to unrecoverable channel instability (Kirkby 1995). These disturbances may give rise to feedback systems whereby small instabilities can be propagated into larger and larger instabilities (Thomas 2001).

A number of studies have sought to correlate the amount of urbanization in a watershed and stream instability (Bledsoe 2001; Booth 1990, 1991; Both and Jackson 1997; MacRae 1992; 1993; 1996; Coleman et al. 2005). Evidence from these studies suggests that below a certain threshold of watershed imperviousness, streams maintain stability. This threshold or imperviousness transition zone appears to be around seven to ten percent watershed urbanization for perennial streams (Schueler 1998 and Booth 1997), but may begin at a lower level for intermittent streams such as those found in Southern California. Studies done in Santa Fe, New Mexico (Leopold and Dunne 1978) suggest that changes occur at four percent impervious area of the watershed.

Initial studies by Coleman et al. (2005) suggest that a response in the stream channel may begin to occur at two to three percent watershed imperviousness for intermittent streams in Southern California. It is important to understand that use of impermeable cover alone is a poor predictor of channel erosion due to differences in stormwater detention and infiltration within regions.

In highly urbanized watersheds returning a stream to a natural condition is infeasible due to existing development in the watershed.

Though it is well established that watershed urbanization causes channel degradation, a detailed understanding of how development alters runoff and how this altered runoff in turn causes erosion is still being developed. This section briefly describes these processes and summarizes methods used to quantify hydromodification impacts.

Effective Work

The ability of a stream to transport sediment is proportional to the amount of flow in the stream: as flow increases, the amount of sediment moved within a channel also increases. The ability of a stream channel to transport sediment is termed stream power, which integrated over time is work. As described earlier, Leopold (1964) introduced the concept of effective work, whereby the flow-frequency relationship of a channel is multiplied by sediment transport rate. This gives a mass-frequency relationship for erosion rates in a channel. Flows on the lower end of the relationship (e.g., two-year flows) may transport less material, but occur more frequently than higher flows, thereby having a greater overall effect on the work within the channel. Conversely, higher magnitude events, while transporting more material, occur infrequently so cause less effective work. Leopold found that the maximum point on the effective work curve occurred around the 1-to 2-year frequency range.

Urbanization tends to have the greatest relative impact on flows that are frequent and small, and which tend to generate less-than-bankfull flows. Change is greatest in these events because prior to urbanization, infiltration would have absorbed much or all of the potential runoff, but following urbanization, a high percent of the rainfall runs off. Thus, events that might have generated little or no flow in a non-urbanized watershed can contribute flow in urban settings. These smaller less-than-bankfull events have been found to cause a significant proportion of the work in urban streams (MacRae 1993) due to their high frequency, and can lead to channel instability. Less frequent, larger magnitude flows (e.g., flows greater than Q_{10}) are less strongly affected by urbanization because during such infrequent storm events, the ground rapidly becomes saturated, and acts (for purposes of runoff generation) in a similar manner as impervious surfaces.

Estimating Critical Q_c

Due to the increase in impervious surfaces and fewer opportunities for infiltration of stormwater, urbanization creates a higher runoff rate and more runoff volume than a non-urbanized watershed. Opportunities for infiltration of excess stormwater exist in urbanized areas, but many times are infeasible due to cost, technical barriers or land use constraints. Therefore, some of the excess stormwater must be discharged to a receiving stream. In order to achieve an E_p comparable to a pre-developed condition, excess runoff volume must be discharged at a rate at which insignificant effective stream work is done.

Bed load sediment moves through transmission of shear stress from the flow of water on the channel bed. An increase in the hydraulic radius (measure of channel flow efficiency through a ratio of the channel's cross sectional area of the flow to its wetted perimeter) corresponds to an increase in shear stress. In order to initiate movement of bed material, however, a shear stress threshold must be exceeded. This is commonly referred to as critical shear stress, and is dependent on sediment and channel characteristics. For a given point on a channel where the bed composition and cross-section is known, the critical shear can be related to a stream flow. The flow that corresponds to the critical shear is known as the critical flow, Q_c. For a given cross-section, flows that are below the Q_c value do not initiate bed movement, while flows above this value do initiate bed movement.

SCVURPPP expressed Q_c as a percentage of the two-year flow in order to develop a common metric across watersheds of different size, and allow for easy application of HMP requirements. For the two watersheds studied in detail in the SCVURPPP study, a similar relationship was found where Q_c corresponded to 10 percent of the two-year flow. This became the basis for the lower range of geomorphically significant flows under the SCVURPPP HMP and is referred to as Q_{cp} to indicate that it is a percentage of flow. That program also adopted the 10-year flow as the upper end of the range of flows to control with the justification that increases in stream work above the 10-year flow were small for urbanized areas.

Stream Channel Stability

Numerous stream channel stability assessment methods have been proposed to help distinguish which channels are most at risk from hydrograph modification impacts and/or define where HMP requirements should apply. Assessment strategies range from purely empirical approaches to channel evolution models to energy-based models (see Simon et al., 2007 for a critical evaluation). Stream channel stability assessment methods are useful in assessing the impact of urbanization, or control programs over time. Their value lies in showing trends as changes in a watershed occur, rather than classifying the reach of a discrete channel section at a given point in time.

Stream Classification Systems

A recent study by Bledsoe et al. (2008) for SCCWRP describes nine types of classification and mapping systems with an emphasis on assessing stream channel susceptibility in Southern California. The summary below is taken from that study. Bledsoe also provides a summary of the implications of these classification and mapping systems to the development of hydromodification tools for Southern California. The article provides a detailed breakdown of guidelines for developing hydromodification tools given the advantages and disadvantages of each system previously assessed.

The WAP included a risk susceptibility analysis of stream channels. This analysis classified non-engineered, hardened, maintained channels into high, medium, and low risk levels based on the Rapid Stream Risk Classification method (WEST, 2010). Those findings are summarized in Section 3.3.

Planform Classifications and Predictors

Alluvial channels form a continuum of channel types whose lateral variability is primarily governed by three factors: flow magnitude, bank erodibility, and relative sediment supply. Though many natural channels conform to a gradual continuum between straight and intermediate, meandering, and braided patterns, abrupt transitions in lateral variability imply the existence of geomorphic thresholds where sudden change can occur. The conceptual framework for geomorphic thresholds has proven integral to the study of the effects of disturbance on river and stream patterns. Many empirical and theoretical thresholds have been proposed relating stream power, sediment supply and channel gradient to the transition between braiding and meandering channels. Accounting for the effects of bed material size has been shown to provide a vital modification to the traditional approach of defining a discharge-slope combination as the threshold between meandering and braided channel patterns. The many braided planforms in Southern California indicate the need to refine and calibrate established thresholds to river networks of interest. However, at this time there is not a well-accepted model to predict how hydromodification affects channel planform.

Energy-Based Classifications

The link between channel degradation and urbanization has been studied; however, impervious area is not the solitary factor influencing channel response. Studies have shown that the ratio between specific stream power and median bed material size D50b, where b is approximately 0.4 to 0.5 for both sand-and gravel-bed channels, can be used as a valuable predictor of channel form. Stream power, which is related to the square root of total discharge, is the most comprehensive descriptor of hydraulic conditions and sedimentation processes in stream channels. Several studies have been performed relating channel stability to a combination of parameters such as discharge, median bed-material size, and bed slope, as an analog for stream power.

General Stability Assessment Procedures

By assessing an array of qualitative and quantitative parameters of stream channels and floodplains, several investigators have developed qualitative assessment systems for stream and river networks. These assessment methods have been incorporated into models used to analyze channel evolution and stability. Many parameters used to establish methodologies such as the Rosgen approach are extendable to a qualitative assessment of channel response in Californian river networks. Field investigations in Southern California have shown that grade control can be the most important factor in assessing the severity of channel response to hydromodification. Qualitative methodologies have proven extendable to many regions, and they use many parameters that may provide valuable information for similar assessments in California.

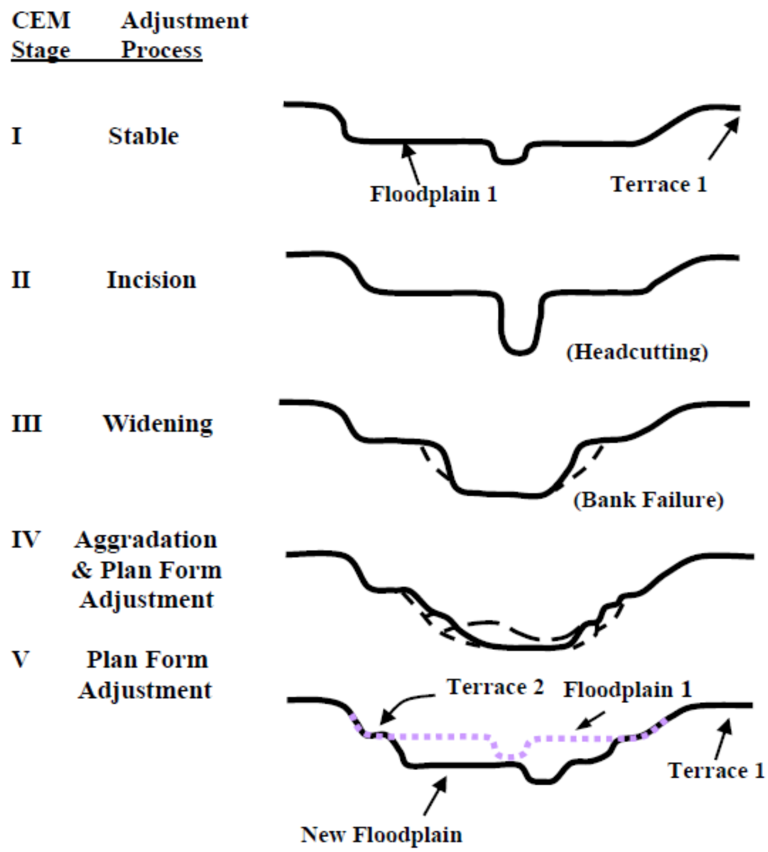
Sand vs. Gravel Behavior / Threshold vs. Live-Bed Contrasts

It is well recognized that the fluvial-geomorphic behavior varies greatly between sand and gravel/cobble systems. Live bed channels (of which sand channels are good examples) are systems where sediment moves at low flows, and where sediment is frequently in motion. Threshold channels, such as gravel streams, by contrast, require considerable flow to initiate bedload movement. Live bed channels are more sensitive to increases in flow and decreases in sediment supply than threshold channels. Scientific consensus shows that sand bed streams lacking vertical control show greater sensitivity to changes in flow and sediment transport regimes than do their gravel/cobble counterparts. Factors such as slope and sedimentation regimes are known to have greater impact on sand-bed streams. This can be an important issue for stormwater systems receiving runoff from watersheds composed primarily of streams with sandy substrate. The transition between sand and gravel bed behavior can be rapid, enabling the use of geographic mapping methods to prioritize channel segments according to their susceptibility to the effects of hydromodification.

Channel Evolution Models of Incising Channels

In addition to the six-stage channel evolution model posited by Simon et. al. (1992), the Channel Evolution Model (CEM) developed by Schumm et al. (1984) posits five stages of incised channel instability organized by increasing degrees of instability severity, followed by a final stage of quasi-equilibrium. Work has been done to quantify channel parameters, such as sediment load and specific stream power, through each phase of the CEM. A dimensionless stability diagram was developed by Watson et al. (2002) to represent thresholds in hydraulic and bank stability. This conceptual diagram can be useful for engineering planning and design purposes in stream restoration projects requiring an understanding of the potential for shifts in bank stability.

Figure A-1: Five Stages of the Channel Evolution Model (CEM)



(Schumm et al. 1984)

Channel Evolution Models (CEM) combining Vertical and Lateral Adjustment Trajectories

Originally, CEM focused primarily on incised channels with geotechnically, rather than fluvially, driven bank failure. Several CEM have been proposed that incorporate channel responses to erosion and sediment transport into the original framework for channel instability. In these new systems, an emphasis is placed on geomorphic adjustments and stability phases that consider both fluvial and geomorphic factors. The state of Vermont has developed a system of stability classification that suggests channel susceptibility is primarily a function of the existing Rosgen stream type and the current stream condition referenced to a range of variability. This system places more weight on entrenchment (vertical erosion of a channel that occurs faster than the channel can widen, resulting in a more confined channel) and slope than differentiation between bed types.

Equilibrium Models of Supply vs. Transport-capacity / Qualitative Response

The qualitative response model builds on an understanding of the dynamic relationship between the erosive forces of flow and slope relative to the resistive forces of grain size and sediment supply to describe channel responses to adjustments in these parameters. In this system, qualitative schematics provide predictions for channel response to positive or negative fluctuations in physical channel characteristics and bed material. Refinements to such frameworks have been made to account for channel susceptibility relative to existing capacity and riparian vegetation among other influential characteristics.

Bank Instability Classifications

Early investigations provided the groundwork for bank instability classifications by analyzing shear, beam, and tensile failure mechanisms. The dimensionless stability approach developed by Watson characterized bank stability as a function of hydraulic and geotechnical stability. Rosgen (1996) proposed the widely applied Bank Erosion Hazard Index (BEHI) as a qualitative approach based on the general stability assessment procedures outlined above. Other classification systems, like the CEM, determine bank instability according to channel characteristics that control hydrogeomorphic behavior.

Hierarchical Approaches to Mapping Using Aerial Photographs / GIS

It has become increasingly common practice to characterize stream networks as hierarchical systems. This practice has presented the value in collecting channel and floodplain attributes on a regional scale. Multiple studies have exploited geographical information systems (GIS) to assess hydrogeomorphic behavior at a basin scale. Important valley scale indices such as valley slope, confinement, entrenchment, riparian vegetation influences, and overbank deposits can provide information for river networks in California. Many agencies are developing protocols for geomorphic assessment using GIS and other database associated mapping methodologies. These tools may be useful as they are further developed in a monitoring program, but are not viable at a scale useful for reach-by-reach channel analysis.

The approach taken by this HMP to monitor its effectiveness is embedded in a derivative of the channel classification approach defined by Rosgen (1996). The author distinguishes three different levels of stream classification:

- Level I that generally describes stream relief, landform, and valley morphology;
- Level II that describes the morphology of stream and associates the later to a stream type based on channel form and bed composition. Field measurements of entrenchment, width-to-depth ratio, sinuosity, slope, and representative sampling of channel material may be suitable;
- Level III that assesses stream condition and departure.

A stream that is geomorphically stable per Rosgen's definition is characterized by two elements: a) the dimensions, pattern, and profile of a stream are maintained over time; and b) the transport capacity of a watershed's flows and detritus is maintained over time. As such, physical and biological functions of a geomorphologically stable stream remain in an optimum condition.

WAP Findings

Causes of Degradation

Three elements were identified to be responsible for the current level of degradation in the three sub-watersheds (San Antonio, Cucamonga and Live Oak) investigated during the preparation of the WAP. The three elements include the local erosive geology, the reduced sediment yield from developed land, and constructed basins that cut off upstream sediment supply.

All three sub-watersheds are dominated by Cenozoic Sedimentary Rocks – Alluvium and showing significant signs of degradation. This geology type is a significant factor in channel degradation. This is especially evident in the most downstream portions of the watersheds where the mean grain size of the sediment will be at its smallest, and thus more likely to degrade.

The development of the land, especially in the San Antonio and Cucamonga Watersheds, has increased the potential runoff while at the same time decreasing the sediment produced. This change caused an imbalance and increased the degradation in the downstream reaches of the watersheds.

The last major cause of degradation, the construction of water storage/debris basins, was not part of the original GIS-based analysis, but its effect on the watersheds was very evident. The downstream portions of the watersheds rely on the coarse sediment from the upper reaches to replenish the channel bottoms. Without the upstream sediment supply, the channels have a much higher potential for degradation. Even with the decrease in peak flow rates, an imbalance within the watersheds was created, resulting in downstream erosion. Additionally the attenuation of the storm flows has caused an increased amount of time that the channels could experience degradation.

The investigations were based on a GIS-based methodology for identifying potential causes of degradation. The methodology was developed by the Southern California Coastal Water Research Project (SCCWRP) and is called "Hydromodification Screening Tools: GIS-Based Catchment Analyses of Potential Changes in Runoff and Sediment Discharge" (SCCWRP, 2010). The methodology assesses parameters that were found to exert the greatest influence on the variability of sediment-production rates in a watershed: geology types, land cover, and hillslope gradient. Each watershed was evaluated individually and the detailed findings per watershed may be found in Appendix D of the WAP.

Potential Restoration and Rehabilitation Opportunities

Potential stream restoration or rehabilitation locations were identified during WAP development. The identification process included a desktop survey based on aerial imagery and a field visit inspection. Channel segments that the SBCFCD or other municipality owned, or had easements for, were the primary targets in this investigation, as implementing retrofit projects in privately owned channels would be less feasible than implementing projects in channels already under public ownership. As for easements, some may contain language restricting channel use solely to flood control purposes, which would preclude retrofit for water quality or other non-flood control related purposes. The factors that were taken into consideration when selecting the restoration sites are:

- The channel was hardened and engineered and/or vulnerable to hydromodification;
- There was sufficient room to widen the channel, either by widening the channel bottom or lowering the bank slopes;

- The overall restoration (including removal of the existing facility) would not have a significantly high cost (example: the removal of an existing regional concrete lined channel);
- The restoration would not adversely affect the primary flood control/drainage function of the facility.
- During the field visit, the channel bank protection and any sign of aggradation/degradation were reported. A basic cross-section was sketched and photographs taken.

Because of high costs and technical challenges associated with the removal of existing channel lining (e.g. m concrete or riprap), only unlined (earthen) channel segments were considered for restoration.

Rehabilitation projects would consider the following concepts:

Create planted/wetland areas: Channel segments were evaluated for the potential to increase habitat value and receiving water quality by creating a planted/wetland area. Since introducing a vegetated lining on an unlined channel may reduce flood conveyance capacity by loss of channel depth or increased channel roughness, the potential to create a wetland/planted area was limited to those channel segments where there appeared to be sufficient right-of-way to accommodate an increased channel width. In addition, creation of a wetland would typically preclude periodic maintenance of that portion of the flood control system, and further engineering investigations would be required to determine the long-term feasibility of constructing such a project.

Reduce channel erosion. Earthen channel segments were assessed for the potential to reduce erosion and thus discharges of sediment to receiving waters where observed erosion would potentially threaten nearby infrastructure (e.g., roads, buildings, etc.); and observed erosion would impact habitat resources.

Potential modifications and stabilization measures for areas include the use of an alternative lining, such as riprap or articulated concrete mat.

APPENDIX B – STREAM CLASSIFICATION PROCEDURE

The Stream Classification Procedure derives from the “Stream Stability Validation” approach that is described by Rosgen (1996). Stream stability over time may be assessed by monitoring the stream channel for five factors: (1) aggradation (2) degradation (3) shifting of particle sizes of stream bed materials (4) changing the rate of lateral extension through accelerated bank erosion (5) morphological changes following the CEM (Simon et al., 1992). If any hydrological changes or disturbance occurs in the watershed, the five elements defined above are critical to analyze the channel response to the implementation of HMP mitigation measures.

One reference stream station will be used for comparison purposes and should coincide with the station selected for the bioassessment. The reference station should be located in a stream that shows the same lithology, sediment regime, and morphometric parameters as the study stream stations. Annual comparisons of channel stability will be carried out at the same time of the year, at the end of the spring season, thus maximizing the chances to monitor similar weather patterns.

Channel stability will be evaluated, on an annual basis, at selected cross-sections in the San Juan hydrologic unit. Evaluation of the vertical or bed stability will serve as the reference method to understand the geomorphological changes of a channel stream over time. Vertical or bed stability will be evaluated at each of the identified cross-sections: this field method will identify a potential aggradation or degradation, if any, of the stream. Rate, magnitude, and direction of vertical change, if any, will be quantified.

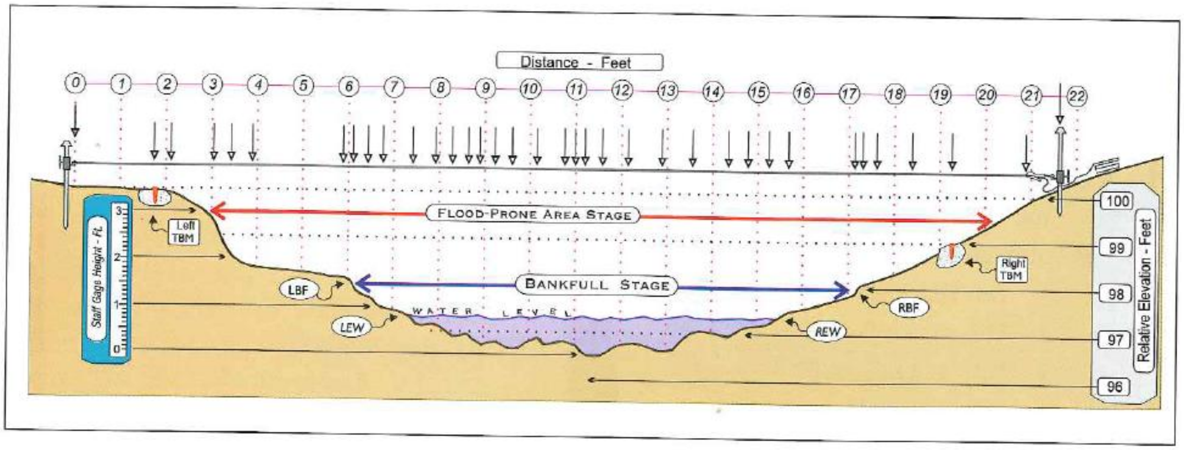
Vertical or bed stability:

Rosgen (1996) has documented a couple methods including one, known as the “Monumented cross-sections method”. At each selected site, the method consists of setting permanently monumented cross-sections that are located on a riffle and pool segment (or step/pool segment), i.e., two monumented cross-sections per site. Annual measurements at the two monumented cross-sections per site will be compared to the reference elevations taken during the initial survey.

Initially, one permanent bench mark should be installed on each bank of the stream: a left temporary bench mark and a right temporary bench mark. These should be made permanent by digging a hole in which a 10-inch stove bolt will be set up by a pad of concrete. The intent is to avoid vandalism damage. These two bench marks will be located at the cross-section on a stable site above and away from the bankfull channel. Additionally, an elevation cross-section is often needed if the left or right side of the cross-section is located on an unstable slope. An elevation bench mark is established and often does not represent a true representation, but rather a relative elevation set at 100 feet.

During each cross-section survey, a leveled tape line is set above the stream channel. Measurements originate from the intercept of the rod with the leveled tape line (Figure B-1).

Figure B-1: Typical permanent channel cross-section with benchmark locations and points of measurement – Rosgen (1996)



Simple measurements are made with the measuring tape and elevation rod method as described by Rosgen (1996):

- Locate the permanent bench mark on both sides of the stream (or, if on one side, a bearing for the transect is needed)
- Stretch the tape very tight with spring clamp and tape level
- Locate tape at same elevation as reference bolt on bench mark
- Read distance and elevation reading of rod intercept with tape
- Measure major features, such as:
- Left bench mark (LBM)
- Left terrace/floodplain (LT, LFP)
- Left bankfull (LBF)
- Left bank (LB)
- Left edge of water (LEW)
- Various bed features, bars, etc.
- Thalweg (TW)
- Inner berm features (IB)
- Right edge of water (REW)
- Right bank (RB)
- Right bankfull (RBF)
- Right terrace/floodplain (RT, RFP)
- Right benchmark (RBM)

Measurements must include the floodplain, terraces, and stream adjacent slopes. Other surveying procedures such as auto or laser levels and total station surveys may be adapted from the described “measuring tape and elevation rod” method. If technically feasible, any exceptional event associated with level higher than the bankfull level needs to be marked and indicated on the cross-section. The cross-section needs to be plotted for each measurement and compared to previous cross-sections to evaluate bed stability.

Finally, the longitudinal slope will be assessed based on measurements taken at two consecutive cross-sections. Rosgen (1996) also recommends developing a vicinity map and detailed site map indicating the locations of monumented cross-sections, as well as upstream and downstream photographs for site documentation. Channel dimensions for stream classification need to be correlated in order to document morphological comparisons for extrapolation.

Each stream segment being surveyed will be classified on an annual basis per the simplified Rosgen system of channel classification (Rosgen, 1996). Classification will be possible upon identification of the following parameters: floodprone width, bankfull width, bankfull depth, and longitudinal slope. Figure B-2 shows the different types of channels per Rosgen channel classification (Rosgen, 1996).

Figure B-2: Simplified Rosgen Channel Classification (Rosgen, 1996)

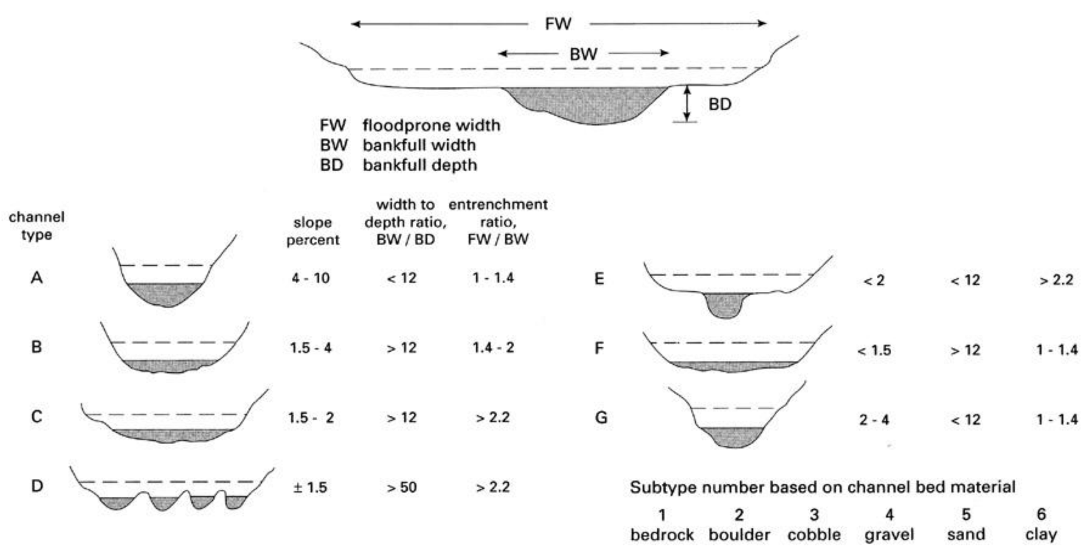


Figure 1.12 The Rosgen system of channel classification.

APPENDIX C– STREAM BIOASSESSMENT PROCEDURE

CALIFORNIA STREAM BIOASSESSMENT PROCEDURE

(Protocol Brief for Biological and Physical/Habitat Assessment in Wadeable Streams)

The California Stream Bioassessment Procedure (CSBP) is a standardized protocol for assessing biological and physical/habitat conditions of wadeable streams in California. The CSBP is a regional adaptation of the national Rapid Bioassessment Protocols outlined by the U.S. Environmental Protection Agency in "Rapid Bioassessment Protocols for use in Streams and Rivers" (EPA 841-D-97-002). The CSBP is a cost-effective tool which utilizes measures of the stream=s benthic macroinvertebrate (BMI) community and its physical/habitat characteristics to determine the stream=s biological and physical integrity. BMIs can have a diverse community structure with individual species residing within the stream for a period of months to several years. They are also sensitive, in varying degrees, to temperature, dissolved oxygen, sedimentation, scouring, nutrient enrichment and chemical and organic pollution. Biological and physical assessment measures integrate the effects of water quality over time, are sensitive to multiple aspects of water and habitat quality and can provide the public with a familiar expression of ecological health.

The purpose of this Protocol Brief is to introduce the techniques of bioassessment to aquatic resource professionals and, hopefully, to encourage them to incorporate measures of biological and physical/habitat into their water quality programs. The use of this procedure will ensure that the data they generate can be used by state regulatory agencies and will be compatible with a statewide bioassessment effort. The Protocol Brief is only a summary and does not contain all the information that may be required to implement a bioassessment program. Additional information and updates on bioassessment can be obtained by visiting the **California Aquatic Bioassessment Web Site at www.dfg.ca.gov/cabw/cabwhome.html**.

CALIFORNIA DEPARTMENT OF FISH AND GAME SCIENTIFIC COLLECTING PERMIT

Anyone who collects fish, amphibians, or invertebrates from the waters of the state must have in their possession a DFG Scientific Collecting Permit. The permit can be obtained from the DFG License and Revenue Branch in Sacramento (916 227-2225). Those people conducting bioassessment in California should specify on the permit application, that they will take freshwater invertebrates (authorization 5) and incidental fish (authorization 6) and amphibians (authorization 8). It is also advisable to contact the local Game Warden and District Fisheries Biologist at the closest Regional Office prior to collecting. Starting in summer 1999, everyone indicating that they will be conducting bioassessment in California will receive the most recent version of the CSBP Protocol Brief and an Access[7] database program to store, process and return a copy of the collected data.

FIELD PROCEDURES FOR COLLECTING BMI SAMPLES AND ASSESSING PHYSICAL/ HABITAT QUALITY

The CSBP can be used to detect aquatic impacts from point and non-point sources of pollution and for assessing ambient biological condition. The sampling unit is an individual riffle or riffles within a reach of stream depending on the type of sampling design used. Riffles are used for collecting biological samples because they are the richest habitat for BMIs in wadeable streams. **The BMI sampling procedures described in this Protocol Brief are intended for sampling wadeable, running water streams with available riffle habitats.** There are approved modifications of this procedure for narrow (< 1m) streams, wadeable streams with sand or mud bottoms and channelized streams. There are also procedures for lentic or still water environments. Contact DFG or visit the California Aquatic Bioassessment Web Site for more information.

Point Source Sampling Design

There will be discernable perturbations, impacting structures or discharges into the stream with point sources of pollution. The sampling units will be individual riffles within the affected section of stream and an upstream unaffected section. At least one riffle in the unaffected section should be sampled and one or more riffles in the affected section depending on the amount of detail that is required on downstream recovery. The riffles used for sampling BMIs should have relatively similar gradient, substrate and physical/habitat characteristics and quality. **One sample will be collected from 3 randomly chosen transects in each riffle**.

FIELD EQUIPMENT AND SUPPLIES

- Measuring tape
- D-shaped kick net (0.5mm mesh)
- Standard Size 35 sieve (0.5mm mesh)
- Wide-mouth 500 ml plastic jars
- White sorting pan and forceps
- 95% ethanol
- California Bioassessment Worksheet (CBW)
- Physical/ Habitat Quality form
- Chain of Custody form
- Random number table
- pH, temperature, DO and conductivity meter
- Stadia rod and hand level/ clinometer
- Densiometer/ Solar Pathfinder
- GPS unit or watershed topographic map

Use the following step-by-step procedures for collecting BMIs using the point source sampling design:

Step 1. Place the measuring tape along the bank of the entire riffle while being careful not to walk in the stream. Each meter or 3 foot mark represents a possible transect location. Select 3 transects from all possible meter marks along the measuring tape using a random number table. Walk to the lowest transect before proceeding to Step 2.

Step 2. Inspect the transect before collecting BMIs by imagining a line going from one bank to the other, perpendicular to the flow. Choose 3 locations along that line where you will place your net to collect BMIs. If the substrate is fairly similar and there is no structure along the transect, the 3 locations will be on the side margins and the center of the stream. If there is substrate and structure complexity along the transect, then as much as possible, select the 3 collections to reflect it.

Step 3. After mentally locating the 3 areas, collect BMIs by placing the D-shaped kick-net on the substrate and disturbing a 1x2 foot portion of substrate upstream of the kick-net to approximately 4-6 inches in depth. Pick-up and scrub large rocks by hand under water in front of the net. Maintain a consistent sampling effort (approximately 1-3 minutes) at each site. Combine the 3 collections within the kick-net to make one Acomposite@ sample.

Step 4. Place the contents of the kick-net in a standard size 35 sieve (0.5 mm mesh) or white enameled tray. Remove the larger twigs, leaves and rocks by hand after carefully inspecting for clinging organisms. If the pan is used, place the material through the sieve to remove the water before placing the material in the jar. Place the sampled material and label (see box) in a jar and completely fill with 95% ethanol. Never fill a jar more than 2/3 full with sampled material and gently agitate jars that contain primarily mud or sand.

Step 5. Proceeding upstream, repeat Steps 2 through 4 for the next two randomly chosen transects within the riffle.

Non-point Source Sampling Design

There will be no obvious perturbations or discharges into the stream with non-point sources of pollution. This sampling design is appropriate for assessing an entire stream or large section of stream. The sampling units will be riffles within a reach of stream. The stream reach must contain at least 5 riffles within the same stream order and relative gradient. **One sample will be collected from the upstream third of 3 randomly chosen riffles.**

Bioassessment Sample Label

Riffle/ Reach Number:____________
Transect Number: _______________
Stream Name: __________________
Date/ Time: ____________________
Sample by: _____________________

Use the following step-by-step procedures for collecting BMIs using the non-point source sampling design:

Step 1. Randomly choose 3 of the 5 riffles within the stream reach using the random number table.

Step 2. Starting with the downstream riffle, place the measuring tape along the bank of the entire riffle while being careful not to walk in the stream. Select 1 transect from all possible meter marks along the top third of the riffle using a random number table.

Step 3. (See Point Source Sampling Design Step 2)

Step 4. (See Point Source Sampling Design Step 3)

Step 5. (See Point Source Sampling Design Step 4)

Step 6. Proceeding upstream, Repeat Steps 2 through 5 for the next two riffles within the stream reach.

Sampling Design for Assessing Ambient Biological Conditions

Assessment of ambient biological condition utilizes both the point and non-point source sampling designs to cover an entire watershed or larger regional area. Ambient bioassessment programs are used to evaluate the biological and physical integrity of targeted inland surface waters. Stream reaches should be established in the upper, middle and lower portions of each watershed and above and below areas of particular interest. Quite often bioassessment is incorporated into an existing chemical or toxicological sampling design. In most cases, the water quality information is being collected at a particular point on the stream. Although there will be the tendency to use the point source design, try to convert to a non-point reach design for biological sampling.

Measuring Physical/Habitat Quality

The physical/habitat scoring criteria is an EPA nationally standardized method. It is used to measure the physical integrity of a stream and can be a stand-alone evaluation or used in conjunction with a bioassessment sampling event. DFG recommends that this procedure be conducted on every reach of stream sampled as part of a bioassessment program. Fill out the Physical/Habitat Quality Form for the entire reach where the BMI samples were collected as part of a non-point source sampling design. Some of the parameters do not apply to a single riffle, so this procedure is usually not performed as part of the point source sampling design. **This procedure is an effective measure of a stream=s physical/habitat quality, but requires field training prior to using it and implementation of quality assurance measures throughout the field season.** A detailed description of the scoring criteria is available through the California Aquatic Bioassessment Web Site.

Measuring Chemical and Physical/Habitat Characteristics

Measurements of the chemical and physical/habitat characteristics are used to describe the riffle environment and help the water resource specialist interpret the BMI data. The information can be used to classify stream reaches and to explain anomalies that might occur in the data. **They are not necessarily a good substitute for a quantitative fisheries habitat survey**.

Use the following step-by-step procedures to measure chemical and physical/habitat characteristics:
Step 1. Water temperature, specific conductance, pH and dissolved oxygen should be measured at the sampling site using approved standardized procedures and instruments.

Step 2. Record the riffle length determine for the procedure to choose the transect locations. Estimate the average riffle width by averaging several measurements along its length. Measure the riffle depth by placing the stadia rod at several places within the riffle and averaging the measurements.

Step 3. Estimate or measure the entire length of the reach where the three riffles are chosen as part of the non-point source sampling design.

Step 4. Measure the riffle velocity using a flow meter placed in front of the three locations along the transect(s) where the BMI samples were collected. Average the readings.

Step 5. Estimate the percent of the riffle surface that is covered by shade from streamside vegetation (canopy cover) using a densiometer at several places along the riffle and averaging the readings.

Step 6. Determine substrate complexity and embeddedness by applying Parameters 1 and 2, respectively from the Physical/Habitat Quality Form to the riffle where the BMI sample was collected. Use the entire riffle to assess these parameters and make note if the area along the transect(s) is considerably different from the rest of the riffle.

Step 7. Visually estimate the percent of riffle in each of the following substrate categories: fines (<0.1"), gravel (0.1-2"), cobble (2-10"), boulder (>10") and bedrock (solid). Use the entire riffle to assess this parameter and make note if the area along the transect(s) is considerable different from the rest of the riffle.

Step 8. Estimate substrate consolidation by kicking the substrate with the heel of your wader boots to note whether it is loosely, moderately or tightly cemented. The estimate should also take into consideration the hands-on experience obtained from collecting the BMI sample.

Step 9. Measure the gradient or slope of the riffle using a stadia rod and hand level or a clinometer.

Using the California Bioassessment Worksheet

A California Bioassessment Worksheet (CBW) should be filled out for each individual riffle when following the Point Source Sampling Design and for the entire reach when using the Non-point Sampling Design. Use the following step-by-step procedures for filling out the CBW:

Step 1. Enter the watershed and stream name, date and time of sample collection, name of the company or agency collecting the samples, sample identification number(s), and a short site description on the CBW.

Step 2. Enter the names of each crew member in the Crew Member Box.

Step 3. Determine the longitude and latitude coordinates and elevation from a GPS unit or watershed topographic map. Determine which California ecoregion or sub-ecoregion the site is located in by using the U.S. Forest Service map obtained by visiting the California Aquatic Bioassessment Web Site. Record this information and any other comments on the sampling site in the Site Location Box.

Step 4. Record the water temperature, specific conductance, pH and dissolved oxygen measurements in the Chemical Characteristics Box.

Step 5. Record the physical/habitat characteristics in the Riffle/Reach Characteristics Box. For the Point Source Sampling Design, record the riffle length, the 3 transect locations along the riffle and the physical/habitat characteristics information (starting with Ave. Riffle Width) on the lines below the Ariffle 1" column. For the Non-point Source Sampling Design, record the reach length, the total score from the Physical/Habitat Quality Form and all physical/habitat characteristics information on the lines below the Ariffle 1" through Ariffle 3" columns.

Step 6. Record the name and address of the Bioassessment Laboratory that received the samples along with the laboratory sample numbers if they are different than the field sample identification numbers.

Using the Chain of Custody (COC) Form

The Chain of Custody (COC) form is a necessary part of collecting BMI samples. It is an official document for tracking the samples from the field to the laboratory and then to their final storage area. The COC will also provide important information if samples are lost or misplaced. Use the following step-by-step procedures for using the COC:

Step 1. At the end of the field day, record the following information on the COC for each group of BMI samples: program name; watershed name; field ID numbers; sampling dates; and name, address, telephone number and signature of one of the crew members collecting the sample.

Step 2. Field samples and COCs must remain in a locked sample depository until a decision has been made to send them to a bioassessment laboratory for processing.

Step 3. When transporting to a bioassessment laboratory, each group of samples must be accompanied by a COC. Upon delivery, a Bioassessment Laboratory Number will be assigned to each sample. Record this number on the COC and each individual CBW along with the name and address of the bioassessment laboratory. When all samples listed on the COC are accounted for, then the individual delivering the samples will sign the "Released By" portion and the laboratory personnel will sign the "Received By" portion of the COC. The original COC will remain at the laboratory and a copy will be retained by the project supervisor.

PROFESSIONAL (LEVEL 3) LABORATORY PROCEDURES

The CSBP has three levels of BMI identification. Level 3 is the professional level equivalent and requires identification of BMIs to a standard level of taxonomy, usually to genus and/or species level. **All professional Bioassessment Laboratories should belong to the California Bioassessment Laboratories Network (CAMLnet).** This organization was conceived to provide technical assistance to laboratories and ensure that laboratory efforts are consistent throughout California. Contact DFG or visit the California Aquatic Bioassessment Web Site for information on CAMLnet.

LABORATORY EQUIPMENT

- Dissecting microscopes
- Standard Size 35 sieve (0.5 mm)
- Gridded picking tray
- Wide-mouth glass jars
- Glass petri dishes
- Vials
- Taxonomic Keys
- 70% EtOH/ 5% glycerol
- Fine dissection forceps
- Standardized taxonomic list
- Waterproof paper/ pencils
- Laboratory benchsheets
- Random number generator
- Chain of Custody form

Subsampling

Step 1. Retrieve the sample from the sample depository and cross-check the sample number with the bioassessment laboratory number on the COC.

Step 2. Empty the contents of the sample jar into the # 35 sieve (0.5 mm mesh) and thoroughly rinse with water.

Step 3. Once the sample is rinsed, clean and remove debris larger than **2** inch. Remove and discard green leaves, twigs and rocks. Do not remove filamentous algae and skeletonized leaves.

Step 4. After cleaning, place the material into a plastic tray marked with equally sized, numbered grids (approximately 2x2 inches). Do not allow any excess water into the tray. Spread the moist, cleaned debris on the bottom of the tray using as many grids necessary to obtain an approximate thickness of **2** inch. Make an effort to distribute the material as evenly as possible.

Step 5. Remove and count macroinvertebrates from randomly chosen grids until 300 BMIs are removed. Place the BMIs in a clean petri dish containing 70% ethanol/5% glycerin. Completely count the remaining organisms in the last grid but do not include them with the 300 used for identification. The final count should be recorded on the benchsheet for eventual abundance calculations.

Step 6. The debris from processed grids should be put in a clean Aremnant@ jar and the remaining contents of the tray should be placed back into the original sample jar. Both jars should be filled with fresh 70% ethanol, labeled (bioassessment laboratory number and either Aoriginal@ or Aremnant@) and returned to the sample depository.

Identification of BMIs

Step 7. Identify the 300 BMIs from each sample to the standardized level recommended by CAMLnet using appropriate taxonomic keys.

Step 8. Place identified BMIs in individual glass vials for each taxon. Each vial should contain a label with taxonomic name, bioassessment laboratory number, stream, county, collection date and collector's name. This voucher collection should be labeled and returned to the Sample Depository.

Step 9. Record taxonomic information on a Macroinvertebrate Laboratory Bench Sheet. The bench sheet should include the following information: watershed or project name; sampling date; sample ID number; bioassessment laboratory number; date of subsampling; name of subsampler; remnant jar number; taxonomy completion date; name of taxonomist; taxonomic list of organism and enumeration; total number of organisms; total number of taxa; list of unknowns, problem groups and comments.

Step 10. Maintain a reference collection of representative specimens of all accurately identified BMI taxa.

QUALITY ASSURANCE (QA) PROCEDURES FOR THE FIELD AND LABORATORY

QA for Collecting BMIs

The CSBP is designed to produce consistent, random samples of BMIs. It is important to prevent bias in riffle choice and transect placement. The following procedures will help field crews collect unbiased and consistent BMI samples:

1. In using the CSBP, most sampling reaches should contain riffles that are at least 10 meters long, one meter wide and have a homogenous gravel/cobble substrate with swift water velocity. **There are approved modifications of the CSBP when these conditions do not exist. Contact DFG or visit the California Aquatic Bioassessment Web Site for methods to sample narrow streams, wadeable streams with muddy bottoms and channelized streams.**

2. A DFG biologists or project supervisor should train field crews in the use of the BMI sampling procedures described in the CSBP. Field personnel should review the CSBPs before each field season.

3. During the training, crew members should practice collecting BMI samples as described in the CSBP. The 2 ft^2 area upstream of the sampling device should be delineated using the measuring tape or a metal grid and the collection effort should be timed. Practice repeatedly until each crew member has demonstrated sampling consistency. Throughout the sampling season, assure that effort and sampling area remain consistent by timing sampling effort and measuring sampled area for approximately 20% of the sampling events. The results should be discussed immediately and need not be reported.

QA for Measuring Physical/Habitat Quality

Physical/habitat parameters are assessed using a ranking system ranging from optimal to poor condition. This rapid ranking system relies on visual evaluation and is inherently subjective. The following procedures will help to standardize individual observations to reduce differences in scores:

1. A DFG biologist or a project supervisor should train field crews in the use of the EPA physical/habitat assessment procedures. Contact DFG or visit the California Aquatic Bioassessment Web Site for a detailed description of the procedures. Field personnel should review these procedures before each field season.

2. At the beginning of each field season, all crew members should conduct a physical/habitat assessment of two practice stream reaches. Assess the first stream reach as a team and discuss in detail each of the 10 physical/habitat parameters described in the EPA procedure. Assess the second stream reach individually and when members are finished, discuss the 10 parameters and resolve discrepancies.

3.Crews or individuals assessing physical/habitat quality should frequently mix personnel or alternate assessment responsibilities. At the end of each field day, crew members should discuss habitat assessment results and resolve discrepancies.

4.The Project Supervisor should randomly pre-select 10 - 20% of the stream reaches where each crew member will be asked to assess the physical/habitat parameters separately. The discrepancies in individual crew member scores should be discussed and resolved with the Project Supervisor.

QA for the Laboratory

Laboratory analysis of macroinvertebrate samples can be a significant cost for bioassessment programs. The CSBP specifies identification of BMIs to a standard level of taxonomy, usually to genus and/or species level. The CSBP also requires subsampling procedures using a fixed count of 300 organisms. Employing these procedures with confidence requires an effective quality assurance program. Complete quality assurance compliance will require a minimal 10% cost overhead. However, it will allow for testing whether subsampling, organism enumeration and taxonomic identification are consistent and accurate. Use the following procedures in the bioassessment laboratory to ensuring that quality data is produced:

The California Macroinvertebrate Laboratory Network (CAMLnet) - All individuals, private consulting firms and agency personnel using the CSBP laboratory procedures should contact the WPCL for information on CAMLnet. This group consists of personnel from bioassessment laboratories throughout California. The group provides a forum where laboratory procedures are discussed and the BMI taxonomic levels are determined. It also provides taxonomic workshops and assistance with interlaboratory taxonomic verification.

Standard Operation Procedures (SOP) - Each bioassessment laboratory should produce an SOP manual following the procedures outlined in the CSBP, but with detailed instructions specific to each laboratory. The SOP manual should be maintained for all laboratory operations and updated regularly. The assigned personnel and the duties of a Laboratory Supervisor and QA Taxonomist should be specified in the SOP manual. Customized benchsheets should be developed for each phase of subsampling and identification.

Sample Handling and Custody - When samples arrive, laboratory staff should inspect the samples for a sufficient volume of ethanol and labels for pertinent information including water-body name, sample date and time, location, transect number and sampler name. The steps discussed in the AUsing the Chain of Custody (COC)@ section in this protocol should be followed. The sample description information should be recorded in the Laboratory Sample Inventory Log and each sample given a unique identification number. A written and electronic record should be maintained to trace the samples from entry into the laboratory through final analysis. Samples should be stored in the a Sample Repository until processing and returned after processing.

Subsampling - Subsampling involves removing 300 organisms from each sample, or all organisms if the entire sample contains fewer than 300. The procedure to estimate abundance usually requires removing more than 300 organisms from each sample; however, only 300 are retained for identification. The Subsampling Technician systematically transfers organisms from the sample to a collection vial then transfers the processed sample debris (remnant) into a Remnant jar. At least 10% of the Remnant samples should be examined by the QA Taxonomist for organisms that may have been overlooked during subsampling. For subsamples containing 300 or more organisms, the Remnant sample should contain fewer than 10% of the total organisms subsampled. The Remnant for samples containing fewer than 300 organisms should contain fewer than 30 organisms.

Taxonomic Identification and Enumeration - The CSBP requires that all organisms are identified to a standardized taxonomic level using established taxonomic keys and references. The QA Taxonomist should check at least 10% of the samples for taxonomic accuracy and enumeration of individuals within each taxon. The same sample numbers that were selected randomly for the subsampling quality control should be used for this procedure. Misidentifications and/or taxonomic discrepancies as well as enumeration errors should be noted on the laboratory benchsheets. The Laboratory Supervisor determines if the errors warrant corrective action.

Organism Recovery - During the sorting and identification process organisms may be lost, miscounted or discarded. Taxonomists will record the number of organisms discarded and a justification for discarding on the laboratory benchsheets. Organisms may be discarded for several reasons including: 1) subsampler mistakes (e.g. inclusion of terrestrial or semi-aquatic organisms or exuviae), 2) small size (< 0.5 mm), 3) poor condition or 4) fragments of organisms. The number of organisms recovered at the end of sample processing will also be recorded and a percent recovery determined for all samples. Concern is warranted when organism recoveries fall below 90%. Samples with recoveries below 90% should be checked for counting errors and laboratory benchsheets should be checked to determine the number of discarded organisms. If the number of discarded organisms is high, then the technician that performed the subsampling should be informed and re-trained if necessary.

Corrective Action - Any quality control parameter that is considered out of range should be followed by a standard corrective action that includes two levels. Level I corrective action includes an investigation for the source of error or discrepancy derived from the quality control parameter. Level II corrective action includes checking all samples for the error derived from the quality control parameter but is initiated only after the results of the Level 1 process justify it. The decision to initiate Level II corrective action and reanalyze samples or conduct quality control on additional samples should be made by the Laboratory Supervisor.

Interlaboratory Taxonomic Validation - An external laboratory or taxonomic specialist should be consulted on a regular basis to verify taxonomic accuracy. External validation can be performed on selected taxa to help the laboratory taxonomists with problem groups of BMIs and to verify representative specimens of all taxa assembled in a reference collection.

Bioassessment Validation - The CSBP recommends at least 10% bioassessment validation where whole samples of 300 identified BMIs are randomly selected from all samples either for a particular project or for all samples processed within a set time period such as each 6 months or a year. The labels should be removed from the vials and replaced with a coded label that does not show the taxonomic name of the BMIs. The validation laboratory or specialist should be instructed to identify and enumerate all specimens in each vial and produce a taxonomic list. There will inevitably be some disagreements between the bioassessment and the external laboratory on taxonomic identification. These taxa should be re-examined by both parties and a resolution reached before a final QA report is written. **DFG is working on this QA technique to determine the acceptable level of misidentification and appropriate corrective actions.**

DATA DEVELOPMENT AND ANALYSIS

The CSBP analysis procedures are based on the EPA:s multi-metric approach to bioassessment data analysis. The EPA is developing procedures for multi-variate analysis of bioassessment data, but that method is not presented here. However, the sampling protocols presented in this document were designed to facilitate the use of multi-variate analysis and more information will be presented when standardizes techniques for California become available.

A taxonomic list of the BMIs identified for each sample should be generated for each project along with a table of sample values and means for the biological metrics listed on the last page of this document. Variability of the sample values should be expressed as the coefficient of variability (CV). Significance testing can be use for point source sampling programs and ranking procedures can be used to compare sites sampled using the non-point sampling design (contact DFG for information on ranking formulas). Ultimately, there will be a regional Index of Biological Integrity (IBI) to compare sample site mean values.

Starting in summer 1999, an Access[7] database program to store, process and return a copy of the collected data will be available. Contact DFG or visit the California Aquatic Bioassessment Web Site to learn more about the availability of regional IBIs and the database program.