EFFECTIVENESS ASSESSMENT OF THE SAN DIEGO HYDROMODIFICATION MANAGEMENT PLAN

Final Report

Prepared for
The San Diego Regional
Water Quality Control Board
(Region 9)

November 9. 2016

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1. Introduction

1.1 HMP Monitoring Project and Final Report

The purpose of this document is to summarize the key findings and conclusions resulting from the San Diego Hydromodification Management Plan (HMP) that has been implemented over the past 5 years. Detailed results of the monitoring program have been presented in a series of annual monitoring reports between 2011 and 2016. This Final HMP Report compiles and summarizes the results and findings of the five year field monitoring and desk-top analyses. This Final HMP Report includes the following monitoring and technical reports as exhibits that provide discussions that are more detailed and data from which the conclusions in this report are based. The exhibits include the following:

- Exhibit A: Revised Chapter 8 Monitoring Plan and Supporting Technical Report and Correspondences – provides the revised Chapter 8 Monitoring Plan and the Technical Report that presents the results of the adaptive management assessment of the monitoring program and recommendations for the revisions to the Monitoring Plan.
- Exhibit B: Effectiveness Assessment Monitoring for the HMP – Wet Weather Event Monitoring Report 2015-2016 – presents a summary of the 5 years of wet weather sampling at multiple sites and the detailed results from the 2015-2016 wet weather event monitoring.
- Exhibit C: BMP Site Selection Memorandum – presents technical memorandum documenting the site selection process for the monitoring of the BMP sites as part of the HMP effectiveness assessment monitoring.
- Exhibit D: Supporting Watershed Studies – presents the results of additional studies documented in the Remote Sensing of Monitoring sites to Document Historical Channel Evolution and Potential Future Trajectories Technical Memorandum and Calibration Report by San Diego State University.
- Exhibit E - 2016 Data Analysis Report – presents a more detailed discussion of both the field and desk-top analysis conducted for the effectiveness assessment of the HMP and with the Wet Weather Report (Exhibit B) provides the basis for this Final HMP Report.
- Exhibit F – Post El Niño Channel Surveys Technical Memorandum – provides a summary of additional analysis of stream channels performed by SDSU.

These supporting monitoring and technical reports and technical memorandums provide the basis for the findings and conclusions presented in this Final HMP Report.

1.1.1 HMP Monitoring Background

The San Diego HMP (Brown and Caldwell, 2010, with update in March 2011) was developed by the San Diego Municipal Stormwater Copermittees (Copermittees hereafter) in response to the hydromodification management requirements outlined in the San Diego Regional Water Quality Control Board (SDRWQCB) 2007 Municipal Separate Stormwater Sewer Systems (MS4) Permit (Board Order No. R9-2007-0001)(2007 MS4 Permit). The primary requirement of the HMP was to develop a program to minimize the effects of hydromodification and protect the beneficial uses of channels receiving stormwater, runoff from new and re-development in part by controlling

stormwater runoff within the flow range that cumulatively caused most channel erosion. Channel protection is achieved by designing stormwater Best Management Practices (BMPs) so that the post-project flow duration curve matches the pre-project curve within certain tolerances, between a low-flow threshold and high-flow threshold. The low-flow threshold is the flow that corresponds to the initiation of erosion for receiving channels. A key innovation of the San Diego HMP was the adoption of three potential low-flow thresholds, based on the susceptibility of the channel to erosion (high, medium, and low erosion potential). For example, channels consisting of cobbles would likely have a lower erosion potential and therefore a higher low-flow threshold, whereas a sand-based channel with a higher erosion potential would have a lower (more conservative) low-flow threshold. The HMP outlined an approach to assessing the susceptibility of different receiving channels to hydromodification, to determine the range of flows to control, and developed appropriate design standards for hydromodification mitigation facilities or flow-control BMPs.

In accordance with Part 1(k) of provision D.1.g of the 2007 MS4 Permit and as subsequently required in re-issued SDRWQCB Order R9-2013-0001 part D.1.a.(2) (2013 MS4 Permit), the HMP shall "include a description of pre- and post-project monitoring and other program evaluations to be conducted to assess the effectiveness of implementation of the HMP." For the purposes of developing an HMP monitoring approach, an effective HMP is defined as a program that results in no significant receiving stream channel degradation due to increased erosive force caused by new development. The Copermittees addressed this requirement with the development of a monitoring plan in Chapter 8 of the HMP (referred to Monitoring Plan hereafter) (in Exhbit A it is referred to as Chapter 8 Monitoring Plan for the HMP monitoring (Brown and Caldwell, 2010, with update in March 2011). Following the first phase of implementing the Monitoring Plan, a more detailed HMP Effectiveness Assessment Monitoring Plan (referred hereafter as Detailed Monitoring Plan) and Quality Assurance Project Plan (QAPP) were developed in 2012 to provide additional details on monitoring methods. The Monitoring Plan was modified in 2013 to document updates based on following the adaptive management approach (see Exhibit A). This revised Monitoring Plan was submitted to the SDRWQCB, and deemed adequate and compliant based on their January 2014 letter (see Exhibit A). Additional updates to the Detailed Monitoring Plan based on the SWRWQCB approved Monitoring Plan, were subsequently completed to reflect BMP site selection. This Detailed Monitoring Plan provides more detail on the monitoring methods consistent with the approved Monitoring Plan. As this Detailed Monitoring Plan is consistent with approved Monitoring Plan, the term "Monitoring Plan" used in this report reflects the content of the both Monitoring Plans. Exhibit A provides the complete content of the "Monitoring Plan" that includes the original and various updates to the Monitoring Plan, the technical reports that support these revisions, approval letter from the SWRBC and the Detailed Monitoring Plan. The results summarized in this report and presented in the exhibits was performed in accordance with the SDRWQCB approved Monitoring Plan.

1.1.2 HMP Effectiveness Assessment Program

The Monitoring Plan (Exhibit A) defines an effective HMP as a program that ensures compliance with HMP design criteria and results in no significant stream degradation due to increased erosive force caused by new development in accordance with the 2013 MS4 Permit (RWQCB Order R9-

2013-0001 part D.1.a.(2)). The HMP identified BMP guidelines for managing geomorphically significant flows based on three thresholds of erosion tied to the susceptibility rating of the receiving channel. In keeping with standard practice for HMPs across the West Coast, the lower flow thresholds bounding the range of most erosive flows were defined as multiples of the 2-year return flow (Q_2), while the upper flow threshold was defined as the 10-year flow (Q_{10}). The low-flow thresholds are:

- 0.1 Q_2 for streams with HIGH susceptibility to channel erosion
- 0.3 Q_2 for streams with MEDIUM susceptibility to channel erosion
- 0.5 Q_2 for streams with LOW susceptibility to channel erosion

As a result of 2007 MS4 Permit conditions (and subsequently required in the 2013 MS4 Permit), and the desire to generate data that could potentially be used to refine the HMP under future MS4 permits, the Copermittees implemented a 5-year monitoring project to assess the effectiveness of the HMP at preventing "increased erosion of channel beds and banks, sediment pollution generation, or other impacts to beneficial uses and stream habitat" as a result of land development (SDRWQCB Order R9-2013-0001).

Monitoring Plan activities, such as event-based bedload sampling, continuous water level and flow sampling, and repeat topographic channel surveys, were selected and tailored to answer the following management questions regarding HMP assessment, where feasible:

1. Do field observations confirm that the HMP appropriately defines the flow rate (expressed as a function of the 2-year runoff event) that initiates the movement of channel bed and bank materials?
2. Are mitigation facilities adequately meeting flow duration design criteria outlined in the HMP?
3. What is the effect of development on downstream cross section stability?

In addition, two other program evaluations and supporting studies were conducted to supplement the monitoring data and reduce uncertainty in key HMP assumptions. First, continuous simulation rainfall-runoff models were developed by San Diego State University (SDSU) to refine discharge estimates at un-gauged receiving channel monitoring sites. Second, aerial photography was used to assess the historic watershed conditions and land use, and to document apparent changes in stream channel stability and form over time. Both of these studies improved the overall understanding of watershed behavior in monitored sites and helped to better analyze and interpret the monitoring data.

1.2 Goals and Objectives of Effectiveness Assessment

The primary goals of the monitoring project were to evaluate whether the HMP standards outlined in the Provision D.1.g and J.2. of the 2007 MS4 Permit (SDRWQCB Order No. R9-2007-0001) are effective, and, if not, to provide recommendations for improving them. The program evaluation focused on answering the three questions listed above regarding HMP effectiveness through analysis of monitoring data.

1.3 Overview of Final Report Content

The final report is organized as follows:

- **Introduction** – This section provides a background and overview of the HMP Monitoring project.
- **Project Background and Monitoring Components** – This section provides an overview of the project time line from the HMP inception to the submittal of the final report. The section presents an overview of the monitoring components associated with the project, the monitoring site selection process, and the development of the Detailed Monitoring Plan (Exhibit B – Appendix A) and QAPP (Exhibit B – Appendix B).
- **Analysis of HMP Monitoring Data –** This section provides a summary to the analytical approaches that were required to assess the effectiveness of the HMP.
- **Supporting Watershed Studies –** This section of the report discusses the use of several methods used to support the HMP, such as hydrologic studies, remote sensing, and the use of supplemental survey data.
- **HMP Effectiveness Assessment –** This section looks at what defines an effective HMP and will discuss the effectiveness as related to the three key questions outlined in Section 1.1.2 and several supporting study results.
- **Findings and Conclusions –** This section discusses key findings and conclusions as a result of the 5 years of focused monitoring, program evaluations, and supporting studies.

2. Project Background and Monitoring Components

2.1 Checklist of Chapter 8 Requirements

Table 1 presents a list of key requirements and recommendations of the Monitoring Plan (Exhibit A) and provides a "checklist" to assess whether the current HMP project met these requirements and recommendations.

TABLE 1
KEY REQUIREMENTS AND RECOMMENDATIONS OF THE MONITORING PLAN

Key Requirements and Recommendations	Was the Requirement Addressed?
The HMP shall include a description of pre- and post-development and other program evaluations to be conducted to assess the effectiveness of the HMP.	✓
Develop and implement monitoring activities to answer three questions regarding the effectiveness of the HMP.[1]	✓
Monitoring sites should be located to maximize the variability in watershed and receiving channel characteristics, and where applicable, to isolate the potential effects of urban development.[2]	✓
If mitigated development projects are not completed in the study catchment within the study timeframe, then assessment of rainfall-runoff simulation accuracy for the urbanized study sites will need to suffice as a representation of conditions for a developed but unmitigated watershed.	✓
The Copermittees will look for other opportunities to monitor hydromodification mitigation measures that are not in the study catchment (referred to as "decoupled" monitoring).	✓
Compare current and historical photos, aerial photography, and site inspections for importing supporting evidence of channel instability.	✓
Conduct hydrologic studies to verify the use of Hydrological Simulation Program – Fortran (HSPF) models for small watersheds.	✓

1 Specific implementation requirements are outlined at the end of Chapter 8 (Brown and Caldwell, 2011)
2 Additional site selection criteria for receiving channels are discussed in the monitoring site selection technical memorandum (ESA, 2013).

More specific conclusions and recommendations are provided in Section 6, *Findings and Conclusions*.

2.2 Project Timeline

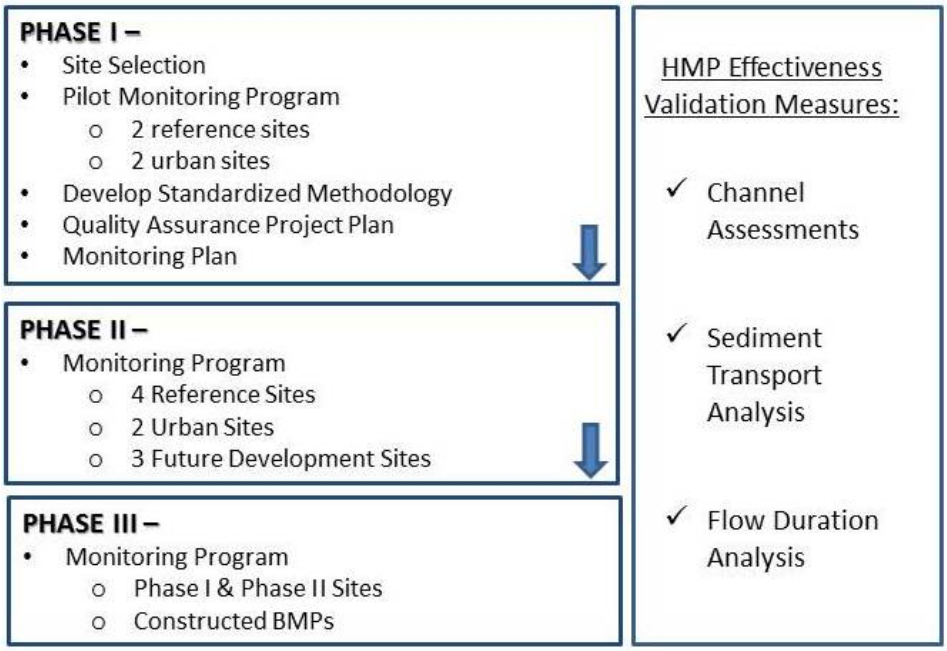
Provisions D.1.g and J.2.a of the 2007 MS4 Permit required the Copermittees to develop an HMP that manages increases in runoff discharge rates and durations from all Priority Development Projects (PDPs), where such increased rates and durations are likely to cause increased erosion of channel bed and banks, sediment pollutant generation, or other impacts to beneficial uses and stream habitat due to increased erosive force. Part (1)(k) of provision D.1.g of the 2007 MS4 Permit requires that the HMP shall "include a description of pre- and post-project monitoring and other program evaluations to be conducted to assess the effectiveness of implementation of the HMP (SDRWCB Order No. R9-2007-0001)." **Table 2** provides a timeline for the development and implementation of the HMP with the conclusion of the monitoring program presented in this

report. Key events in this timeline are the development of the Monitoring Plan and the revisions to this Monitoring Plan to address field conditions through the adaptive management approach.

TABLE 2.
SAN DIEGO COPERMITTEES HMP MONITORING PROJECT TIMELINE

Date	Milestone
Jan 2007	MS4 Permit adoption
Mar 2008	Interim HMP for >50ac
Dec 2009	Final HMP submittal
Jul 2010	RWQCB approves Final HMP
Sept 2010 - Dec 2011	Initial site research & developing QAPP
Jan 2012 – May 2013	Sub workgroup increased efforts toward site selection
Oct 2011 – Apr 2012	Wet Season 1 – Phase 1 monitoring (reference/urban)
July 2012 – Ongoing	Consultations and site visits with SWRCB and RWQCB Staff
Oct 2012 – Apr 2013	Wet Season 2 – Phase 2 monitoring (+development) Preparation of the Detailed Monitoring Plan and QAPP that provided more detail on the monitoring elements and approach of the revised Chapter 8 Monitoring Plan
Apr 2013	Formation of Technical Advisory Committee
Dec 2013	Revised Chapter 8 Monitoring Plan submittal based on changes outlined in the HMP Monitoring Plan Revisions Technical Report
Oct 2013 – Apr 2014	Wet Season 3 – Phase 2 Monitoring
Oct 2014 – Apr 2015	Wet Season 4 – Phase 2 Monitoring
Oct 2015 – Apr 2016	SDHM Modeling
Oct 2015 – Apr 2016	Wet Season 5 – Phase 3 Monitoring
Oct 2015 – Apr 2016	BMP Monitoring – Phase 3 Monitoring
Dec 2016	Effectiveness Assessment of the San Diego HMP – Final Report submittal

As part of the HMP, the San Diego Copermittees were required to develop an effectiveness assessment monitoring plan and a QAPP for the HMP monitoring. An initial Monitoring Plan was established in Chapter 8 of the approved HMP (2010) for the San Diego Region and updated in March 2011 (Brown and Caldwell, 2011) which outlined a 5-year monitoring plan to assess the effectiveness of the HMP implementation. The baseline requirements of the Monitoring Plan included a re-evaluation period for the 2013 calendar year with stipulations to review "findings from the Statewide HMP Monitoring Technical Advisory Group" and the anticipated "Framework for Developing Hydromodification Monitoring Programs" (Stein and Bledsoe, 2012). The Copermittees began implementing the Monitoring Plan in the Fiscal Year (FY) 2011-2012. A phased monitoring approach was used to gain knowledge in successive steps, apply successful monitoring techniques, and to allow for adaptation during the 5-year project (**Figure 1**). A formal Monitoring Subworkgroup (Subworkgroup) composed of the County and City of San Diego, was formed in January of 2012 to represent the Copermittees in the management and implementation of the Monitoring Plan.



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Source: Weston 2015

Figure 1
Phased Monitoring Approach

Phase I of the HMP began in FY 2011-2012. Phase I focused on the selection of long-term monitoring sites, geomorphic assessments, channel surveys, continuous sediment transport, and flow duration studies to provide direct measures of HMP effectiveness. An extensive literature review of sediment transport monitoring studies was conducted to develop a standardized methodology for sediment transport monitoring and data acquisition. In addition, sediment transport studies were performed to determine whether critical shear stress was the appropriate parameter for selecting the lower flow threshold of the geomorphically significant flow range. Field data was collected to determine the best monitoring methodology for conducting stream ratings and collecting bedload sediment material. After data analysis and review of this data, the field protocols were refined. These refinements were presented in a more detailed Monitoring Plan used by the consultant team to implement Phase II (July 2012–June 2014) and Phase III (July 2014–June 2016) of the project in accordance with the Monitoring Plan.

During the implementation of the Monitoring Plan in Phase I, it was evident that specific elements of the plan would need to be adjusted as a result of the difficulties in finding sufficient monitoring sites that met the plan's criteria. In early 2012, the Subworkgroup engaged in communication with the State Water Resources Control Board's (SWRCB's) lead for Hydromodification Programs, and in April 2013, the Copermittees formed a Technical Advisory Committee (TAC) to review data collected, re-evaluate the Monitoring Plan, and develop a list of potential modifications that would help ensure protection of receiving channels and compliance with regulatory requirements. Inputs received from the TAC and other supporting components of the re-evaluation process included a review of other California regional HMPs, the Southern California Coastal Water Research Project (SCCWRP) Framework for Developing

Hydromodification Monitoring Programs, findings from the hydromodification workshops hosted by SWRCB, and input from other technical experts. The results of this re-evaluation and subsequent revisions of the Monitoring Plan in 2013 are presented in Exhibit A. The revisions to the Monitoring Plan were deemed necessary based on data collected and findings made during the implementation of the Monitoring Plan. The HMP Monitoring Plan Revisions Technical Report (Weston & ESA, 2013) that provided the processes and specific changes generated by the TAC, Copermittees, and consultant team is provided as Attachment 1 to Exhibit A. Results of this re-evaluation were presented in the redlined version of the original Monitoring Plan that was submitted to the SDRWQCB for approval in December 2013. Exhibit A provides the Monitoring Plan revisions, supporting documents, and the letter received from the SDRWQCB that deemed the revised Monitoring Plan adequate and compliant. .

Revisions to the Monitoring Plan were incorporated and made part of the Detailed Monitoring Plan, and provides more detail on the sampling methods. Since the Detailed Monitoring Plan is consistent and based on the SDWQCB approved Monitoring Plan and revisions, the term Monitoring Plan in this report reflects the content of these plans. The Monitoring Plan is provided in Exhibit A. The most current version of the Monitoring Plan reflects changes in the Phase 3 monitoring of the BMP sites based on in-field conditions, which are further described in Section 2.3.3.

2.3 Overview of Monitoring Components

The monitoring activities were implemented over a 5-year period to collect the necessary data to assess the effectiveness of the HMP. Monitoring activities were selected to achieve statistical data collection requirements while balancing regional financial constraints and highly variable scientific, regulatory, and physical elements. The monitoring activities were carefully crafted to collect data that will be useful in answering the following questions regarding HMP assessment:

1. Do field observations confirm that the HMP appropriately defines the flow rate (expressed as a function of the 2-year runoff event) that initiates the movement of channel bed and bank materials?
2. Are mitigation facilities adequately meeting flow duration design criteria outlined in the HMP?
3. What is the effect of development on downstream cross section stability?

Results from each monitoring element can be interpreted together to assess the effectiveness of the HMP.

The sections below provide a summary of the monitoring activities that were implemented to answer the study questions and produce the following:

- Geomorphic assessments
- Cross section and thalweg surveys of monitoring locations (abbreviated geomorphic assessments)
- In-stream flow monitoring data

- In-stream suspended sediment concentration monitoring data
- Hydromodification mitigation facility (BMP) facility inflow and outflow monitoring data

Detailed field monitoring methodologies can be found in the Detailed Monitoring Plan (Exhibit A) and the QAPP (Exhibit B, Appendix B). The more detailed methods presented in this Detailed Monitoring Plan are consistent with the SDWQCB approved Monitoring Plan (Exhibit A). The combined content of these plans is referred to as Monitoring Plan in this report.

2.3.1 Low-Flow Thresholds

The evaluation of increased erosive force resulting from increased flows due to hydromodification has been limited to the geomorphically effective flow range, which is defined between the flow associated with the minimum or critical shear stress required to erode channel materials (low-flow threshold) and the 10-year flow event (Q_{10}). The HMP used the following assessment tools to determine the low-flow threshold of receiving channels downstream of BMP outfalls:

- Hydromodification Screening Tools (Bledsoe et al., 2010)
- Channel Vulnerability Calculator
- BMP Sizing Spreadsheet (County of San Diego, Version 1 2014, Version 2.0 2016)

The Hydromodification Screening Tools and the Channel Vulnerability Calculator are based on a variety of channel and valley measurements and observations including bed and bank materials, channel slope, channel cross section, and stream assessment characteristics. Both tools rate the overall susceptibility to channel erosion, and assign a low-flow threshold as a function of the 2-year flow event (Q_2):

- 0.1 Q_2 for streams with HIGH susceptibility to channel erosion
- 0.3 Q_2 for streams with MEDIUM susceptibility to channel erosion
- 0.5 Q_2 for streams with LOW susceptibility to channel erosion

The final susceptibility rating and low-flow threshold assigned to a receiving channel is determined from the more conservative of the two methods.

2.3.2 Receiving Water Channel Monitoring Sites

Permission to perform ongoing monitoring was secured for a total of nine receiving water channels, and the sites were instrumented for in-stream monitoring with continuous simulation sensors to collect water level, velocity, turbidity, flow and rainfall data. Each monitoring site consisted of a monumented cross section for repeat channel cross-sectional surveys and event-based monitoring, mounting brackets for continuous flow monitoring equipment, and a nearby rain gauge. In order to assess the potential effects of hydromodification on receiving channels and the performance of HMP mitigation facilities, monitoring sites were selected to represent three site categories:

- Development Sites – receiving channels located downstream of hydromodification BMP outfalls from future urban development projects located in the upper watershed

- Reference Sites – channel cross sections selected within relatively undeveloped watersheds in the upper watershed
- Urban Sites – receiving channels downstream of existing development in the middle watershed that were developed prior to the HMP

Figure 2 presents the monitoring sites that were selected to focus on more susceptible stream types, MEDIUM and HIGH, since these are the most common in the San Diego region. Care was given to select monitoring sites that encompass a broad geographic area and a range of watershed and receiving channel conditions.

2.3.3 BMP Monitoring Sites

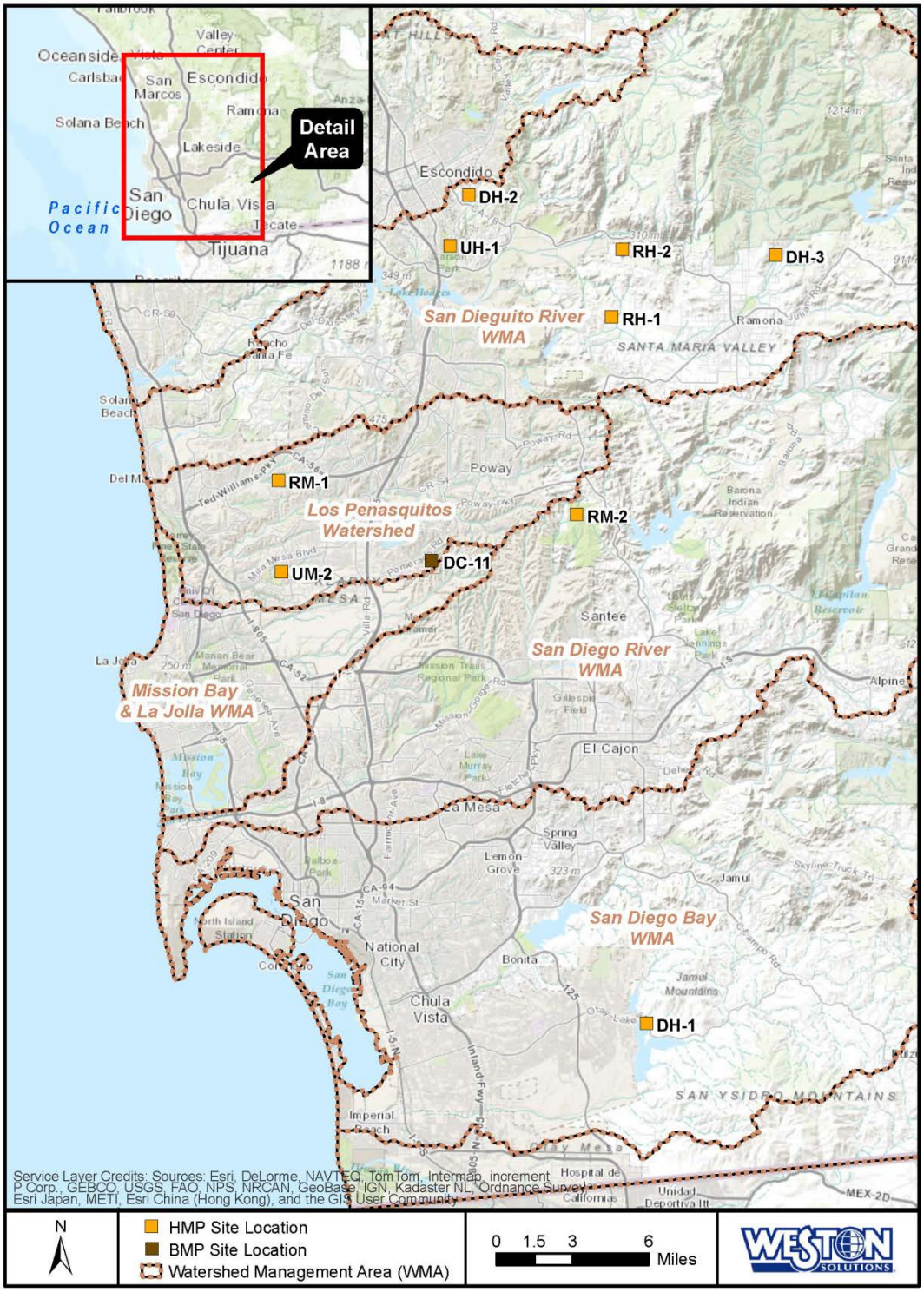
During initial development of the Monitoring Plan it was envisaged that BMP monitoring would be coupled to channel monitoring (BMPs would be monitored in a new development that drained to a channel that was also monitored for geomorphic response). However, the slow pace of urban development within the county during the first few years of the monitoring period due to the severe economic downturn, and the need to commence channel monitoring, made coupling sites impossible. Decoupling of BMP monitoring from receiving channel monitored was a key recommendation during the 2013 re-evaluation of the monitoring plan (Exhibit A, Attachment 1). One “decoupled” BMP location was subsequently instrumented for continuous monitoring. These changes are reflected in the Monitoring Plan. The term Monitoring Plan in this report reflects the content of the Detailed Monitoring Plan and approved Monitoring Plan and revisions in Exhibit A.

2.3.4 Question 1 – Validity of Low-Flow Thresholds

Monitoring of receiving water channels was used to provide data to evaluate use of low-flow thresholds for different channel types and associated susceptibility ratings (e.g., HIGH, MEDIUM, or LOW susceptibility to hydromodification). Since low-flow thresholds were developed using a large sensitivity analysis of hypothetical data, and the sediment transport modeling prepared as part of the HMP development relied on laboratory flume data, it is important to supplement the sediment transport data set with field observations.

A total of nine receiving water channels were secured for long-term monitoring, and instrumented for in-stream monitoring. Stream stage (depth), velocity, turbidity, suspended sediment, and bedload were sampled at each of the monitoring sites when appropriate flow events could be captured.

Because no long-term flow data had been collected at any of the receiving channel monitoring sites prior to this project and such small watersheds are rarely monitored in general, the 2-year and 10-year peak flow events were estimated using two sets of regional regression equations (USGS 1977 and the updated USGS 2012). Rating curves showing discharge and sediment load were developed to analyze the relationship between the two parameters, and to identify the minimum discharge as a function of the 2-year flow event required to mobilize bed sediments.



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Source: Weston 2015

Figure 2
Overview of Monitoring Sites

Because the relationship between discharge and sediment transport rate is subject to some "noise" the precise threshold discharge at which sediment transport commences is not always clear: for this analysis the consultant team used three different methods to estimate the point at which significant transport was occurring. These were visual identification of a marked inflection point in the sediment rating curve, de-trending of an inflection point, and use of a cumulative sediment transport analysis in which the threshold of sediment transport is taken as the discharge above which 95% of sediment transport occurs over a wide range of flows (work curve analysis). The process of determining the thresholds using these methods is described in Exhibit E - 2016 Data Analysis Report, and examples presented in **Figures 3** through **5**. Figure 3 presents an example of the method that uses the identification of the inflection points of the sediment rating curve to determine the threshold of sediment transport. Figure 4 and 5 presents examples of the de-trending of an inflection point and use of cumulative sediment transport analysis Further detailed presentation and discussion of these methods is presented in Exhibit E.

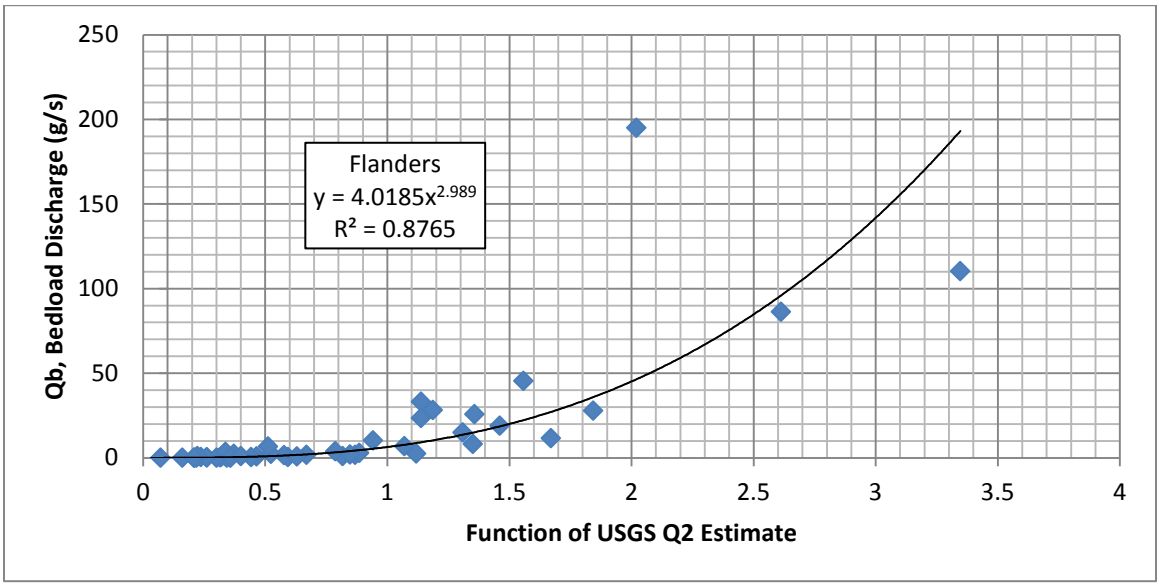

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Figure 3
Visual Identification of Inflection Point

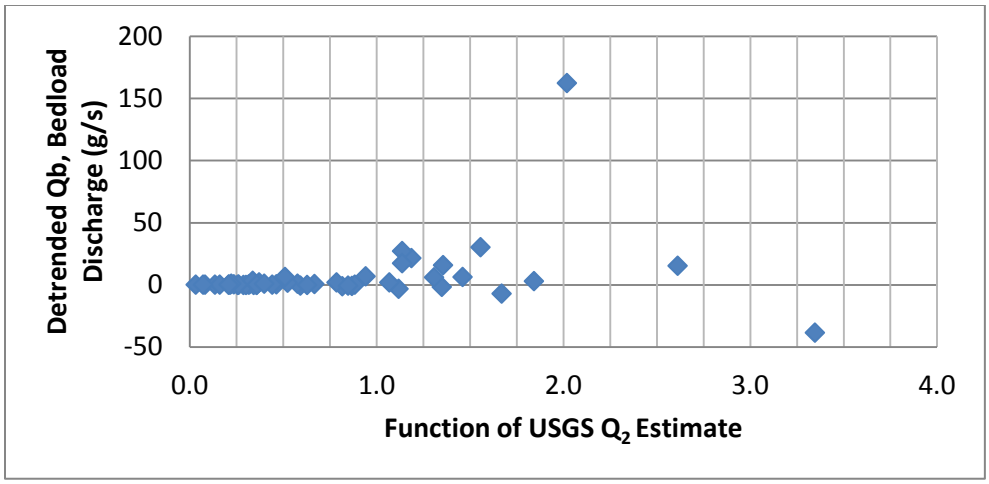

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Figure 4
De-Trended Sediment Rating Curve

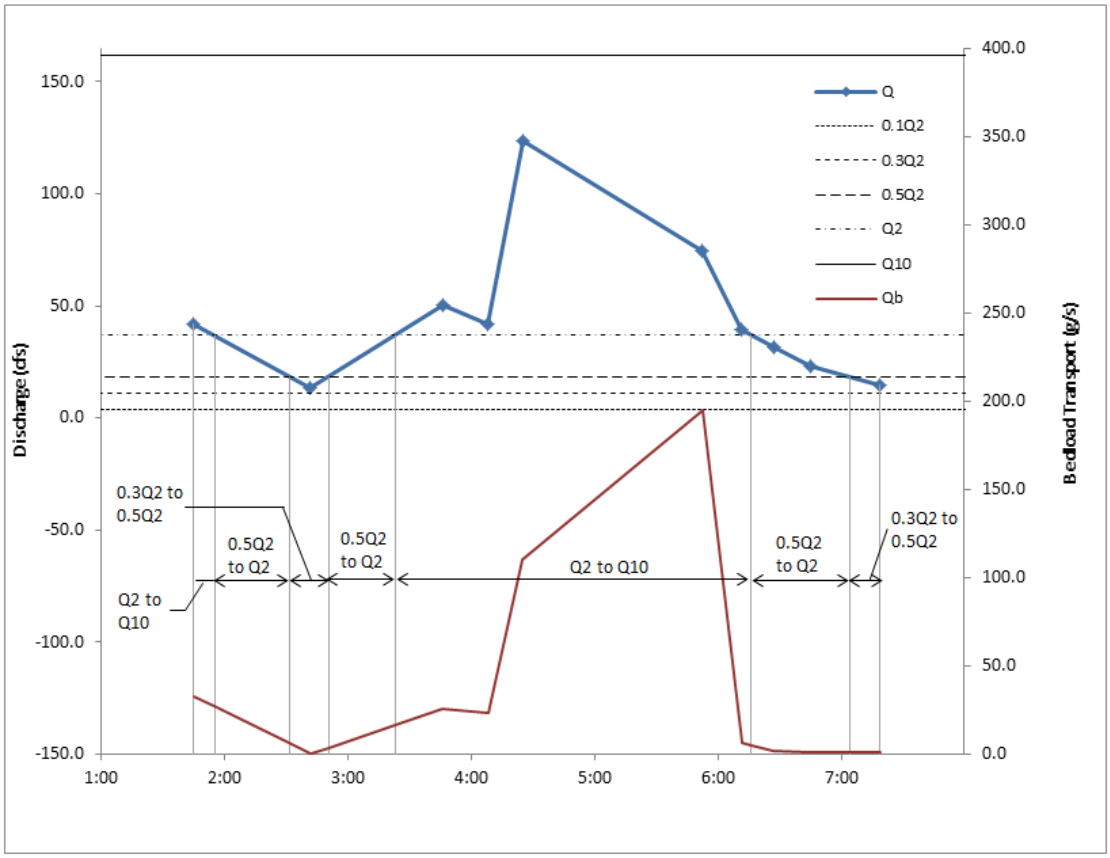

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Figure 5
Work Curve Method of Identifying Sediment Transport Threshold

2.3.4 Question 2 – Performance of Flow-Control BMPs

Once hydromodification mitigation facilities or flow-control BMPs are constructed and operational, observed inflow and outflow data can be analyzed to determine if the facilities are reducing the post-project peak flow frequency and duration to pre-project levels.

The flow-control BMPs coupled with the Development Sites used for in-stream monitoring were not constructed during the 5-year study; therefore, the flow-control BMPs for those developments were not monitored. BMP monitoring was decoupled, meaning that the BMP location did not need to be co-located with the in-stream monitoring site. This approach is presented in the Monitoring Plan approved by SDRWQCB. One decoupled BMP location was instrumented for continuous monitoring to allow for collection of performance-based flow frequency and duration data within the 5-year study.

Flow-control BMP monitoring was conducted to measure inflow and outflow of the BMP to compare the peak flows and flow duration before and after the storm flows entered the BMP. Monitoring activities included continuously monitoring precipitation, water surface elevation, inflows and outflows of the BMP, and event-based monitoring of velocity and depth at the BMP inflows and outflows.

2.3.5 Question 3 – Stability of Receiving Water Channels

Since the minimization of accelerated channel degradation as a result of urban development is the central purpose of the HMP, analysis of channel cross sections downstream of development projects is a component of the Monitoring Plan.

Annual cross section and longitudinal profile surveys were conducted to assess changes in channel dimension and the potential effect of development sites on channel cross-sectional stability, forming an abbreviated geomorphic assessment. The receiving channel of each monitoring site was monumented and initially surveyed by collecting cross section and longitudinal profile data. Repeat surveys with a basic level and survey rod were conducted during subsequent years after each wet weather season. The length of cross section surveys and longitudinal profiles were truncated to focus on the main area around the active channel in subsequent surveys using the rod and level method. Repeat full geomorphic assessments were subsequently conducted at all receiving channel monitoring sites that showed evidence of change, to validate the original assessment or any change in channel stability state.

Comparing the long-term physical response of Reference Site channels to receiving water channels downstream of Development Sites provided insight into the natural variability in channel form (e.g., width, depth, slope) over time, versus changes resulting from landuse changes such as development. While changes in Development Sites can be considered as “signal” changes in Reference Sites can be considered as “noise”. The channel surveys (abbreviated and full) were used to measure the receiving channel before development and to determine if the flow-control BMPs were effective at mitigating effects of the development on downstream receiving waters. A comparison of the Development Sites with Urban and Reference Sites provided further context in the range of variability.

2.4 Monitoring Site Selection Process

2.4.1 HMP Receiving Channel Site Selection

As part of the HMP effectiveness assessment project, the consultant team helped develop the San Diego HMP and Monitoring Plan and was subsequently tasked to conduct a receiving channel site selection process for the Copermittees. In order to assess the potential effects of hydromodification on receiving channels and the performance of hydromodification mitigation facilities, the monitoring sites selection process looked to include site candidates that were representative of three site categories:

- Development Sites – receiving channels located downstream of hydromodification BMP outfalls from future development projects located in the upper watershed
- Reference Sites – receiving channel sites located in relatively undeveloped watersheds in the upper watershed
- Urban Sites – receiving channels downstream of existing urban development in the middle watershed that were developed prior to the HMP

A monitoring subworkgroup (Subworkgroup) was formed to facilitate the selection of monitoring sites and oversee the implementation of the Monitoring Plan. The Subworkgroup was composed of staff from the County of San Diego Watershed Protection Group and from the City of San Diego Stormwater Division.

During the initial phase of the site selection process, the consultant team met with members of the Subworkgroup and a TAC assembled during the development of the HMP to provide an overview of the Monitoring Plan components and an initial list of monitoring site candidates. The HMP TAC augmented the the Subworkgroup and was composed of members of County of San Diego, City of San Diego, SCCWRP, Natural Resources Defense Council, United States Geological Survey (USGS), San Diego Coastkeeper, SDSU, and local consulting firms. The Copermittees and their consultant team identified relevant site criteria and developed a site selection process to identify, screen, and secure access to long-term monitoring locations.

The Subworkgroup and the consultant team worked together to develop a formal site selection process to more efficiently select and screen potential monitoring sites. After nearly 2 years of effort by the Subworkgroup, Copermittees, and consultant team, nine sites were selected from an initial list of 300 sites, and secured for monitoring – three Development (D) sites, four Reference (R) sites, and two Urban (U) sites (see Figure 2). A more detailed description of the site selection process can be found in the San Diego Regional HMP – Monitoring Site Selection Summary Memo, August 2011, Exhibit A- Appendix C.

2.4.2 BMP Site Selection

To effectively answer the question “Are mitigation facilities (or BMPs) of priority development projects adequately meeting flow duration design criteria as outlined in the HMP?” as outlined in the Monitoring Plan, the Subworkgroup screened a total of 15 BMP locations offered by the Copermittees for potential monitoring.

Screening of the BMPs included a focused review of Water Quality Technical Reports, Storm Drain Plans, and other associated documents and exhibits supplied by the Copermittees. Upon completion of the initial screening, site visits were conducted at five BMP locations that appeared appropriate for instrumentation. The purpose of the site visit was to confirm as-built site conditions and to select the most appropriate monitoring locations. All but one (DC-11) of the BMP locations were removed from the site selection process due to incomplete documentation, the use of pre-HMP design criteria, ongoing construction, or complications with land ownership and access agreements (Figure 3). In April 2015, one BMP site, DC-11, was instrumented for continuous and event-based validation monitoring. Continuous monitoring and event-based validation monitoring was completed during the 2015-2016 wet weather season, results and findings of the BMP monitoring effort are discussed in Section 6.2.2. The complete BMP Monitoring Site Selection and instrumentation Memo dated June 2015 can be found in Exhibit C.

The BMP that was monitored is located in a residential development. As shown in **Figure 6**, the project area consists of two drainage areas from which stormwater is captured and directed into bioswales. Drainage Management Area 1 (DMA1) consists of 1.3 acres of suburban development and drains to bioswale 1. Drainage Management Area 2 (DMA2) consists of 6.3 acres of suburban development and 3.1 areas of open space, and drains to bioswale 2. The bioswales direct the stormwater into a vegetated bioretention basin with outflow controls. The outlet structure is composed of a concrete box that provides for pollution removal and peak flow and peak flow duration control through a series of outlet controls. These controls include a subsurface underdrain that enters the base of the concrete outlet structure and extend from the outlet to the basin. Storm flows are filtered through the underdrain prior to entering the outlet box. As flows increase and the basin fills, a 1 inch diameter orifice 0.5 inches above the base of the basin controls the outflow. A second orifice located 4 feet from the ground surface of the basin and 1 foot in diameter, controls outflow when water levels in the basin rise to this elevation. When storm flows reach the top elevation of the outlet structure 5 feet from the basin bottom, flows enter the top of the open box structure. All flows into the outlet structure enter a 2 foot diameter outlet pipe that discharges downstream of the basin as shown on Figure 6.

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Figure 6
BMP Site DC-11 Site Layout

3. Analysis of HMP Monitoring Data

3.1 Compilation and Quality Control of Wet-Weather Monitoring Data

Wet-weather event monitoring for the HMP project included the collection of field data, field observations, and laboratory data from samples collected at up to nine sites in San Diego County over the course of the three phases of the project. During the 5-year study period, a total of 47 events were monitored.

Site-specific rain gauges and water level loggers were used to collect continuous precipitation and flow data for each of the nine sites. During a monitoring event, stream stage (depth) and velocity data across the stream-wetted width was paired with sediment bedload samples and water quality grab samples (analyzed for turbidity and suspended sediment concentration (SSC)). Up to 12 paired flow and bedload samples were collected at each site for each monitoring event. During Phase III, additional monitoring was conducted at one of the decoupled BMP site (DC-11). Stream stage (depth) and velocity measurements were taken at four locations around the BMP. All Phase II and Phase III monitoring activities were conducted following the protocols established in the Detailed Monitoring Plan and the QAPP (Exhibit B, Appendices A and B).

Laboratory and field data from each monitoring event underwent thorough quality assurance/quality control (QA/QC) review prior to producing final data tables and graphs. A data quality assessment was conducted on each of the laboratory reports to ensure that the data quality objectives listed in the QAPP was met. Any issues with the data quality objectives were resolved with the analytical laboratory prior to reporting the data. Field data QA/QC involved comparing the flow measurements recorded by field staff during monitoring to the flow measurements recorded by the level logger. The field stream data was converted to an instantaneous flow by using calculations to convert the water stage (depth) and velocity data in accordance with accepted United State Geological Survey (USGS) protocols. These calculations resulted in an assessment of all recorded data for consistency and reasonableness. A comparison of the field measured instantaneous flows and Manning's calculated flows using stage data also provided a valuable quality control review data point.

Each year of monitoring data was compiled into an annual report titled "Wet Weather Event Monitoring Report" that was submitted to the Subworkgroup. The most recent version of the Wet Weather Event Monitoring Report for 2015-2016 wet weather season is provided as Exhibit B. The annual report included the monitoring locations, sampling methods, and descriptions of wet-weather results for sampling events that occurred during each year of monitoring for the Phase I, II, and III projects. Channel cross section and stream-gradient survey data were used to develop site-specific rating curves. The flow rating reports (i.e., stream rating curve and head versus flow tables) as well as the cross section and stream-gradient profiles were provided in appendices to the annual report. In addition, graphs and tables were provided in the annual report for monitored events at each site showing results for the flow, instantaneous flow, rainfall, bedload samples, SSC samples, and turbidity samples (both field and lab results).

3.2 Receiving Channel Sediment Transport Analysis and Critical Flow Determination

A key innovation of the San Diego HMP was the designation of three potential low-flow thresholds, with the appropriate threshold determined by conducting a channel susceptibility assessment. This approach assumes that channels with a low susceptibility start to experience erosion at higher flows (proportional to Q_2) than channels that have a high susceptibility. This may be due to more resistant channel materials, less confined bankfull geometry, or flatter channel gradient. By raising the low-flow threshold but keeping it below the erosion threshold, the same degree of channel protection can be achieved with a smaller flow-control BMP.

To test and validate this approach the consultant team has monitored streamflow and sediment transport in the nine test sites during wet weather. Each site has undergone a channel susceptibility assessment and has an associated estimated low-flow threshold. During rainfall events that have the potential to cause enough flow that warrants monitoring, the team has visited the test sites and measured flow velocity, suspended sediment and bedload. Over the course of several events and seasons, these data have been used to develop suspended and bedload sediment rating curves. By overlaying the sediment rating curves with flow recurrence intervals, the team has been able to determine whether the HMP low-flow threshold matches the sediment rating curve. For example, if a stream has been classified as Medium Susceptibility, we would expect the rating curve to show negligible or no sediment transport occurring at flows below 0.3 Q_2. Because in sand-bed streams tiny amounts of sediment transport occur at almost all flows, the consultant team developed several ways of assessing these data:

- Visual assessment of rating curve inflection points: do the rating curves show no erosion until the appropriate low-flow threshold has been crossed based on qualitative visual interpretation of the rating curve?
- De-trended identification of rating curve inflection point: do the rating curves show no erosion until the appropriate low-flow threshold has been crossed based on a quantitative analysis of the rating curve?
- Work curve method: Does the designated low-flow threshold control at least 95% of the cumulative sediment transport?

Based on comparisons of the various methods to estimate the low flow threshold using calibrated and uncalibrated continuous rainfall-runoff models, event-based methods such as USGS empirical relationships and actual measured flow data, the Subworkgroup has adopted the USGS 2012 regression equations as the standard method of estimating the low flow threshold.

3.3 Assessing the Accuracy of Performance of Flow-Control BMPs Using Monitoring Data

As described in Section 2.3.5, the flow-control BMPs coupled with the Development Sites used for in-stream monitoring were not constructed during the 5-year study, and therefore, the flow-control BMPs for those developments were not monitored. BMP monitoring was decoupled and one BMP location was selected for continuous monitoring to allow for collection of performance-

based flow frequency and duration data within the 5-year study. Inflows and outflows to the BMP were monitored during the 2015-16 wet weather period and a total of twelve flow events were analyzed. The inflows and outflows were compared to assess the effectiveness of the BMP in controlling geomorphically significant flows and preventing hydromodification.

3.4 Assessing the Impact of Development on Downstream Channel Stability and Response

The purpose of this task is to assess whether channels downstream of developed areas (whether developed prior to the HMP or after the HMP) are actively eroding. Collecting data on developed (before and after HMP) and undeveloped watersheds potentially provides insight into several issues:

- Erosion at undeveloped sites would indicate “background” erosion due to climatic or legacy land-use reasons, and likely not due to urban development and hydromodification. This would be a measure of the “noise” against which to assess the hydromodification “signal.”
- Erosion at developed (pre-HMP) sites and less or no erosion at developed (post-HMP) and reference sites would indicate that the HMP was working at those developed sites.
- Erosion at the developed (pre- and post-HMP) sites but not at the reference sites would indicate that the HMP was not working at the target watershed.

To determine channel response, repeated channel cross section and long profile surveys were performed through the duration of the monitoring project. Results were overlaid and analyzed to identify reaches that were eroding or depositing. The results of this task are reported in Exhibit E.

4. Supporting Watershed Studies

4.1 Hydrologic Studies to Refine Peak Discharge Estimates

As with most small watersheds across the county, none of the nine receiving channel monitoring sites are gauged to collect real-time stream flow measurements or stage recordings to estimate stream flow, therefore the need to estimate streamflow was required. Methods used to refine the peak discharge estimates for determining low-flow thresholds at the receiving channel sites were the use of 2012 USGS regression equations as well the development of a calibrated SDHM to more accurately model small watersheds typical of the contributing watersheds of the nine receiving channels.

4.1.1 Validation and Calibration of SDHM 2011 and USGS Regressions

Exhibit D –Supporting Watershed Studies – Calibration Report provides more detailed discussion of the SDHM (2011 version) validation and calibration efforts that are summarized in this section. The Calibration Report in Exhibit D presents the comparison of key flow metrics using 1) observed flow data 2) the SDHM with default parameters, both without and with channel infiltration and 3) the SDHM calibrated for two small, undisturbed watersheds in San Diego County. One of the two watersheds has a small drainage area (0.6 mi2) and another a larger drainage area (22.4 mi2). The flow metrics include the flow duration curve (FDC) and flood peaks at different recurrence intervals (Q2, Q5, Q10), calculated from both the annual maximum series and the partial duration series. The Calibration Report summarizes how the default SDHM parameters differ from the calibrated model, and highlights key differences between the default and calibrated models. The Q2-Q10 values are also compared with regression equations that predict Q2-Q10 from drainage area and mean annual precipitation, including two different regressions from the USGS, one from 1977 (Waananen and Crippen, 1977), a second in 2012 (Gotvald et al., 2012) and a third set of regressions developed specifically for southern California (Hawley and Bledsoe, 2011).

The SDHM (2011 version, hereafter SD11) was validated and using the observed runoff in two gauged streams in San Diego County (Wilson Creek Tributary, 0.6 mi^2, and Guejito Creek, 22.4 mi^2). Using the observed data, SD11 was recalibrated to provide a better fit to daily flow and 15-minute peak flows. SD11 with default parameters produced estimates of peak dischargesfor the large watershed (Guejito), with errors of +58% (Q_2, annual maximum method), +28% (Q_5), and +20% (Q_{10}). Errors in this range are considered reasonable for an uncalibrated rainfall-runoff model. Errors were larger for the small watershed, where SD11 overpredicted peak discharge by 1200% (Q_2), 195% (Q_5) and 125% (Q_{10}). Errors in peak discharge from the partial duration series were similar to errors in the annual maximum at the large watershed (+58% Q_2, +28% Q_5, +21% Q_{10}). Insufficient data were available to calculate errors in the partial duration series for the small watershed.

USGS regression equations were used to establish the Q_2, Q_5, and $Q_{10,.,}$ and compare with SD11. For the annual maximum series, the USGS regressions were better predictors of all return intervals in the small watershed and for Q_5 and Q_{10} in the large watershed when compared with SD11. In general, USGS 2012 was the best model overall for estimating Q_5 and Q_{10}, and USGS 1977 was best for estimating Q_2. Q_2 was particularly difficult to predict compared with Q_5 and Q_{10}, and HMP metrics based on Q_5 or Q_{10} may be more certain and reliable than metrics based on Q_2. SD11 was also recalibrated to the observed runoff, with consistent parameters for both watersheds.

4.1.2 Peak-Flow Estimation for HMP Sites

Peak flows for both annual maximum and partial duration series were calculated for all nine HMP sites using the default and calibrated SD11 models. The annual maximum series was compared with the USGS regressions. Similar to the observations in the calibration phase, SD11 predicted higher peak flows compared with USGS equations: from 1.5 times to 4 times for Q_2, up to 6 times for Q_5, and up to 3 times for Q_{10}. Peaks estimated using calibrated SD11 model were most different from the uncalibrated SD11 model in the undisturbed reference watersheds, and very similar in the urbanized watersheds.

Overall, the hydrological modeling suggested that: (1) the SDHM 2011 currently used for HMP regulation overpredicts flows of different return periods, with larger overprediction for small watersheds and low return intervals (Q_2), and (2) USGS regression equations outperformed the uncalibrated SDHM 2011 model for the annual maximum series. These findings identify inherent variability in the model results, which have been assessed with regard to the sensitivity and accuracy of the results in the different model versions. The findings show the value of calibrating these models. The overall conclusion is that the HMP tools provide protection of receiving waters using the best available science.

4.2 Remote Sensing of Receiving Channels to Assess Natural Variability and Historical Channel Response

Small ephemeral headwater channels, similar to the nine HMP receiving channels, are subject to large inter-annual variations in precipitation and runoff and are sensitive to changes in land use within the contributing watershed. These channels respond to changes in runoff and sediment supply by adjusting their physical form. These adjustments may occur over varied timespans ranging from a few hours to several years depending on watershed conditions and the nature of driving events. While HMP monitoring elements—channel surveys and geomorphic assessments—documented channel form in the short-term, little was known about the historical form and long-term evolution of the receiving channel. In order to improve the understanding of long-term drivers and historical trajectories of channel response and to predict future responses the San Diego Copermittees identified “remote sensing” of HMP monitoring sites as a medium priority addition in the 2013 re-evaluation of the monitoring plan. The County of San Diego issued a task to ESA and SDSU to conduct remote sensing work for the nine HMP sites. The results of this task are reported in Exhibit D.

Historic aerial photography and topographic maps were used to document variations in channel form over time, and helped identify landscape-altering events, natural or anthropogenic, which may have contributed to contemporary channel form. Each map and image was closely examined to identify changes in land use, the occurrence of major watershed events, and changes in receiving channel. Some examples include:

- The conversion of agricultural land to suburban residences
- Changes in vegetation coverage and sediment delivery post-wildfire
- Channel relocation and channelization
- Channel widening and braiding
- Disturbance and recovery of riparian vegetation after flood events

Channel and valley measurements such as top width and sinuosity were recorded where relevant. To the extent possible, the channel evolution model for Southern California (Hawley et al., 2012) was used to reconstruct the historical evolution of the receiving channel based on observed watershed drivers (e.g., increased sediment supply from the basin due to wildfire) and changes in channel form (e.g., widening and braiding of channel then recovery to a single thread channel). Predictions of future channel changes were made based on the existing channel evolution stage, historic trajectory of channel changes, expected future watershed condition, and watershed management considerations.

In order to bring additional data and analysis in to addressing Question 3: “What is the effect of development on downstream cross section stability?” an assessment of the impact of runoff on receiving channel stability was conducted using historic observations at urban monitoring sites and concurrent monitoring studies conducted by members of the TAC (SDSU, SCCWRP). These studies have shown that unmitigated hydromodification leads to channel enlargement, and that high-susceptibility channels tend to incise, while medium-susceptibility channels tend to widen.

4.3 Use of Supplemental Survey Data to Assess Event-based Channel Response and Extent of Response

SDSU conducted pre-El Niño channel surveys at several of our HMP receiving channel monitoring sites and obtained several new cross sections and longitudinal profiles. (El Niño is the warm phase of the El Niño Southern Oscillation, during which warming of water in the Pacific is often accompanied by extreme high rainfall events in Southern California.) As part of future work outside the scope of this report, these data will be compared with post-El Niño season data to assess how different channel types respond to potentially high-magnitude and long-duration events, where the actual range of events is yet to be determined. Channel cross sections were measured at the HMP sites in fall 2015 using either differential GPS or total station surveys. A total of seven sites were selected with four to nine cross sections at each site. Longitudinal profiles were also generated up and downstream of each cross section. The same seven sites were resurveyed in spring 2016 following rainfall events.

Contrary to expectation, the El Niño did not generate large storm events in winter to spring 2016, so an assessment of channel response to large events was not possible. However, channel changes were observed in several HMP reaches following a relatively small storm. Channel response was heterogeneous, with only certain cross sections in a reach showing response. The data on the channel response is in Exhibit F.

5. HMP Effectiveness Assessment

5.1 Definition of an Effective HMP

As mentioned previously, the Monitoring Plan developed by Brown and Caldwell (2011), revised in 2013 and deemed compliant by the SDRWQCB defined an effective HMP as a program that ensures compliance with HMP design criteria and results in no significant stream degradation due to increased erosive force caused by new urban development. Based on the approved Monitoring Plan the Copermittees implemented a 5-year monitoring project to assess the effectiveness of the HMP at preventing increased erosion of channel beds and banks, sediment pollution generation, or other impacts to beneficial uses and stream habitat as a result of urban development. For ephemeral systems, this protection of the beneficial use of receiving channels is primarily a physical interpretation in which there should be no channel degradation occurring.

5.2 Effectiveness Assessment – Answering Three Key Questions

As stated previously, the 5-year monitoring project along with several supporting studies was implemented to answer three key questions to determine the effectiveness of the HMP.

1. Do field observations confirm that the HMP appropriately defines the flow rate (expressed as a function of the 2-year runoff event) that initiates the movement of channel bed and bank materials?
2. Are mitigation facilities adequately meeting flow duration design criteria outlined in the HMP?
3. What is the effect of development on downstream cross section stability?

Results from each monitoring element can be interpreted together to assess the effectiveness of the HMP. Results and conclusions are presented in Section 6.

6. Conclusions

6.1 Was the Checklist of Chapter 8 Requirements Fully Met?

Based on 5 years of focused monitoring, supporting studies, and other program evaluations, the available results indicate that the HMP elements are working as planned to protect stream physical integrity, using the best available science. In most cases, the HMP tools are conservative when comparing flow peaks and erosion thresholds with monitored results. The results of the 5 years of HMP effectiveness assessment monitoring are discussed in more detail in the 2015-2016 Wet Weather Monitoring Report (Exhibit B) and the 2016 Annual Data Analysis Report (Exhibit E).

6.2 Answers to Effectiveness Assessment Questions

Question 1: Do field observations confirm that the HMP appropriately defines the flow rate (expressed as a function of the 2-year runoff event) that initiates the movement of channel bed and bank materials?

For three geomorphically diverse sites (Flanders [urban, medium susceptibility], Saratoga [urban, high susceptibility], and Bear [development, high susceptibility]) sufficient measurements of flow and sediment (bedload and/or suspended load) have been made to develop sediment rating curves that encompass the three potential HMP low-flow thresholds (0.1, 0.3, and 0.5 Q_2). Analyzing the rating curves using three different methods (listed in **Table 3** and includes visual inflections, de-trended inflections and work curves) to identify the threshold of significant sediment transport shows a convergence of evidence that the low-flow threshold as estimated using the HMP channel susceptibility tools is appropriate (Saratoga and Bear) or conservative (Flanders) (see Table 3). This analysis supports the use of condition-specific low-flow thresholds based on the characteristics of the receiving water, and the HMP appropriately defines the flow rate that initiates the movement of channel bed and bank materials.

The use of Q_2 as a normalizing metric for describing stream flows in HMPs is widely adopted in California, Oregon and Washington. Based on the results of the analysis of the use of different method to establish the low flow thresholds as presented in the report by SDSU (see Exhibit D), the USGS regression equations (1997 and as updated in 2012) estimates for Q_2 (when used as the denominator for low-flow thresholds and using the USGS PRISM rainfall dataset), show good agreement with the observed sediment transport thresholds. This method also has the benefit of being easy to estimate and is not dependent on calibration. Additional information on the use of USGS regressions and the PRISM dataset is provided in Exhibit E.

TABLE 3
COMPARISON OF LOW THRESHOLDS FOR BEDLOAD TRANSPORT SUGGESTED BY DIFFERENT ANALYSIS METHODS.

Site Name/Analysis Method	Low-Flow Threshold (Proportion of Q_2)†			Stream Susceptibility Rating
	Visual Inflections	De-trended Inflections	Work curves	
Flanders	1.2	1.2	0.35	0.3 (Medium)
Saratoga	0.1	0.1	0.1	0.1 (High)
Bear	0.1	0.1	0.03	0.1 (High)

† Q_2 is estimated using the USGS 2012 equations

Question 2: Are hydromodification mitigation facilities adequately meeting flow duration design criteria outlined in the HMP?

As discussed in section 2.3.3, the monitoring program "decoupled" BMP monitoring from stream channel monitoring in response to the slow pace of development. Decoupling of BMP monitoring

from the receiving channel monitored was a key recommendation during the 2013 re-evaluation of the Monitoring Plan (ESA PWA and Weston, 2013). One decoupled BMP location was instrumented for continuous monitoring during the 2015-2016 wet weather season to allow for collection of performance-based flow frequency and duration data within the 5-year study.

The DC-11 BMP site description is presented in Section 2.3.5. The BMP consist of two bioswales that collect stormwater runoff from a residential development and direct storm flows to bioretention basin that has a series of outlet controls to reduce pollutants and peak flows and duration. The BMP site was instrumented for continuous monitoring to allow for collection of flow frequency and duration data within the 5-year study. During the 2015-2016 wet weather season, flow control BMP monitoring activities included continuous monitoring of precipitation, stage, inflows and outflow, and event-based monitoring of BMP components to validate the continuous monitoring. The event-based stream ratings were collected over the course of two storm events to develop precise rating curves for each of the BMP inflow monitoring locations. The monitoring equipment was used to quantify stormwater flows into the BMP from the two tributary drainage areas, water levels in the bioretention basin, and discharge from the BMP.

An example of the flow data collected during the 2015-2016 Wet Weather Season is summarized in **Table 4**. During the January 2016 storm event, intense rainfall (peak intensity of 1.22 inches per hour) caused the bioretention basin to rapidly fill and begin bypassing peak storm flows. Note that this event exceeds the upper flow duration control threshold (Q_{10}) for HMP BMPs. The differences in the total infiltration volume presented for the examples in Table 4, is due to variation in antecedent soil moisture conditions and irrigation in the landscaped areas of drainage areas and within the BMP to establish the specified vegetation in the bioswales and bioretention basin.

TABLE 4
BMP SITE DC-11 PERFORMANCE DURING THE 2015-2016 WET WEATHER SEASON

Characteristic	11/25/2015	1/4–8/16	3/6/2016	3/7/2016	3/11/2016
Total Rainfall (in)	0.1	5.24	0.29	0.6	0.17
Peak Rainfall (in-hour)	*0.10*	*1.22*	*0.17*	*0.20*	*0.10*
Swale 1 Inflow (In-1 A, cft)	309	28,179	705	2,071	956
Swale 2 Inflow (In-2 A, cft)	773	101,657	3,597	8,499	1,718
Basin Discharge (Out, cft)	1,172	128,754	2,777	5,961	1,588
Total Infiltrated Volume (cft)	**0**	**1,082**	**1,524**	**4,608**	**1,085**

Twelve discrete runoff events were monitored in the 2015-16 wet weather period, of which ten had inflows exceeding 0.13 cfs (the estimated 0.1Q2 for the watershed draining to the DC-11 BMP).

The measured inflows and outflows are shown on **Figure 7**. The BMP inflows and outflows show that for these events, significant peak flow attenuation occurred, as intended. The average peak inflow (all twelve events) was 2.0 cfs while the average peak outflow was 0.3 cfs. Plotting the continuous measurements as a flow duration curve (**Figure 8**) shows that the duration of flow at the Q2 threshold, 1.3 cfs (considered to be the dominant flow for Southern California receiving waters), was reduced from 0.17% to 0.07%,. The twelve events monitored show the BMP

working as designed to prevent hydromodification across a wide range of geomorphically-significant conditions.

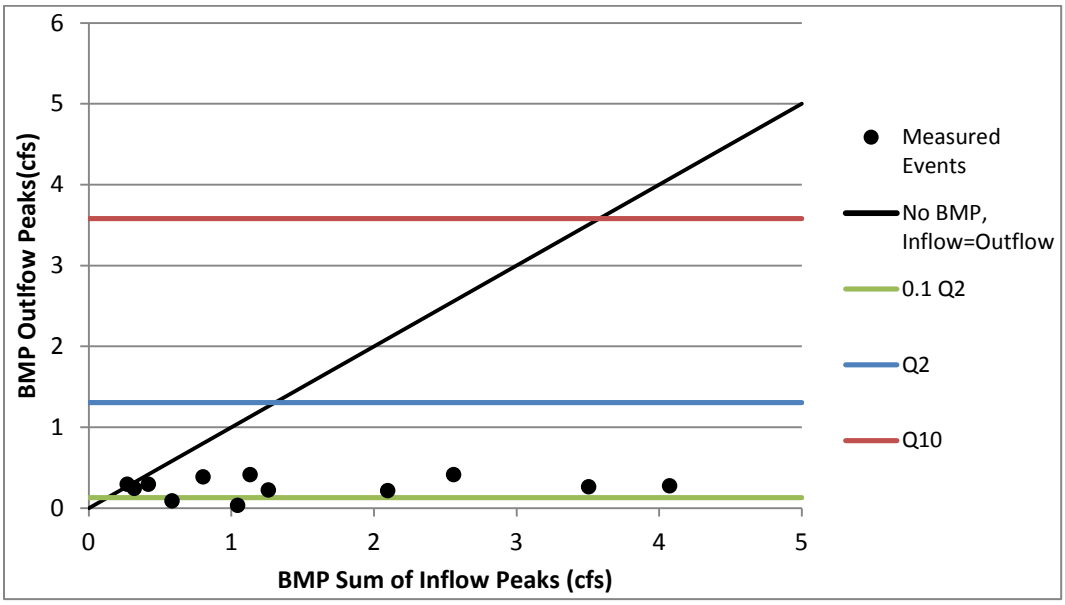

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Figure 7
Flow Peak Attenuation for DC-11 BMP – 2015-2016 Wet Season

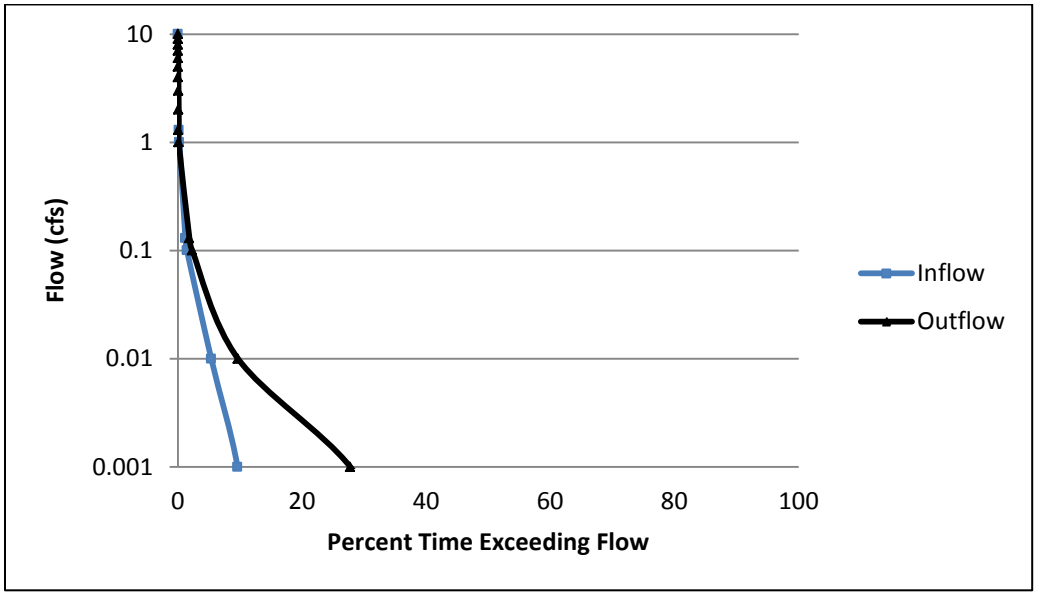

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Figure 8
Flow Duration Curve for DC-11 BMP – 2015-2016 Wet Season

The hydrograph for a representative week of monitored data shows attenuation of peak flows (**Figure 9**). The small event of November 23rd shows BMP outflow exceeding total BMP inflows. A compacted dirt lot between the BMP swales that will eventually be developed into a park bypasses flows directly into the retention basin during high flows and can contribute to the inflow, but is not monitored.

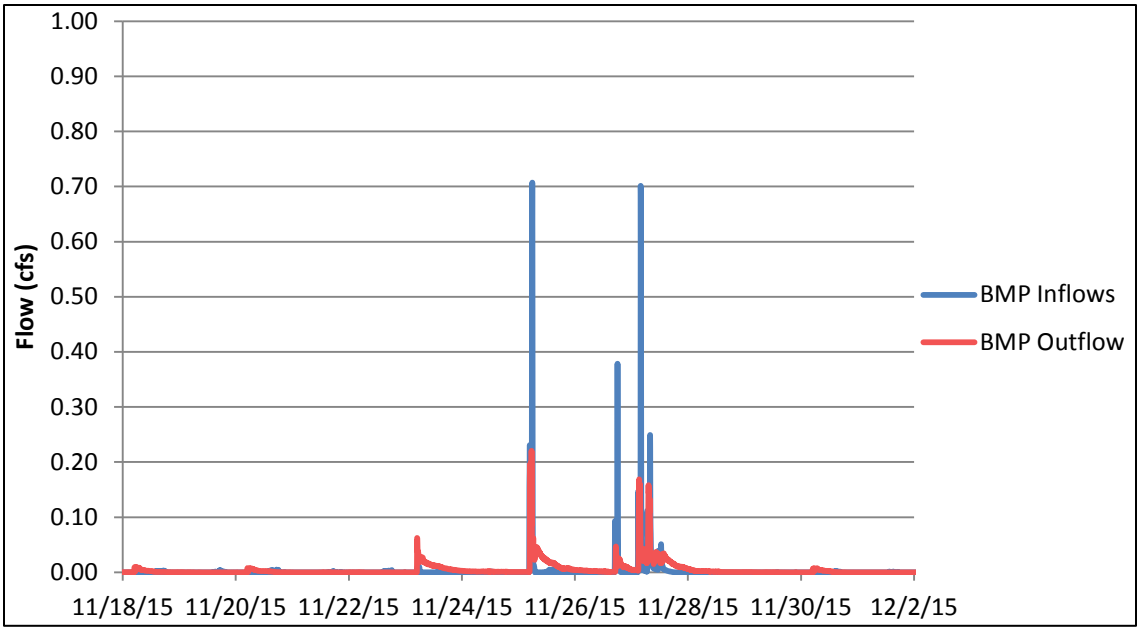

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Figure 9
Monitored Hydrographs for DC-11 BMP – November 2015

Question 3: What is the effect of development on receiving water channel cross section stability downstream of urban development?

To address this question, three channel monitoring sites were selected downstream of pending development under the 2013 MS4 Permit. These development projects were delayed and are in initial construction phases or in the planning stage. Relatively dry conditions were also observed during the monitoring program. No major changes in channel stability have occurred within the nine monitored channel sites during the monitoring period, though small changes have been noted.

The results of the monitoring program have shed valuable light on the amount of "noise" within channels in this environment (e.g., the rate of channel change in undeveloped watersheds due to fire and in developed watersheds due to legacy urbanization). Several channels have undergone cyclical patterns of erosion and deposition in the channel bed, often in the form of finer sediment passing over coarser armored substrate as a "wave" or pulse. Fire in undeveloped watersheds has caused several inches of fine sediment deposition in several channels. Receiving channel cross sectional monitoring has also shown the effects of legacy urban development that occurred prior

to the HMP, with existing areas of channel erosion in developed watersheds migrating upstream as headcuts. These transitory changes in channel geometry show the noise against which measurements of potential "signal" from hydromodification would need to stand out in order to be detected in the future. Channel cross sectional monitoring also provide lessons learned for future channel susceptibility classification efforts (e.g., the potential for the presence of transitory sand beds over armored gravel and cobble beds leading to higher-than-appropriate susceptibility classifications). Examples of channel cross sections for three sites are shown in **Figures 10** through **12** to show the variability encountered, and a summary of the findings for all nine sites based on repeating the detailed geomorphic assessment after five years is shown in **Table 5**.

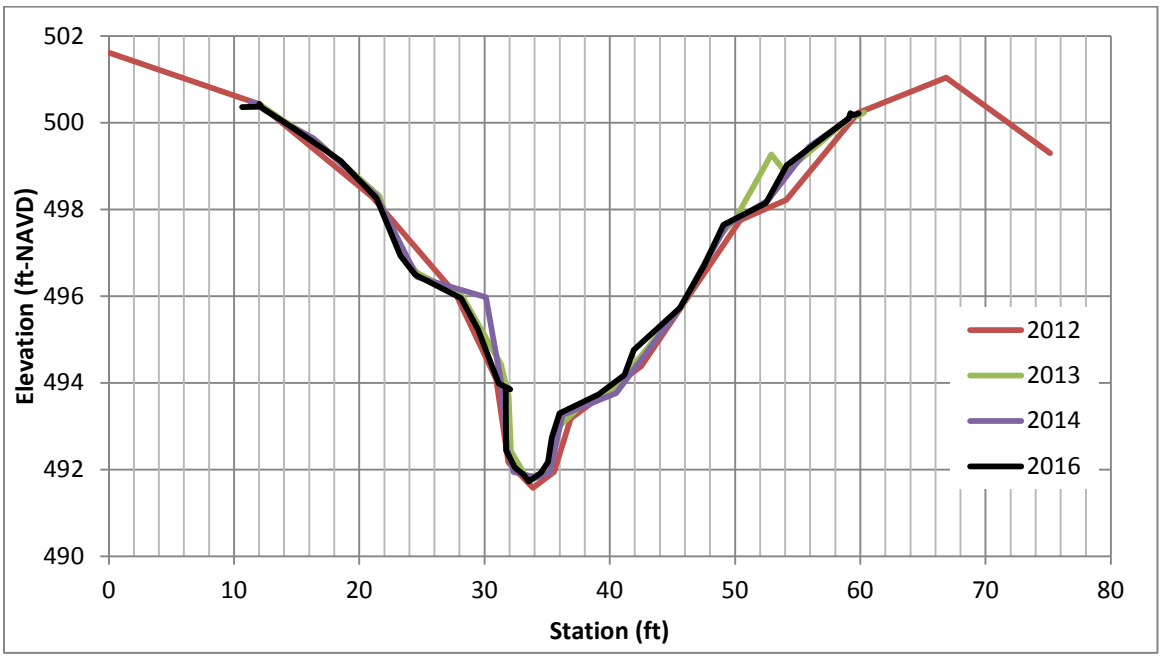

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Figure 10
Otay Village Cross Section – An Example of a Reference Site Where No Change Occurred During the Monitoring Period

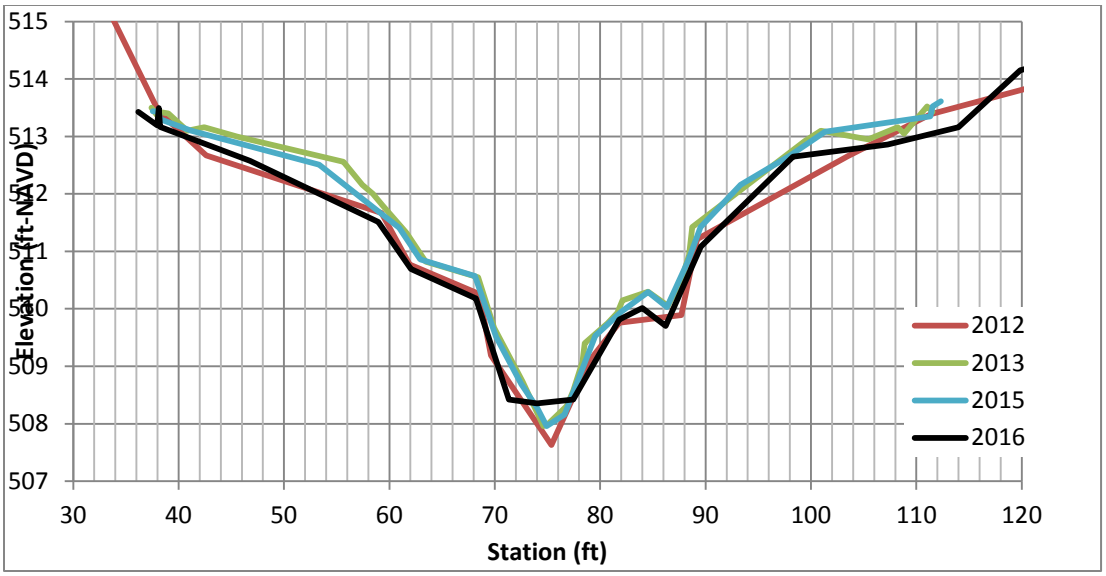

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Figure 11
Schoolhouse Canyon Cross Section – An Example of a Reference Site Where Significant Fine Sediment Aggradation Occurred Following Fire in the Watershed

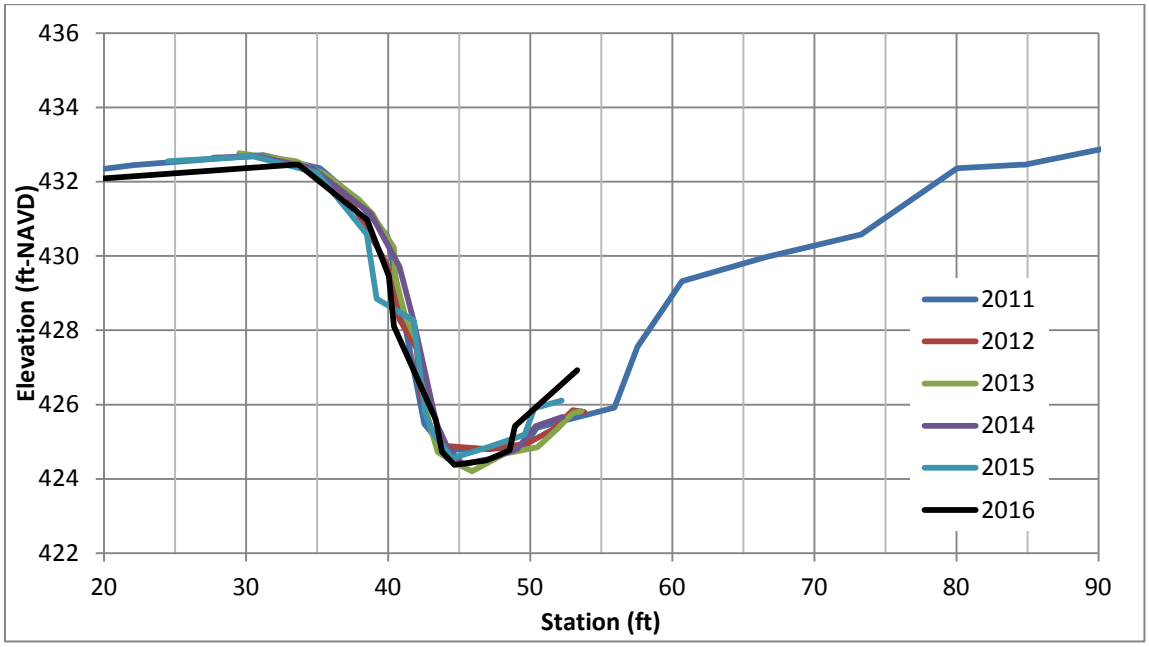

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Figure 12
Saratoga Cross Section – An Example of Legacy Incision at a Site Developed Prior to Current Stormwater Controls (Dense Brush on Right Bank Outside Active Channel was not Resurveyed)

TABLE 5
SUMMARY OF REVISED GEOMORPHIC ASSESSMENTS FOR MONITORING SITES

Site Name	HMP Monitoring Type	Evidence of Erosion/ Deposition?	Repeat Assessment?	Susceptibility Class Changed?	Notes and interpretation. Is change (if observed) indicative of instability in channel or watershed?
Ramona	Reference	2–4" of deposition in long profile. No change in cross section.	Yes	No	Fine sediment from watershed has formed a thin layer on the channel bed over original bed (also sand). Appears to be cyclical deposition, potentially sheet wash from the surrounding former floodplain terrace, likely to be washed out in subsequent years. Site appears stable.
Deer Valley	Reference	Small patches of up to 6" of fine sediment depositing in channel	Yes	Yes (Medium to High)	Fine sediment from watershed has formed a thin layer on the channel bed (originally gravel). Appears to be cyclical deposition, fines likely to be washed out in subsequent years. Fine sediment has caused changed classification. Site appears stable.
Schoolhouse	Reference	9–18" of fine sediment deposition in channel	Yes	No	Significant fine sediment from watershed (potential fire effects). Deposition is pronounced enough to potentially cause channel infilling/avulsion and lateral migration within the valley floor. Potentially unstable site in medium term.
Sycamore	Reference	4–6" of fine sediment deposition in much of reach	Yes	Yes (Medium to High)	Fine sediment from watershed has formed a thin layer on the channel bed (formerly gravel). Appears to be cyclical deposition, likely to be washed out in subsequent years. Fine sediment has caused changed classification. Site appears stable.
Bear Valley	Development	Up to 9" of erosion over a short reach	Yes	No	Local scour set against overall influx of fine sediment (potentially from development upstream). Possible migration of outside bend and infilling/avulsion of downstream channel.
Otay Village	Development	No	No	-	-
MDS Development	Development	6-12" of upstream erosion, 6–12" of deposition downstream	Yes	No	Upstream sections of channel have eroded due to watershed runoff, depositing sediment in culvert backwater. Incision and channel widening occurring between two grade controls. Site appears moderately unstable in medium term.
Flanders	Urban	~12" of upstream erosion and downstream deposition	Yes	No	Gravel pulse passing through site. Cyclical deposition of intermediate size bed–lining material, likely to be washed out in subsequent years. Site appears stable.
Saratoga	Urban	Upstream headcut migration and downstream deposition	Yes	No	Headcut migrating through reach causing upstream incision and downstream deposition. Headcut likely to proceed until arrested by grade control. Site appears unstable.

The overall conclusion based on the five years of effectiveness assessment monitoring and additional desk-top analysis, indicate that the HMP elements are working as planned to protect stream physical integrity. Based on five years of extensive wet weather monitoring of three geomorphically diverse sites (Flanders, Saratoga, and Bear) sufficient measurements of flow and

sediment (bedload and/or suspended load) have been made to develop sediment rating curves that encompass the three potential HMP low-flow thresholds (0.1, 0.3, and 0.5 Q_2). Analyzing the rating curves using three different methods to identify the threshold of significant sediment transport shows a convergence of evidence that the low-flow threshold as estimated using the HMP channel susceptibility tools is appropriate (Saratoga and Bear) or conservative (Flanders) (see Table 3). This analysis supports the use of condition-specific low-flow thresholds based on the characteristics of the receiving water, and the HMP appropriately defines the flow rate that initiates the movement of channel bed and bank materials.

Furthermore, the HMP provides for the protection of the beneficial uses of receiving waters in the San Diego region from effects of hydromodification from new and redevelopment priority projects, based on monitoring of stream cross sections over the past five years. The results of this monitoring indicate no major changes in channel stability have occurred within the nine monitored channel sites located throughout the County. Based on these findings of five years of data collection and analysis, the effectiveness assessment monitoring for the HMP is completed and no additional monitoring to address the key questions is recommended .

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7. References

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8. Exhibits

Exhibits for this document are included on the following pages.