TORY R. WALKER ENGINEERING
RELIABLE SOLUTIONS IN WATER RESOURCES

July 30, 2015

VIA EMAIL to: SanDiego@waterboards.ca.gov

San Diego Regional Water Quality Control Board
2375 Northside Drive, Suite 100
San Diego, California 92110
Attn: Mrs. Christina Arias

Subject: Hydromodification Management BMP Exemptions

Dear Mrs. Arias,

I would like to thank you for the opportunity to comment on the Region's Water Quality Improvement Plans. This letter is being submitted alongside a detailed statistical hydrology report conducted by Tory R. Walker Engineering (TRWE). The study employs a detailed statistical hydrologic modeling approach and has gained the approval of TRWE's hydrologic modeling experts and two respected university professors. We believe the study adequately analyzes the effects of the hydromodification management BMP exemptions for Priority Development Projects that directly discharge to the five exempt river reaches identified by the 2011 Final Hydromodification Management Plan. We understand the Regional Watershed Management Area Analysis proposes certain exemption criteria based upon a geomorphic analysis for each river system. However, we seek to provide a complimentary alternative approach that focuses strictly on the hydrologic behavior of the watersheds under a variety of scenarios.

The study has two major conclusions. First, the study concludes that the existing river impoundments have a more significant effect on overall watershed hydrology than any proposed land development downstream of the impoundments. Secondly, the study's hydrologic continuous simulation modeling further concludes that reinstatement of the HMP exemptions for directly-discharging PDPs has a very minor and insignificant influence on the 2-year through 10-year peak flows within these river reaches. These findings agree with the initial hydromodification management BMP exemption criteria proposed by the 2011 HMP Technical Advisory Committee. Therefore, we believe it is appropriate to reinstate the 2011 HMP exemptions based upon this confirmation.

It is with great hope for the prosperity of our waterways and our Region that we present these findings. Thank you for your time and consideration in our shared endeavor.

Best regards,

Tory R. Walker, P.E.
President

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Hydrologic Review and Analysis of San Diego County Hydromodification Exemption for Five River Reaches

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Date:
July 22, 2015

Executive Summary

The purpose of this study is to use a strict hydrologic assessment to either justify or invalidate the renewal of the current hydromodification exemption for projects draining directly to five river reaches (Otay River, San Diego River, San Dieguito River, San Luis Rey River, and Sweetwater River). These reaches have been exempted by the San Diego County Hydromodification Management Plan (HMP) (San Diego County, 2011), based on the wide-spread perception that existing large upstream reservoirs reduce river discharge and erosion potential to a larger extent than potential increases attributed to downstream land developments. In 2013, the San Diego Regional Water Quality Control Board (SDRWQCB) issued a new Permit that now requires justification of exemptions with further hydrologic analysis.

Accordingly, this study evaluates the hydrology of these five watersheds to determine if the continuance of the exemptions may be justified. A rigorous two-step approach is used to describe the effects of either renewing or revoking the 2011 HMP Exemptions through: (1) Statistical Peak Flow Analysis and (2) US Environmental Protection Agency (EPA) Storm Water Management Model (SWMM) Peak Flow Analysis. The Statistical Peak Flow Analysis uses a combination of observed streamflow measurements and USGS Linear Regression Equations to estimate the 2-year, 5-year, and 10-year peak flows at the mouth of each exempt river reach and describe the influence of the upstream impoundments for “dam-in-place” and theoretical “no dam” conditions. The Statistical Peak Flow Analysis characterizes flow reductions as a result of upstream impoundments and serves as a preface for more detailed peak flow simulations. EPA SWMM is used to determine the relative numerical influence of storm water runoff from project development on peak flows and durations, using continuous rainfall-runoff simulation to estimate the 2-year, 5-year, and 10-year peak flows at the mouth of each exempt river reach. Hydromodification flow controls are simulated for all non-directly discharging developable lands and are conditionally simulated for directly discharging developable lands in order to assess the impact of the hydromodification exemptions on the watershed-wide peak flows. The simulated hydromodification controls are modeled both with and without the presence of the dams to assess the influence of impoundment versus land development.

Both analyses resolve that the upstream impoundment is a very significant factor in peak flow alteration for each watershed. The Statistical Peak Flow Analysis results suggest a 29 to 65% peak flow reduction for each watershed due to upstream impoundment. The SWMM Peak Flow Analysis results suggest that peak flows for each watershed, if exemptions are granted, will remain 22 to 79% less than peak flows corresponding to an undammed watershed condition. These pre- to post-dam ratios are consistent with flow impoundment behavior found in other semi-arid, Mediterranean systems. The SWMM results further suggest that the areas directly discharging to exempt river reaches are less than significant, as evidenced by the near-0% peak flow increase granted by the proposed HMP exemption. Therefore, it is recommended that the exemptions be reinstated along all five river reaches for projects directly discharging to the rivers, due to confirmation of significant impoundment effects and the negligible peak flow increase attributable to those directly discharging developable lands.

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ACRONYMS AND ABBREVIATIONS

BMP	Best Management Practice
DEM	Digital Elevation Model
EPA	Environmental Protection Agency
FEMA	Federal Emergency Management Agency
FIS	Flood Insurance Study
GIS	Geographic Information System
HMP	Hydromodification Management Plan
HSG	Hydrologic Soil Group
JURMP	Jurisdictional Urban Runoff Management Plan
MS4	Municipal Separate Storm Sewer System
NED	National Elevation Dataset
OTAY	Otay River
PDP	Priority Development Project
PRISM	Parameter-elevation Regressions on Independent Slopes Model Monthly Climate Data for the Continental United States
SDCFCD	San Diego County Flood Control District
SDGTO	San Dieguito River
SDR	San Diego River
SLR	San Luis Rey River
SW	Sweetwater River
SWMM	Storm Water Management Model
TAC	Technical Advisory Committee
USGS	United States Geological Survey
WMAA	Watershed Management Area Analysis
WQIP	Water Quality Improvement Plan
WY	Water Year (October 1st to September 30th)

1. BACKGROUND & CONTEXT FOR STUDY

A watershed's natural hydrologic state may become severely altered due to land use changes. Hydrologic alterations may include fluctuations to natural stream discharge rates, durations and sediment transport behavior. A stream's physical response to changes in watershed runoff and sediment yield is collectively referred to as hydromodification. The confidence that most hydromodification is highly attributable to changes in land surface—namely urbanization and other development—has recently led to more focused efforts in an attempt to understand and manage these processes.

Hydromodification is occurring in many Southern California creeks and waterways and has become a key element of most stormwater programs in California (Southern California Coastal Water Research Project, 2010). In San Diego, Orange, and Riverside counties, recent storm water regulations have imposed discharge flow and duration control requirements on certain new development and redevelopment projects. As evidenced in 2007 by the San Diego Regional Water Quality Control Board Order No. R9-2007-0001 (the "2007 Municipal Separate Storm Sewer System (MS4) Permit"), the Municipal Copermittees were required to implement a Hydromodification Management Plan (HMP) "...to manage increases in runoff discharge rates and durations from all Priority Development Projects, where such increased rates and durations are likely to cause increased erosion of channel beds and banks, sediment pollutant generation, or other impacts to beneficial uses and stream habitat due to increased erosive force" (San Diego Regional Water Quality Control Board, 2007). Consequently, in 2007 the Copermittees began to prepare the San Diego County HMP (Brown and Caldwell, 2011). The San Diego County HMP effort continued over the span of two years, consisted of a 14 member Technical Advisory Committee (TAC), and received input from a gamut of private and public stakeholders. The total HMP development effort exceeded one million dollars. The Final 2011 HMP was adopted by the San Diego Regional Water Quality Control Board (San Diego Water Board) on July 14, 2010 through Resolution No. R9-2010-0066 (San Diego Regional Water Quality Control Board, 2010).

The 2011 HMP provides San Diego Copermittees with guidance on hydromodification methods, technical approach, requirements, standards, best management practice (BMP) selection and implementation, monitoring, and exemptions. One such HMP applicability requirement provided exemption rationale for Priority Development Projects (PDPs) directly discharging to five large river reaches in San Diego County (developable lands that directly discharge to the exempt river reaches are herein referred to as Project Lands). The Project Lands within each watershed equate to a considerably small fraction of the total watershed area (less than 5%, as summarized in Table 1). The exempt river reaches are summarized in Table 2 and are shown in Figure 1.

Table 1: Watershed Land Use Distribution (Downstream of Dam)

Reach	Total (ac)	[1]Developable (ac)	[2]Project Lands (ac)	% Developable	%Project Lands
Otay	29,571	4,310	1,412	15%	5%
San Diego	111,014	13,667	1,196	12%	1%
San Dieguito	28,710	4,653	1,055	16%	4%
San Luis Rey	118,846	77,180	4,151	65%	3%
Sweetwater	25,135	1,332	255	5%	1%

[1]Acreages were determined using "Developable Land" GIS data from the SanGIS Regional Data Warehouse.
[2]Acreages were determined through desktop analysis using available MS4 GIS data provided by Copermittees.

Table 2: Summary of Exempt River Reaches as Defined by the 2011 HMP

River	Downstream Limit	Upstream Limit
Otay River	Outfall to San Diego Bay	Lower Otay Reservoir Dam
San Diego River	Outfall to Pacific Ocean	Confluence with San Vicente Creek
San Dieguito River	Outfall to Pacific Ocean	Lake Hodges Dam
San Luis Rey River	Outfall to Pacific Ocean	Upstream river limit of Basin Plan subwatershed 903.1 upstream of Bonsall and near Interstate 15
Sweetwater River	Outfall to San Diego Bay	Sweetwater Reservoir Dam

For all proposed exempt river reaches supported by the 2011 HMP, each has:

- a drainage area in excess of 100 square miles;
- a 100-year flow in excess of 20,000 cubic feet per second;
- significant upstream reservoir flow regulation;
- predominantly wide floodplains and/or stabilized channel areas, and;
- low gradients (less than 1 %)

These factors concurred with field observations and were backed by years of historical perspective and practice from the TAC members (Bowling, Grey, Parra, Walker, & Weeden, 2013). There was a conditional requirement for the river reach exemption: a properly-sized energy dissipation feature must be existing or installed at the respective outfall location. Using the exemption rationale provided within the 2011 HMP, Copermittees were permitted to exempt PDPs from the hydromodification management BMP performance requirements prescribed by the 2007 MS4 Permit (herein referred to as the 2011 HMP Exemptions) so long as said PDPs were listed in the Development Planning section of the Copermittees' Jurisdictional Urban Runoff Management Program Annual Report (JURMP).

The current and succeeding municipal storm water permit, the 2013 MS4 Permit, was adopted on May 8, 2013. Similar to the preceding 2007 MS4 Permit, the 2013 MS4 Permit presents a list of criteria that must all be satisfied in order to grant hydromodification management BMP performance requirement exemptions. However, the 2013 MS4 Permit revised the hydromodification management BMP performance requirement exemption language from the 2007 MS4 Permit as follows:

- The project would discharge into channels that are significantly hardened (e.g., with rip-rap, sackcrete, etc.) downstream to their outfall in bays or the ocean;
- The project would discharge to a channel where the watershed areas below the project's discharge points are highly impervious (e.g. >70%).

The 2013 MS4 Permit conditionally excludes the five exempt river reaches justified by the 2011 HMP—exemptions that were based on prior studies of these rivers, the consensus of the TAC, an extensive public review process, and were approved by the San Diego Regional Board. However, the adopted language within the 2013 MS4 Permit does provide an opportunity to grant hydromodification management BMP performance requirement exemptions. A PDP may be exempt from hydromodification management BMP performance requirements when the project discharges storm water runoff to an area identified by the Copermittees as appropriate for an exemption by the optional Watershed Management Area Analysis (WMAA) incorporated into the Water Quality Improvement Plan (WQIP) pursuant to Provision B.3.b.(4).

This language was included to allow further evaluation of these previously exempt channels, rivers, or highly impervious watershed areas for continued exemption under a WQIP. Thus, a complete new analysis is required under the Watershed Management Area Analysis (Bowling, Grey, Parra, Walker, & Weeden, 2013). The Copermittees have since elected to perform the optional Watershed Management Area Analysis, represented by the County of San Diego (Geosyntec Consultants & Rick Engineering, 2015). The April 2015 San Diego County Regional WMAA uses a geomorphic assessment to evaluate the relationship between Erosion Potential (Ep) and Sediment Supply Potential (Sp). Based upon the instream erosion assessment, the Draft Regional WMAA recommends hydromodification management BMP performance requirement exemptions for PDPs directly discharging to the following river reaches:

Table 3: Summary of Exempt River Reaches as Proposed by the Regional WMAA

River	Downstream Limit	Upstream Limit
Otay River	Outfall to San Diego Bay	Interstate 805*
San Diego River	Outfall to Pacific Ocean	Confluence with San Vicente Creek
San Dieguito River	Upstream edge of the railroad crossing*	Lake Hodges Dam
San Luis Rey River	Outfall to Pacific Ocean	Upstream river limit of Basin Plan subwatershed 903.1 upstream of Bonsall and near Interstate 15
Sweetwater River	Outfall to San Diego Bay	Sweetwater Reservoir Dam

*limit changed from 2011 HMP recommendation

The Copermittees will now be able to grant hydromodification management BMP performance requirement exemptions offered by the 2013 MS4 Permit so long as the exemptions are approved via the WMAA and are incorporated into the WQIP—both of which are subject to the vetted public review and San Diego Water Board approval process.

1.1 Impoundment Characteristics

It is well understood that a river is in dynamic equilibrium with its geomorphic components: quantity of sediment, particle size, water discharge, and slope (Lane, 1955). This relationship, known as the Lane relation, is commonly expressed as:

$$Q_s d_s \propto Q_w S_o$$

Where Q_s is the quantity of sediment, d_s is the sediment particle diameter, Q_w is the water discharge, and S_o is the stream bed slope. This relationship is used to describe the qualitative balance between stream power and the discharge of bed material sediment and not intended to be used as an equation (Bowling, Grey, Parra, Walker, & Weeden, 2013).

Generally, long-term channel forms are naturally defined by frequent bankfull floods, approximately 1 to 2-year events in many cases (Wolman & Miller, 1960; Andrews, 1980). However, anthropogenic disturbances in natural systems invalidate assumptions of stationarity (Milly, et al., 2008). An alteration to one or more of the river equilibrium components will usually result in a feedback response to re-establish river equilibrium. A considerable amount of time may be required to achieve a new equilibrium condition; therefore, the effects of hydromodification may not be immediately observable (Trimble, 1997). In the context of all five exempt river reaches, the common denominators are sediment and flow sequestration due to upstream impoundments. The exact rate of sediment and flow sequestration accomplished by the upstream reservoirs is not well known at the desired temporal resolution. Sedimentation processes in a reservoir are quite complex because of the wide variation in many of the influencing factors (United States Bureau of Reclamation, 1987). Nonetheless, a significant reduction in sediment quantity and water discharge is reasonably assumed due to the steep and elevated nature of the impounded watershed drainage areas.

The exempt river reach impoundment summary is summarized as follows:

Table 4: Exempt River Reach Impoundment Summary

River	Major Impoundment[1]	Constructed	Owner	Miles from Mouth	Capacity (acre-ft)	Impounded Area (mi^2)	Percent Impounded[2]
Otay River	Lower Otay Reservoir	1919[a]	City of San Diego	13.1	49,849	100	70%
San Diego River	El Capitan Reservoir	1935	City of San Diego	28.0	112,807	185	61%
	San Vicente Reservoir	1943	City of San Diego	24.6	242,000[b]	75[b]	
San Dieguito River	Hodges Reservoir	1918	City of San Diego	11.0	30,251	245	89%
	Sutherland Reservoir	1954	City of San Diego	22.0	29,508	55	
San Luis Rey River	Lake Henshaw	1923	Vista Irrigation District	53.6	53,160	205	39%
Sweetwater River[3]	Sweetwater Reservoir	1888	Sweetwater Authority	8.2	28,079	85	82%
	Loveland Reservoir	1945	Sweetwater Authority	28.4	25,387	95	

[1] This study defines a Major Impoundment as a reservoir having storage capacity in excess of 25,000 acre feet and able to spill to the river reach
[2] percentage of total area impounded above downstream-most dam
[3] linear reservoir sequence
[a] originally constructed in 1897; reconstructed in 1919 after 1916 dam breach
[b] project recently completed to double reservoir capacity; overflows through tributary to main reach

1.2 Study Objectives

The objective of this study is to perform a rigorous hydrologic analysis to either justify or invalidate the renewal of the 2011 HMP Exemptions for PDPs on Project Lands using highly relevant and available tools, methods, and data. Due to the strict hydrologic focus of this study, sediment transport is not evaluated. This study used a two-step approach to describe the effects of either renewing or revoking the 2011 HMP Exemptions through: (1) Statistical Peak Flow Analysis, and (2) US Environmental Protection Agency (EPA) Storm Water Management Model (SWMM) Peak Flow Analysis. The analyses are summarized below.

1.2.1 Statistical Peak Flow Analysis

The Statistical Peak Flow Analysis seeks to provide a frame of reference for the SWMM Peak Flow Analysis and to describe the general influence of the upstream impoundments on peak flows by using measured flow gage discharge, peak flow estimation, and reservoir overflow data, where possible, to estimate the 2-year, 5-year, and 10-year peak flows at the mouth of the exempt river reach during:

- the ”dam-in-place” condition, which includes the existence of the upstream reservoir(s);
- the hypothetical “no dam” condition, which seeks to remove the significant impoundment effects induced by the upstream reservoir(s)

1.2.2 SWMM Peak Flow Analysis

As hydromodification is a complex phenomenon established in a large scale range, two possible outcomes can occur: (1) the combined effect of the impoundment and potential development may be more similar to the hypothetical and natural peak flow than simply including hydromodification control for an area already modified by a dam, or (2) the combined effect of the impoundment and potential development could improve the situation in a portion of the range of analysis, but be detrimental in another portion of the range of analysis, in which case an exemption to hydromodification is not recommended. The Statistical Peak Flow Analysis serves as a preface to the more detailed SWMM Peak Flow Analysis and seeks to provide a general agreement between impoundment and peak flow behavior on a watershed-by-watershed basis.

The SWMM Peak Flow Analysis seeks to reinforce the Statistical Peak Flow Analysis. The SWMM Analysis will determine the relative change in peak flows from PDPs on Project Lands using EPA SWMM continuous simulation modeling to estimate the 2-year, 5-year, and 10-year peak flows at the mouth of the exempt river reach during:

- the dam-in-place HMP exemption scenario, which accounts for river impoundment and subjects only non-directly discharging developable lands to hydromodification management BMP performance requirements;
- the dam-in-place full HMP scenario, which accounts for river impoundment and subjects all directly and non-directly discharging developable lands to hydromodification management BMP performance requirements;
- the hypothetical “no dam” HMP exemption scenario, which removes the effect of river impoundment and subjects only non-directly discharging developable lands to hydromodification management BMP performance requirements;

- the hypothetical "no dam" full HMP scenario, which removes the effect of river impoundment and subjects all directly and non-directly discharging developable lands to hydromodification management BMP performance requirements.

If the SWMM Peak Flow Analysis demonstrates that the flows and durations of those flows contributed by the exempt Project Lands are insignificant, then the exemptions are justifiable. Contrarily, if the SWMM Peak Flow Analysis demonstrates that the flows and durations of those flows contributed by the exempt Project Lands are significant, then the exemptions are not justifiable and should be revoked.

2. METHODOLOGIES

2.1 Statistical Peak Flow Analysis

The United States Geological Survey (USGS) records and maintains stream station data for locations along each of the exempt river reaches. The period, quality, and availability of data vary significantly depending upon the river. Instantaneous stream flow measurements are desired in order to most accurately assess the true peak flows occurring within the river channel. Often, reliable flow data recorded prior to impounded flow conditions are not available. Therefore, the best available local USGS instantaneous stream stations were selected to represent earlier conditions.

Typical peak flow estimates (2-, 5-, and 10-year) are derived from annual maximum series data. Accurate peak flow assessment requires knowledge of the river's behavior throughout the water year and over a sufficient period of record, with consideration to the prevailing climate. Southern California's semi-arid Mediterranean climate is characterized by a unique seasonal precipitation, with wet winters and warm, dry summers that can produce multiple low-frequency events within the same year, or none at all. Due to this phenomenon, peak flow analyses developed upon single peak annual events will inevitably omit flows that have a significant influence on Mediterranean river morphology. The ultimate result of using the annual maximum series to determine peak flows for high-frequency events (the 2 and 5-year peaks) in a Mediterranean climate is a gross underestimation of the more probable peak flow frequency. This underestimation is likely more pronounced for the higher frequency events (i.e., the 2 and 5-year peak flows (Brown and Caldwell, 2011)). Therefore, a partial-duration series analysis is used to estimate the 2 and 5-year peak flows in this Statistical Peak Flow Analysis. A partial duration series contains "N" values from "N" years of data. For the 10-year peak flow, the annual maximum series will be used, unless the instantaneous data is found to be erroneous, in which case the partial duration will be used.

The USGS began to record instantaneous (15 minute) flow data in water year (WY) 1988 to present. The present-day instantaneous flow data are used to quantify the peak flow events for each reach by partial duration and annual series analyses. A set of peak flow regression equations are applied to the same drainage area recorded by the USGS stream station to develop a ratio of the measured post-dam peak flow to the peak flow estimation equation value; this ratio is named the flood peak ratio (FPR) in this study.

With the flood peak ratio (FPR) established, the 2-, 5-, and 10-year pre-dam peak flow events are estimated by multiplying the FPR by the regression peak flow estimate derived for the entire watershed-wide area. The process is repeated for each watershed to produce impoundment-free 2-, 5-, and 10-year peak flow estimates. For validation, the impoundment-free peak flows are compared with the measured peak flows for those watersheds with USGS stream stations located at or near the river mouth. For additional reference, the impoundment-free 10-year peak flow is compared to the 10-year peak flow estimates published by the 2012 Federal Emergency Management Agency (FEMA) Flood Insurance Study (FIS) to roughly quantify the relative impact of the upstream impoundments.

USGS regional flood-frequency equations, originally introduced by Waananen and Crippen (1977), are used to estimate flood frequencies in six regions in California (Table 5). These equations relate flood magnitudes of selected frequency to drainage area, precipitation, and altitude (Waananen & Crippen, 1977). These equations (herein referred to as the 1977 USGS Equations) were regressed using available annual peak flow data from 778 USGS stream stations throughout California, 148 of which are located within the South Coast Region concerned with San Diego County. The 1977 USGS Equations are not applicable to sites where the usable storage within the basin exceeds 103 acre feet per square mile, to sites just downstream from large reservoirs, or to streams in urban areas affected substantially by urban development. The relations are primarily used to determine peak discharge values for flow under natural conditions (Waananen & Crippen, 1977). It is noted by a 2004 USGS study of Northern California watersheds that the 1977 USGS Regression equations produce the greatest errors at lower recurrence intervals (2-, 5-, and 10-year) peak flows, which is likely attributable to the lack of more than two decades of peak-flow data at the time of the study (Mann, Rizzardo, & Satkowski, 2004). It is expected that the underestimation would be even more pronounced for southern California’s Mediterranean semi-arid climate for the reasons previously discussed.

The 1977 USGS Regression Equations were revised by Gotvald, Barth, Veilleux, & Parrett (2012). These equations (herein referred to as the 2012 USGS Equations) incorporated 30 years of additional annual peak flow data, among other improvements (Gotvald, Barth, Veilleux, & Parrett, 2012). Similarly, the 2012 USGS Regression Equations are specific to one of six hydrologic regions in California. San Diego County is located in the South Coast hydrologic region (Region 5), which was used for the 2-, 5-, and 10-year flood peak analysis. A comparison between the 1977 and 2012 USGS Equations are summarized in Table 5 as follows:

Table 5. 1977 and 2012 USGS Regression Equations for Region 5

Peak Flow	1977 USGS Equation	2012 USGS Equation
2-year	$0.14(DRNAREA)^{0.72}(PRECIP)^{1.62}$	$3.60(DRNAREA)^{0.672}(PRECIP)^{0.753}$
5-year	$0.40(DRNAREA)^{0.77}(PRECIP)^{1.69}$	$7.43(DRNAREA)^{0.739}(PRECIP)^{0.872}$
10-year	$0.63(DRNAREA)^{0.79}(PRECIP)^{1.75}$	$6.56(DRNAREA)^{0.783}(PRECIP)^{1.07}$

DRNAREA, drainage area, in square miles; *PRECIP*, mean annual precipitation, in inches

Drainage area values are estimated with USGS Digital Elevation Map (DEM) analysis using Esri ArcMap. Mean annual precipitation values were estimated using the Parameter-elevation Regressions on Independent Slopes Model Monthly Climate Data for the Continental United States (PRISM) areal statistics for water years 1988-2013 (October 1, 1987 to September 30, 2013) (Daly, 1994, 1997, 2001). PRISM provides an estimation of mean annual precipitation and is noted to have some bias at the monthly scale; however, this product is continuously updated to incorporate point data, a digital elevation model, and expert knowledge of complex climatic extremes, including rain shadows, coastal effects, and temperature inversions. Conterminous U.S. precipitation products can be downloaded from the PRISM Climate Group (http://www.prism.oregonstate.edu/); this study extracted and averaged monthly 4 km pixels for each watershed domain.

The USGS instantaneous stream station data are analyzed to identify individual peak flow events. Individual peak flow events are distinguished by satisfying the following criteria (United States Geological Survey, 1982):

1. Events must be separated by at least five days plus the natural logarithm of the square miles of the drainage area, and;
2. Intermediate flows must drop below 75 percent of the lower of the two separate maximum flows.

For any given time period where a recorded reservoir spill occurred and would have likely influenced the corresponding stream station flow measurement, the potential impacted data is omitted from the instantaneous stream flow record and analysis.

Two of the five river reaches (namely, the San Diego and San Luis Rey rivers) have instantaneous stream gage flow data near the mouth to the Pacific Ocean, where the Statistical Peak Flow Analysis provides an empirical relationship between the urbanized watershed-specific drainage area and partial duration peak flow events downstream of the impoundments. For the three remaining river reaches (namely, the Otay, San Dieguito, and Sweetwater rivers), the USGS stream stations are located upstream of the major impoundments, where the Statistical Peak Flow Analysis provides an empirical relationship between the sparsely developed, watershed-specific drainage area and partial duration peak flow events upstream of the impoundments. For both cases then, the watershed-wide drainage areas are not entirely represented, due to the impoundment in all cases, and due to the absence of a stream station near the mouth in three cases. Hence, these empirical relationships are used in combination with the 2012 USGS regional flood-frequency equations for rural ungaged streams in California to develop a relationship between the empirical and regression estimates on a watershed-wide scale; thus, a methodology is developed for estimating the peak flows at or near the river mouth. This simplified relationship is therefore used to scale the estimated regional flood-frequencies to the watershed-wide extent for each river by developing flood peak ratios (FPRs), defined as:

$$FPR = \frac{Q_{PDS}}{Q_{USGS}} \tag{1}$$

Where:

Q_{PDS} is the partial duration series T-year peak flow, as determined from the stream station instantaneous data record;

Q_{USGS} is the T-year peak flow, as determined by application of the T-year 2012 USGS regression equation to the equivalent stream station drainage area

Assuming a linear watershed-wide relationship between the stream station drainage area peak flows and 2012 USGS Regression peak flows:

$$\frac{Q_{PDS}}{Q_{USGS}} = \frac{Q_{ND}}{Q_{WS}} \tag{2}$$

Where:

Q_{ND} is the T-year estimated “no dam” statistical series peak at the river mouth

Q_{WS} is the 2012 USGS T-year annual peak applied to the entire watershed area

Therefore, the estimated “no dam” peak flow at the river mouth is:

$$Q_{ND} = FPR \times Q_{WS} \tag{3}$$

Figure 1 and Table 6 summarize the information pertinent to this methodology.

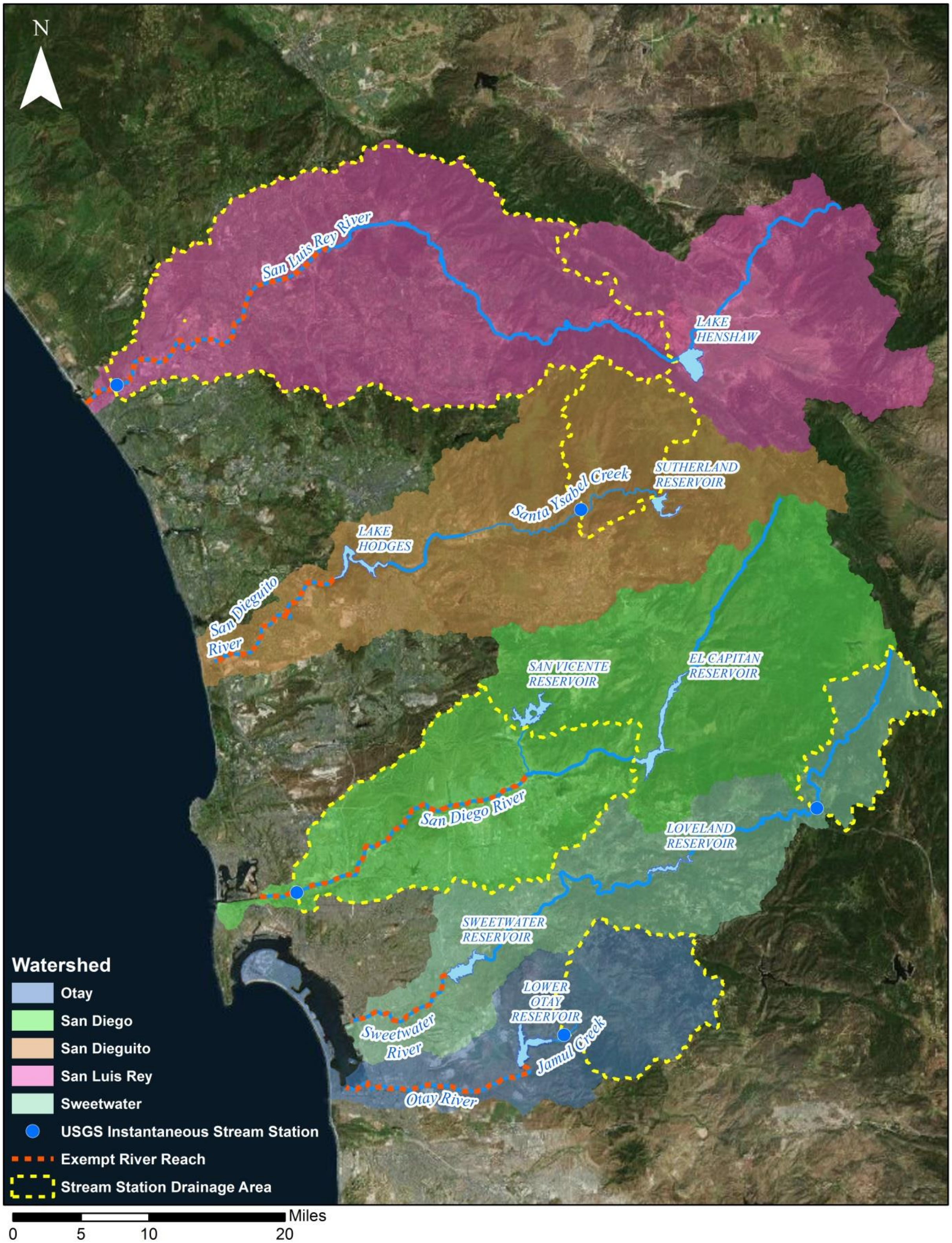

Figure 1. USGS Instantaneous Stream Stations

Table 6: USGS Instantaneous Stream Station Data Summary

River	Stream Station	Date Range (WY)	Month(s) Missing from Flow Record	Spill(s) During Flow Record
Otay River (OTAY)	USGS 11014000 JAMUL C NR JAMUL CA	1988-2014	Dec 1990 Mar 2002	Jan-Mar 1993* Feb-Apr 1994* Feb-Mar 2005* Sep 2005*
San Diego River (SDR)	USGS 11023000 SAN DIEGO R A FASHION VALLEY AT SAN DIEGO CA	1988-2014	-	Feb-Apr 1993 Mar-May 1995
San Dieguito River (SDGTO)	USGS 11025500 SANTA YSABEL C NR RAMONA CA	1988-2014	Dec 1992 Apr 1993 Jul 1994	Feb-Apr 1993 Mar-May 1995
San Luis Rey River (SLR)	USGS 11042000 SAN LUIS REY R A OCEANSIDE CA	1988-2014	Jul-Dec 1992 Jan-Jul 1993 Aug-Dec 1997 Jan-Mar 1998 Oct-Dec 2001 Jan-Dec 2002 Jan-Sep 2003	Feb-Apr 1993
Sweetwater River (SWTR)	USGS 11015000 SWEETWATER R NR DESCANSO CA	1988-2014	-	Jan 1993* Apr 1995* May 1998*

*spills have no influence on USGS stream station

2.2 SWMM Peak Flow Analysis

The SWMM Peak Flow Analysis is used to assess the contribution of storm water runoff discharging from Project Lands to the exempt river reaches. Using available USGS and SanGIS land use data, SWMM models the rainfall-runoff relationship for each watershed under a set of different scenarios. The watersheds were modeled under the planned land use (PLU) condition in order to analyze the developed hydrology. Each watershed is modeled to evaluate the direct runoff from Project Lands, both with and without hydromodification management BMP performance requirements in place, and also without the effect of upstream impoundment.

As stated earlier, only PDPs on land directly discharging to the exempt river reaches (Project Lands) could qualify for the 2011 HMP Exemption. Using the "LANDUSE_PLANNED" SanGIS shapefile, developable lands were classified as such if they were geographically contained within the present-day "Developable_Land" SanGIS shapefile. These developable lands were then sub-classified as either directly-discharging (Project Lands) or non-directly discharging (non-exempt developable). Drainage behavior was assessed based upon available storm drain infrastructure databases and best professional judgment. In all likelihood, not all areas classified as Project Lands by this study would be named as such due to site-specific post development hydrology, jurisdictional requirements, and other related factors. When the effect of the dam was to be considered, the total watershed area upstream of the lower-most impoundment was introduced into the model. Areas upstream of the dam were conservatively assumed to be in a fully built-out condition and subject to hydromodification flow control. Since hydromodification management BMPs, when properly designed, effectively maintain the pre-development hydrology, this conservative assumption effectively models the impounded area as having a "natural" overland flow behavior. For all lumped land classification groups, the area was further divided into four sub-areas based upon hydrologic soil group (HSG) as A, B, C, or D.

To simulate the effects of hydromodification management BMPs, we averaged the percent flow reduction achieved by 25 separate hydromodification design projects performed by TRWE for our clients throughout San Diego County. The 25 projects all met the hydromodification management BMP volume and time-based performance requirements, as prescribed in the 2013 MS4 Permit. The average percent flow reduction for the 2-year to the 10-year peak flow was 43%. In nearly all cases, a hydromodification design project will not perfectly match the pre-development flow duration curve. It would not be practical to produce such a finely-tuned design. In order to safely meet hydromodification BMP performance requirements, the final design will typically produce less runoff than the pre-development hydrologic condition. Therefore, a 43% flow reduction is a conservative expectation for the unmitigated to mitigated post-development scenario. Furthermore, given that the 43% flow reduction estimate was developed from projects that met the hydromodification flow duration requirement, the 43%

flow reduction, when applied, can be assumed to satisfy the post-development flow duration component as well.

In order to simulate the effect of hydromodification on a given land use group, the 43% flow reduction was applied via the inflow scale factor for the respective junction node in SWMM. A conceptual SWMM model schematic is provided in Figure 2.

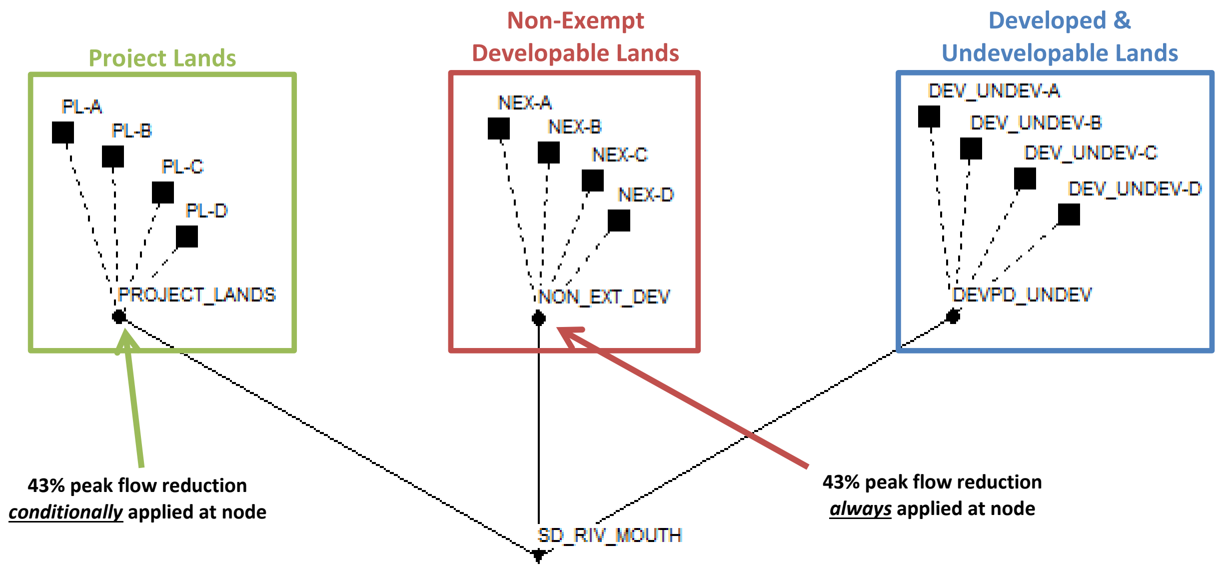

Figure 2: SWMM Model Conceptual Schematic for the San Diego River "Dam-In-Place" Scenario

The rainfall time series provided by the County of San Diego as a work product of the 2011 Final HMP have been analyzed for their accuracy in other studies. It was found that the disaggregation process artificially increases the frequency of the high intensity values (Parra-Rosales, Walker, & Ponce, 2012). Of the 19 rainfall stations produced by the Final 2011 HMP, Parra et al. found Lindbergh and Oceanside to be the most acceptable stations due to the completeness of the original data and quality of data from external stations used to fill data gaps. Therefore, this study used the Oceanside rainfall data for the San Luis Rey Watershed and the Lindbergh rainfall data for the San Diego Watershed. For all other watersheds, an alternate rainfall data source was used, as described below.

Available rainfall data was obtained through coordination with Rand Allan of the San Diego County Flood Control District (SDCFCD). Rainfall stations were selected based on their time format (hourly or finer) and proximity to the study watersheds. Collocated historical hourly and ALERT event-based rainfall stations were combined to make a continuous 50 year record. Natural variability in hourly and daily data exists between stations. Thus, annual values provide a reliable means to estimate precipitation patterns between nearby gages and gages with similar elevation and climatological attributes. To develop continuous precipitation records, a linear regression between SDCFCD stations was used to estimate missing precipitation values and validated on a separate subset of data, where available data exists for both gages. The correlation value (R^2) indicates the ability of the independent variable to predict the dependent variable and ranges from 0 to 1. Only correlations greater than 0.7 were used to guide interpolation of precipitation data. Table 7 summarizes the developed regression equations, the correlation coefficient, and values estimated at each station:

Table 7: Rainfall Station Regression Equations Used for Data Gaps

Independent Station (x)	Dependent Station (y)	Regression Equation[a-h]	Correlation
Kearny Mesa	La Mesa	[1]y = 0.9813x	R^2 = 0.8815
Poway	Kearny Mesa	[2]y = 0.9371x	R^2 = 0.7993
Encinitas	San Marcos	[3]y = 1.0574x	R^2 = 0.7260
Bonita	Sweetwater	[4]y = 1.0942x	R^2 = 0.8734
Kearny Mesa	Sweetwater	[5]y = 0.9007x	R^2 = 0.7520
Encinitas	Escondido	[6]y = 1.3275x	R^2 = 0.7720

a. Kearny Mesa data was used to estimate missing values in **La Mesa**[1] for the period of record for 8/10/1969-3/1/2015. A total of 9447 values (hourly time step) were filled. Note that La Mesa ALERT tipping bucket record begins 9/15/1982, which may account for the number of values filled.

b. Available data from Kearny Mesa was used to estimate missing values in **Poway**[2] for 1/23/1964-2/28/2015. A total of 3278 values (hourly time step) were filled. Note that Poway ALERT tipping bucket record begins 7/19/1982, which may account for the number of values filled. Now, a complete record is available for Poway from 11/1/1962-2/28/2015.

c. Poway data was used to estimate missing values in **Kearny Mesa**[2] for the period of record for 1/22/1964-2/28/2015. A total of 36 values (hourly time step) were filled.

d. Available data from Encinitas was used to estimate missing values in **San Marcos**[3] for 7/1/1963-2/28/2015. A total of 17 values (hourly time step) were filled during this time period. Note that San Marcos ALERT tipping bucket record begins 5/28/1981-3/3/2006 during which, there was 217135 missing values (hourly time step). These values were filled with data from Encinitas. Now, a complete record is available for San Marcos from 11/16/1962-2/28/2015.

e. Kearny Mesa data was used to estimate missing values in **Sweetwater**[5] for the period of record for 2/1/1965-10/30/1992. A total of 765 values (hourly time step) were filled.

f. Available data from Escondido was used to estimate missing values in **Encinitas**[6] for 11/19/1964-2/28/2015. A total of 1862 values (hourly time step) were filled. Now, a complete record is available for Encinitas from 7/1/1963-2/28/2015.

g. Encinitas data was used to estimate missing values in **Escondido**[6] for the period of record for 11/19/1964-2/28/2015. A total of 7761 values (hourly time step) were filled. Note that Encinitas ALERT tipping bucket record begins 7/1/1984, which may account for the number of values filled.

Rainfall data assignment and sources for each watershed are shown in Table 8

Table 8: Select Rainfall Stations for SWMM Peak Flow Analysis

Watershed	Rainfall Station	Record	Elevation (ft)	Source
Otay[1]	Bonita	1975-2015	139	SDCFCD
	Sweetwater[2]	1965-1992	310	SDCFCD
San Diego	Lindbergh[3]	1948-2005	15	Project Clean Water
San Dieguito[1]	Encinitas	1963-2015	250	SDCFCD
	Escondido	1964-2015	660	SDCFCD
	San Marcos	1962-2015	580	SDCFCD
San Luis Rey	Oceanside[3]	1951-2008	30	Project Clean Water
Sweetwater[1]	Bonita	1975-2015	139	SDCFCD
	Sweetwater	1965-1992	310	SDCFCD

[1]Rainfall station rainfall intensity was averaged between rainfall stations and applied uniformly to the entire modeled watershed
[2]No collocated ALERT station
[3]Data downloaded directly from Project Clean Water (http://www.projectcleanwater.org)

The spatial distribution of TRWE sample HMP projects and SDCFCD rainfall stations are illustrated in Figure 3.

2.2.1 Parameters

Physical watershed parameters were estimated using available land use geographic information system (GIS) data from SanGIS. Planned land use classifications were used for all SWMM peak flow analyses, including areas upstream of the dams, which were conservatively assumed to reflect the pre-development hydrology through application of hydromodification flow reduction to the outlet node. Percent imperviousness was determined by using area-weighted averages based upon those values presented in a 2010 County of San Diego imperviousness study. Percent slope was determined by using area-weighted averages based upon relationships between SanGIS land use and the latest USGS National Elevation Dataset (NED) 1/3 arc-second DEM for greater Southern California. The width parameter served as a general calibration parameter for the model using the best available USGS instantaneous stream flow data. Using the relationship between watershed area and river length, a factor was applied to this ratio to match the 5-year peak flow value. The San Diego River station was used to develop this factored relationship due to the completeness of the dataset, the least number of upstream dam overflow events, and location near the river mouth. The remaining SWMM parameters were taken from the San Diego Model BMP Design Manual. General watershed parameters are outlined in Table 9. Specific watershed parameters are provided in Appendix A.

Table 9: SWMM Parameters Used in SWMM Peak Flow Analysis

SWMM Parameter	Description[1]	Value				Source
Area (ac)	Area of the subcatchment.	Watershed-specific				GIS analysis
Width (ft)	Characteristic width of the overland flow path for sheet flow runoff.	Calibrated by factoring the ratio of entire river length to full watershed area to match the PDS-derived San Diego River 5-year peak flow, taken as: $W_{HSG} = 0.184 \frac{A_{HSG}}{L_R}$ where: W_{HSG} is the width of the given HSG subcatchment; A_{HSG} is the area of the given HSG subcatchment; L_R is the length of the entire river reach				TRWE
% Slope	Average percent slope of the subcatchment.	Area-weighted average of percent slope by land use				USGS NED 1/3 arc-second DEM
% Imperv	Percent of the land area which is impervious.	Area-weighted average of percent imperviousness by land use				County of San Diego, 2010
N-Imperv	Manning's n for overland flow over the impervious portion of the subcatchment.	0.012				SD Model BMP Design Manual
N-Perv	Manning's n for overland flow over the pervious portion of the subcatchment.	0.15				SD Model BMP Design Manual
D store-Imperv (in)	Depth of depression storage on the impervious portion of the subcatchment.	0.05				SD Model BMP Design Manual
D store-Perv (in)	Depth of depression storage on the pervious portion of the subcatchment.	0.10				SD Model BMP Design Manual
% Zero-Imperv	Percent of the impervious are with no depression storage.	25%				SD Model BMP Design Manual
Subarea Routing	Choice of internal routing of runoff between pervious and impervious areas	OUTLET				SD Model BMP Design Manual
Percent Routed	Percent of runoff routed between subareas.	100%				SD Model BMP Design Manual
Infiltration	Infiltration parameters for the subcatchment.	GREEN_AMPT				SD Model BMP Design Manual
		HSG A	HSG B	HSG C	HSG D	
	GREEN_AMPT: Suction Head (in)	1.5	3.0	6.0	9.0	SD Model BMP Design Manual
	GREEN_AMPT: Initial Deficit (in/hr)	0.33	0.32	0.31	0.30	SD Model BMP Design Manual
	GREEN_AMPT: Developed Conductivity (in/hr)	0.225	0.15	0.075	0.01875	SD Model BMP Design Manual

[1]Defined by the SWMM User Manual
D/S = downstream; U/S/ = upstream

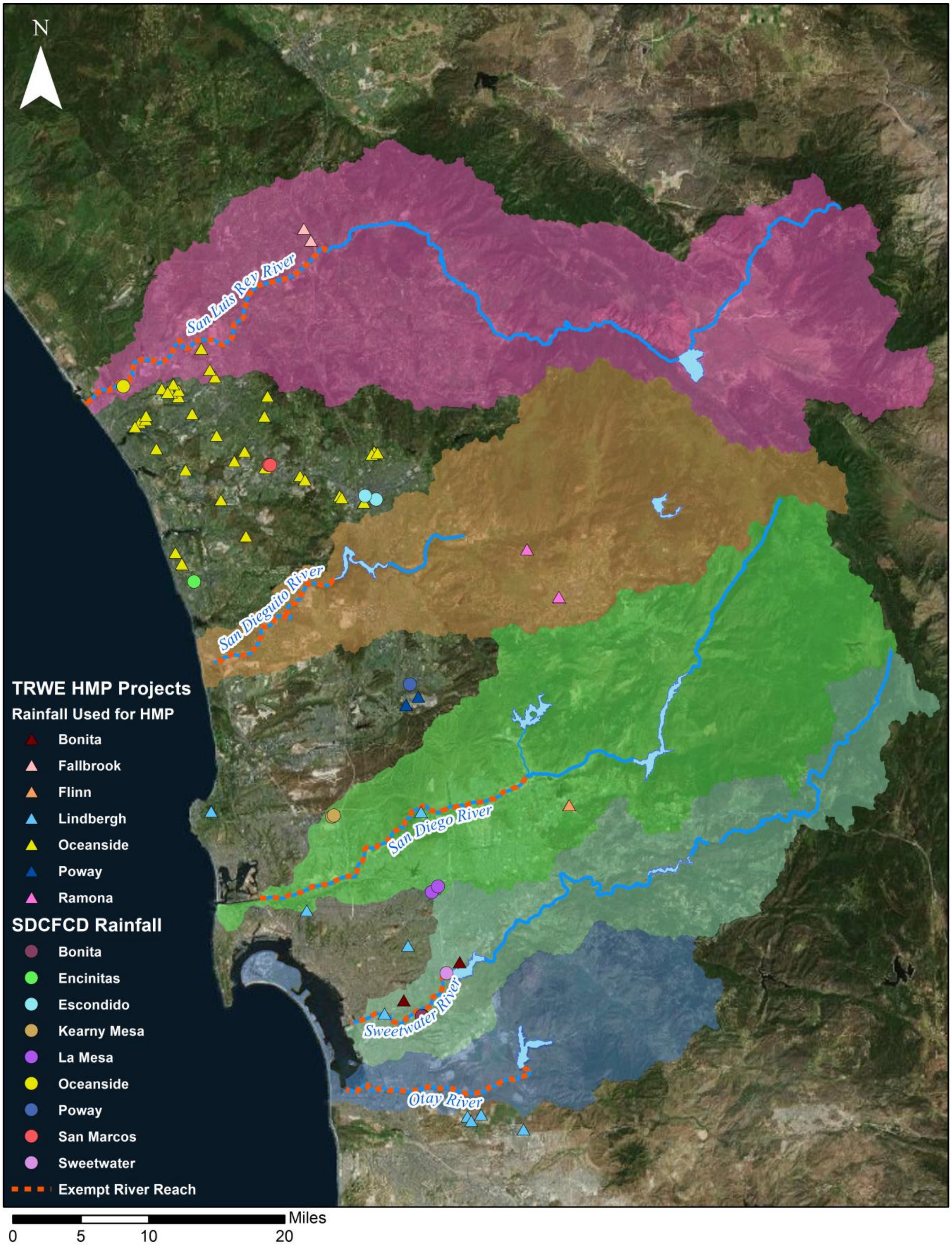

Figure 3. TRWE HMP Project and SDCFCD Rainfall Station Distribution

3. RESULTS

3.1 Statistical Peak Flow Results

Results provided herein are not intended to be used for design purposes, or serve as an exact measurement. The results are solely intended to provide a relative change in peak flow and demonstrate the impact of the upstream impoundment on the peak flow events in each river. The Statistical Peak Flow Analysis results are summarized in Table 10. For those rivers with stream stations located at or near the mouth, the statistical peak flow is compared with the "no dam" peak flows (Table 10, column "Peak[1]"). For those rivers without stream stations located at or near the mouth, the downstream-most available FEMA FIS 10-year peak flows are compared with the "no dam" peak flows. The percent difference or the reduction between the "no dam" and FEMA FIS 10-year peak flows are provided in Table 11. The flow reduction estimates are approximate in nature and are only shown to illustrate significant effects of impoundment on the peak flow events. In developing peak flows for the FIS, FEMA uses an annual series analysis, so it is expected that the percent reductions may be overestimated when used for comparison with a partial duration series analysis.

Table 10: Statistical Peak Flow Results Summary for "No Dam" Peak Flows

River	T-year	Peak[1] (cfs)	A* (mi^2)	P* (in)	Q_{USGS}[b] (cfs)	FPR	A** (mi^2)	P** (in)	Q_{WS}[c] (cfs)	Q_{ND}[d] (cfs)
OTAY	2	850	70	15.0	481	1.8	144	13.4	717	**1,267**
	5	2,265			1,822	1.2			2,811	**3,494**
	10	3,890[a]			3,315	1.2			5,163	**6,059**
SDR	2	2,693	168	12.6	759	3.6	429	16.9	1,778	**6,307**
	5	4,187			2,985	1.4			7,711	**10,813**
	10	7,980			5,454	1.5			15,558	**22,763**
SDGTO	2	930	58	20.5	533	1.7	336	16.6	1,488	**2,594**
	5	2,042			2,069	1.0			6,337	**6,255**
	10	4,434			3,971	1.1			12,605	**14,076**
SLR	2	1,040	350	16.4	1,516	0.7	557	17.2	2,147	**1,473**
	5	5,293			6,462	0.8			9,496	**7,777**
	10	11,461			12,847	0.9			19,450	**17,351**
SWTR	2	669	46	24.9	527	1.3	222	16.4	1,116	**1,417**
	5	2,544			2,059	1.2			4,616	**5,702**
	10	3,296			4,065	0.8			8,995	**7,293**

[1] partial duration series (PDS) value selected for 2-year and 5-year peak; annual maximum series selected for 10-year (unless otherwise specified)
[a] partial duration series value used due to unreasonably low 10-year peak flow; data "affected to unknown degree by Regulation or Diversion"
[b] equivalent drainage area peak flow; 2012 USGS Regression Equation calculation using drainage area parameters from A* (stream station drainage area) and P* (stream station drainage area mean annual precipitation)
[c] watershed-wide peak flow; 2012 USGS Regression Equation calculation using watershed parameters from A** (watershed-wide drainage area) and P** (watershed-wide mean annual precipitation)
[d] "no dam" watershed-wide peak flow estimate

Table 11: Comparison of "No Dam" Peak Flows with Available "Dam-in-Place" Peak Flows

River	T-year	Q_{ND} (cfs)	Peak[1] (cfs)	Reduction	FIS Peak[2] (cfs)	FIS Reduction
OTAY	2	**1,267**	-	-	-	-
	5	**3,494**	-		-	-
	10	**6,059**	-		1,200	80%
SDR	2	**6,307**	2,693	57%	-	-
	5	**10,813**	4,187	61%	-	-
	10	**22,763**	7,980	65%	3,100	86%
SDGTO	2	**2,594**	-	-	-	-
	5	**6,255**	-		-	-
	10	**14,076**	-		5,900	58%
SLR	2	**1,473**	1,040	29%	-	-
	5	**7,777**	5,293	32%	-	-
	10	**17,351**	11,461	34%	6,600	62%
SWTR	2	**1,417**	-	-	-	-
	5	**5,702**	-		-	-
	10	**7,293**	-		1,200	84%

[1]partial duration series value selected for 2-year and 5-year peak; annual maximum series selected for 10-year
[2] (Federal Emergency Management Agency, 2012)

The Statistical Peak Flow Analysis provides reasonable estimation of river impoundment peak flow reduction. For comparison, a 2005 study focused on the hydrological effects of dams on the Sacramento and San Joaquin Rivers in Northern California found that the 2-year peak flow declined anywhere between 35 to 95% of pre-dam values, while the 10-year peak flow was reduced from 2 to 78% (Kondolf & Batalla, 2005). For further comparison, a 2005 study of the hydrological effects of dams in semi-arid portions of north-eastern Spain (also a Mediterranean climate) found that 22 of 23 rivers showed reductions in 2 and 10-year peak flow by 31 and 33%, respectively, with effects more pronounced in the low-rainfall southern Mediterranean tributaries (Batalla, Gomez, & Kondolf, 2003). Therefore, the results (~29-65% reduction) provided in this study are consistent with flow impoundment behavior found in other semi-arid, Mediterranean systems and supports the assumption of significant flow sequestration in the five river reaches.

3.2 SWMM Peak Flow Results

Results from the SWMM Peak Flow Analysis are provided in Table 12 through Table 16 for the “dam-in-place” condition and Table 17 through Table 21 for the “no dam” condition. The results are estimates of peak flows and relative change for the exempt reaches using a simplified continuous modeling approach. These results are not intended to be used for design purposes.

The 2-, 5-, and 10-year flow rates are conservative estimates due to a number of underlying assumptions. First, the assumption of uniform rainfall over a large watershed may produce higher flows than what would actually be realized in each river. However, baseflow was not considered in peak flow determination. Also, the simple rainfall-runoff model is kinematic in nature, not accounting for complex overland flow behaviors such as runoff diffusion. Finally, the overland flow model does not consider channel routing and subsequent longitudinal spreading of the wave base for more mildly-sloped areas within the watershed, which ultimately produces a lower peak flow due to the attenuation and translation of the outflow hydrograph over space and time. Given these assumptions, it is important to note that the main objectives of this study do not require obtaining precise peak flow values. Instead, this study is focused on the relative change of discharges from Project Lands with and without hydromodification management BMP performance requirements.

Table 12: Otay River SWMM Peak Flows: "Dam-in-Place" Condition

Peak	No HMP BMPs (cfs)	Full HMP (cfs)	HMP Exemption (cfs)	Peak Reduction w/ HMP Exemption	Peak Flow Increase Due to Exemption	Exemption Peak Flow Increase (cfs)
2-year	1,481	1,378	1,409	4.9%	**2.0%**	31
5-year	1,950	1,803	1,847	5.3%	**2.3%**	44
10-year	2,378	2,226	2,272	4.5%	**2.0%**	47

Table 13: San Diego River SWMM Peak Flows: "Dam-in-Place" Condition

Peak	No HMP BMPs (cfs)	Full HMP (cfs)	HMP Exemption (cfs)	Peak Reduction w/ HMP Exemption	Peak Flow Increase Due to Exemption	Exemption Peak Flow Increase (cfs)
2-year	3,380	3,225	3,243	4.1%	**0.5%**	18
5-year	4,184	3,993	4,013	4.1%	**0.5%**	20
10-year	4,787	4,564	4,584	4.2%	**0.4%**	21

Table 14: San Dieguito River SWMM Peak Flows: "Dam-in-Place" Condition

Peak	No HMP BMPs (cfs)	Full HMP (cfs)	HMP Exemption (cfs)	Peak Reduction w/ HMP Exemption	Peak Flow Increase Due to Exemption	Exemption Peak Flow Increase (cfs)
2-year	1,265	1,170	1,182	6.6%	**0.9%**	11
5-year	1,754	1,625	1,642	6.4%	**1.0%**	17
10-year	1,950	1,811	1,833	6.0%	**1.1%**	22

Table 15: San Luis Rey River SWMM Peak Flows: "Dam-in-Place" Condition

Peak	No HMP BMPs (cfs)	Full HMP (cfs)	HMP Exemption (cfs)	Peak Reduction w/ HMP Exemption	Peak Flow Increase Due to Exemption	Exemption Peak Flow Increase (cfs)
2-year	6,441	5,731	5,781	10.3%	**0.8%**	50
5-year	8,652	7,630	7,697	11.0%	**0.8%**	67
10-year	10,135	9,031	9,111	10.1%	**0.8%**	80

Table 16: Sweetwater River SWMM Peak Flows: "Dam-in-Place" Condition

Peak	No HMP BMPs (cfs)	Full HMP (cfs)	HMP Exemption (cfs)	Peak Reduction w/ HMP Exemption	Peak Flow Increase Due to Exemption	Exemption Peak Flow Increase (cfs)
2-year	751	739	741	1.3%	**0.4%**	3
5-year	1,092	1,073	1,077	1.4%	**0.4%**	4
10-year	1,273	1,251	1,256	1.3%	**0.4%**	5

Table 17: Otay River SWMM Peak Flows: "No Dam" Condition

Peak	No HMP BMPs (cfs)	Full HMP (cfs)	HMP Exemption (cfs)	Peak Reduction w/ HMP Exemption	Peak Flow Increase Due to Exemption	Exemption Peak Flow Increase (cfs)
2-year	2,274	2,212	2,234	1.8%	**1.0%**	22
5-year	2,876	2,732	2,772	3.6%	**1.4%**	40
10-year	3,658	3,487	3,539	3.2%	**1.4%**	52

Table 18: San Diego River SWMM Peak Flows: "No Dam" Condition

Peak	No HMP BMPs (cfs)	Full HMP (cfs)	HMP Exemption (cfs)	Peak Reduction w/ HMP Exemption	Peak Flow Increase Due to Exemption	Exemption Peak Flow Increase (cfs)
2-year	5,270	5,123	5,137	2.5%	**0.3%**	13
5-year	6,579	6,386	6,407	2.6%	**0.3%**	21
10-year	7,572	7,356	7,380	2.5%	**0.3%**	24

Table 19: San Dieguito River SWMM Peak Flows: "No Dam" Condition

Peak	No HMP BMPs (cfs)	Full HMP (cfs)	HMP Exemption (cfs)	Peak Reduction w/ HMP Exemption	Peak Flow Increase Due to Exemption	Exemption Peak Flow Increase (cfs)
2-year	5,601	5,518	5,531	1.3%	**0.2%**	13
5-year	7,570	7,439	7,457	1.5%	**0.2%**	17
10-year	9,044	8,918	8,940	1.2%	**0.3%**	23

Table 20: San Luis Rey River SWMM Peak Flows: "No Dam" Condition

Peak	No HMP BMPs (cfs)	Full HMP (cfs)	HMP Exemption (cfs)	Peak Reduction w/ HMP Exemption	Peak Flow Increase Due to Exemption	Exemption Peak Flow Increase (cfs)
2-year	8,199	7,488	7,538	8.1%	**0.6%**	50
5-year	11,159	10,151	10,218	8.4%	**0.6%**	67
10-year	12,856	11,746	11,824	8.0%	**0.6%**	78

Table 21: Sweetwater River SWMM Peak Flows: "No Dam" Condition

Peak	No HMP BMPs (cfs)	Full HMP (cfs)	HMP Exemption (cfs)	Peak Reduction w/ HMP Exemption	Peak Flow Increase Due to Exemption	Exemption Peak Flow Increase (cfs)
2-year	2,050	2,039	2,041	0.4%	**0.1%**	2
5-year	2,735	2,718	2,722	0.5%	**0.1%**	4
10-year	3,283	3,265	3,269	0.4%	**0.1%**	4

The SWMM Peak Flow Analysis found that if the HMP exemptions were granted (as opposed to "Full HMP"—no exemptions granted), it would increase the 2-, 5-, and 10-year peak flow events by no more than 1.1% in all rivers except Otay, where at most, a 2.3% increase is predicted. It should be noted, in the case of Otay that, though minor, this additional flow has the potential to aid the many river restoration efforts identified in the 2006 Otay River Watershed Management Plan (Aspen Environmental Group, 2006). With the HMP exemptions in place, the SWMM Peak Flow Analysis applied hydromodification flow reduction to all non-directly discharging developable land to produce peak flow reductions ranging between 1.3 to 11% (as opposed to "No HMP"—no hydromodification flow control). This percent reduction is the peak flow "benefit" achieved through application of peak flow control. When modeled without the influence of the dam, the effects of Project Lands are further diminished—the primary reason for the original exemption. It is worth noting that both the modeled dam-in-place and no-dam peak flows produce reasonable matches with those peak flows presented in the Statistical Peak Flow Analysis.

The most notable comparisons are between the "dam-in-place" peak flows with the HMP exemption ("Dam-in-Place" HMP Exemption) versus the "no dam" peak flows with no HMP exemptions ("No Dam" Full HMP) presented in Table 22 through Table 26. These comparisons were made in order to simulate the impact of the proposed exemptions on peak flows versus the impact of the river impoundment on peak flows. These SWMM Peak Flow comparisons suggest that if, in their current impounded state, only Project Lands were exempt from hydromodification management BMP performance requirements, the resulting peak flows would be far less than the unimpounded, pre-development peak flows. The "No Dam" Full HMP scenario was considered to be the best representation of a pre-development watershed (in the absence of pre-Columbian watershed parameters) because the very nature of hydromodification management is to simulate the pre-development hydrologic condition. In other words, if the entire developed portion of a watershed is subject to hydromodification flow and duration control, then it is assumed to simulate the pre-development hydrologic condition.

Due to the conservative modeling approach, in actuality the "Dam-in-Place" HMP Exemption peak flows would likely be even less than those modeled herein due to strict interpretations on what constitutes a directly discharging developable land. An even greater difference between the HMP exemption peak flows and the pre-development peak flows would result. Therefore, the SWMM Peak Flow Analysis confirms that the major river impoundments are the primary source of peak flow reduction and clearly demonstrates that peak flows discharging from exempted Project Lands would remain considerably less than the natural, pre-development peak flows.

Table 22: Otay River SWMM Scenario Comparison

Peak	"Dam-in-Place" HMP Exemption (cfs)	"No Dam" Full HMP (cfs)	Difference (cfs)	% Less Than
2-year	1,409	2,212	804	**36%**
5-year	1,847	2,732	885	**32%**
10-year	2,272	3,487	1,215	**35%**

Table 23: San Diego River SWMM Scenario Comparison

Peak	"Dam-in-Place" HMP Exemption (cfs)	"No Dam" Full HMP (cfs)	Difference (cfs)	% Less Than
2-year	3,243	5,123	1,880	**37%**
5-year	4,013	6,386	2,373	**37%**
10-year	4,584	7,356	2,772	**38%**

Table 24: San Dieguito River SWMM Scenario Comparison

Peak	"Dam-in-Place" HMP Exemption (cfs)	"No Dam" Full HMP (cfs)	Difference (cfs)	% Less Than
2-year	1,182	5,518	4,336	**79%**
5-year	1,642	7,439	5,797	**78%**
10-year	1,833	8,918	7,085	**79%**

Table 25: San Luis Rey River SWMM Scenario Comparison

Peak	"Dam-in-Place" HMP Exemption (cfs)	"No Dam" Full HMP (cfs)	Difference (cfs)	% Less Than
2-year	5,781	7,488	1,707	**23%**
5-year	7,697	10,151	2,454	**24%**
10-year	9,111	11,746	2,635	**22%**

Table 26: Sweetwater River SWMM Scenario Comparison

Peak	"Dam-in-Place" HMP Exemption (cfs)	"No Dam" Full HMP (cfs)	Difference (cfs)	% Less Than
2-year	741	2,039	1,298	**64%**
5-year	1,077	2,718	1,641	**60%**
10-year	1,256	3,265	2,009	**62%**

4. CONCLUSIONS

All five exempt river reaches are subjected to significant upstream impoundment and are rigorously analyzed with two hydrologic methods. The Statistical Peak Flow Analysis found that the major impoundments reduce peak flows anywhere from 29% to 65% of the unimpounded condition. Similarly, the SWMM Peak Flow Analysis found that the major impoundments reduce peak flows approximately 22% to 79%, depending on the reach and peak flow event. The original assumption of significant flow sequestration in the exempt river reaches made by the 2011 HMP is validated by both the Statistical Peak Flow Analysis and the SWMM Peak Flow Analysis in this study.

The benefit of proper hydromodification management BMP implementation is evidenced by comparison between various HMP scenarios. For all watersheds with more than 1,200 acres of Project Lands, HMP flow controls applied to only non-directly discharging developable lands are projected to achieve peak flow reductions of at least 4%. Furthermore, the projected "cost" of allowing the hydromodification exemptions to stand would increase peak flows by an extremely narrow margin in all reaches. It should be noted that the peak flow reduction estimates presented herein are conservative in nature since all non-directly discharging developed lands will be subject to hydromodification management BMPs in the event any re-development within these areas were to occur, further decreasing any peak flow influence from Project Lands. In reality, the percent peak flow reduction is expected to be even greater.

The results from this analysis suggest that the peak flows from areas directly discharging to exempt river reaches (Otay, San Diego, San Dieguito, San Luis Rey, and Sweetwater River) pose no threat to the erosion potential of the exempt river reaches. If these reaches undergo significant changes (i.e. removal of impoundments), it is recommended that a new hydrologic assessment should be made to determine the resulting implications and continual eligibility for exemption. However, under the current conditions defined in this study, it is clearly demonstrated that the existence of upstream impoundment is the principle factor in peak flow alteration—not developed Project Lands. Changes in peak flows from Project Lands are found to be less than significant. Therefore, it is recommended that the 2011 HMP Exemptions be reinstated for all developable lands directly discharging to the exempt river reaches, so long as the project provides properly designed energy dissipation controls at the outfalls. It is also recommended that hydromodification BMPs be required for non-Project Lands, as these areas account for the majority of the developable land within each watershed and will likely produce the greatest influence on peak flows on these rivers in their current impounded state.

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APPENDIX A

Otay Watershed SWMM Parameters

Table A-1: Otay River Project Lands.

HSG	Area (ac)	Width (ft)	Slope	% Imperv	N-IMP	N-Perv	D store-Imperv (in)	D store-Perv (in)	%Zero-Imperv
A	10.44	1	5.94%	80%	0.012	0.15	0.05	0.10	25%
B	0.00								
C	299.03	24	6.60%	61%	0.012	0.15	0.05	0.10	25%
D	1001.41	80	7.73%	60%	0.012	0.15	0.05	0.10	25%

Table A-2: Otay River Non-Exempt Developable Lands.

HSG	Area (ac)	Width (ft)	Slope	% Imperv	N-IMP	N-Perv	D store-Imperv (in)	D store-Perv (in)	%Zero-Imperv
A	4.08	0.3	6.09%	71%	0.012	0.15	0.05	0.10	25%
B	0.00								
C	143.79	12	6.37%	64%	0.012	0.15	0.05	0.10	25%
D	2851.20	228	6.75%	64%	0.012	0.15	0.05	0.10	25%

Table A-3: Otay River Developed & Non-Developable Lands.

HSG	Area (ac)	Width (ft)	Slope	% Imperv	N-IMP	N-Perv	D store-Imperv (in)	D store-Perv (in)	%Zero-Imperv
A	1024.99	82	19.46%	29%	0.012	0.15	0.05	0.10	25%
B	162.69	13	24.86%	13%	0.012	0.15	0.05	0.10	25%
C	2143.79	172	17.87%	32%	0.012	0.15	0.05	0.10	25%
D	20882.06	1673	16.41%	34%	0.012	0.15	0.05	0.10	25%

Table A-4: Otay River Dammed Lands.

HSG	Area (ac)	Width (ft)	Slope	% Imperv	N-IMP	N-Perv	D store-Imperv (in)	D store-Perv (in)	%Zero-Imperv
A	2993.07	240	16.47%	9%	0.012	0.15	0.05	0.10	25%
B	3016.93	242	21.43%	8%	0.012	0.15	0.05	0.10	25%
C	8658.65	694	20.59%	10%	0.012	0.15	0.05	0.10	25%
D	48588.71	3892	22.59%	8%	0.012	0.15	0.05	0.10	25%

San Diego Watershed SWMM Parameters

Table A-5: San Diego River Project Lands.

HSG	Area (ac)	Width (ft)	Slope	% Imperv	N-IMP	N-Perv	D store-Imperv (in)	D store-Perv (in)	%Zero-Imperv
A	340.90	11	7.2%	68%	0.012	0.15	0.05	0.10	25%
B	111.56	4	8.7%	53%	0.012	0.15	0.05	0.10	25%
C	166.56	5	7.4%	63%	0.012	0.15	0.05	0.10	25%
D	675.39	21	8.1%	59%	0.012	0.15	0.05	0.10	25%

Table A-6: San Diego River Non-Exempt Developable Lands.

HSG	Area (ac)	Width (ft)	Slope	% Imperv	N-IMP	N-Perv	D store-Imperv (in)	D store-Perv (in)	%Zero-Imperv
A	892.75	28	13.9%	25%	0.012	0.15	0.05	0.10	25%
B	1180.34	37	12.7%	21%	0.012	0.15	0.05	0.10	25%
C	1095.09	34	12.4%	23%	0.012	0.15	0.05	0.10	25%
D	9021.30	284	12.9%	22%	0.012	0.15	0.05	0.10	25%

Table A-7: San Diego River Developed & Non-Developable Lands.

HSG	Area (ac)	Width (ft)	Slope	% Imperv	N-IMP	N-Perv	D store-Imperv (in)	D store-Perv (in)	%Zero-Imperv
A	9226.19	291	13.2%	35%	0.012	0.15	0.05	0.10	25%
B	6856.56	216	13.3%	38%	0.012	0.15	0.05	0.10	25%
C	9565.50	301	12.8%	39%	0.012	0.15	0.05	0.10	25%
D	67079.47	2113	17.0%	33%	0.012	0.15	0.05	0.10	25%

Table A-8: San Diego River Dammed Lands.

HSG	Area (ac)	Width (ft)	Slope	% Imperv	N-IMP	N-Perv	D store-Imperv (in)	D store-Perv (in)	%Zero-Imperv
A	23826.07	751	16.7%	14%	0.012	0.15	0.05	0.10	25%
B	7266.39	229	16.9%	16%	0.012	0.15	0.05	0.10	25%
C	42292.04	1332	19.5%	13%	0.012	0.15	0.05	0.10	25%
D	94561.45	2979	19.8%	15%	0.012	0.15	0.05	0.10	25%

San Dieguito Watershed SWMM Parameters

Table A-9: San Dieguito River Project Lands.

HSG	Area (ac)	Width (ft)	Slope	% Imperv	N-IMP	N-Perv	D store-Imperv (in)	D store-Perv (in)	%Zero-Imperv
A	304.92	30	16.35%	10%	0.012	0.15	0.05	0.10	25%
B	74.03	7	16.40%	10%	0.012	0.15	0.05	0.10	25%
C	5.41	1	16.50%	10%	0.012	0.15	0.05	0.10	25%
D	533.66	52	16.07%	11%	0.012	0.15	0.05	0.10	25%

Table A-10: San Dieguito River Non-Exempt Developable Lands.

HSG	Area (ac)	Width (ft)	Slope	% Imperv	N-IMP	N-Perv	D store-Imperv (in)	D store-Perv (in)	%Zero-Imperv
A	32.72	3	11.90%	22%	0.012	0.15	0.05	0.10	25%
B	4.85	0.5	3.27%	42%	0.012	0.15	0.05	0.10	25%
C	257.06	25	9.39%	31%	0.012	0.15	0.05	0.10	25%
D	3247.43	315	9.16%	30%	0.012	0.15	0.05	0.10	25%

Table A-11: San Dieguito River Developed & Non-Developable Lands.

HSG	Area (ac)	Width (ft)	Slope	% Imperv	N-IMP	N-Perv	D store-Imperv (in)	D store-Perv (in)	%Zero-Imperv
A	1640.99	159	14.67%	19%	0.012	0.15	0.05	0.10	25%
B	538.60	52	12.43%	21%	0.012	0.15	0.05	0.10	25%
C	1200.70	116	17.09%	25%	0.012	0.15	0.05	0.10	25%
D	16223.04	1571	17.49%	24%	0.012	0.15	0.05	0.10	25%

Table A-12: San Dieguito River Dammed Lands.

HSG	Area (ac)	Width (ft)	Slope	% Imperv	N-IMP	N-Perv	D store-Imperv (in)	D store-Perv (in)	%Zero-Imperv
A	22792.85	2208	16.00%	16%	0.012	0.15	0.05	0.10	25%
B	12916.07	1251	14.50%	16%	0.012	0.15	0.05	0.10	25%
C	70226.09	6802	17.95%	15%	0.012	0.15	0.05	0.10	25%
D	86888.08	8416	26.80%	13%	0.012	0.15	0.05	0.10	25%

San Luis Rey Watershed SWMM Parameters

Table A-13: San Luis Rey River Project Lands.

HSG	Area (ac)	Width (ft)	Slope	% Imperv	N-IMP	N-Perv	D store-Imperv (in)	D store-Perv (in)	%Zero-Imperv
A	882.77	19	13.01%	24%	0.012	0.15	0.05	0.10	25%
B	630.17	14	13.37%	24%	0.012	0.15	0.05	0.10	25%
C	801.92	17	14.55%	20%	0.012	0.15	0.05	0.10	25%
D	1831.81	40	13.74%	20%	0.012	0.15	0.05	0.10	25%

Table A-14: San Luis Rey River Non-Exempt Developable Lands.

HSG	Area (ac)	Width (ft)	Slope	% Imperv	N-IMP	N-Perv	D store-Imperv (in)	D store-Perv (in)	%Zero-Imperv
A	11583.70	251	15.84%	12%	0.012	0.15	0.05	0.10	25%
B	3901.74	84	15.08%	14%	0.012	0.15	0.05	0.10	25%
C	22677.02	491	15.75%	13%	0.012	0.15	0.05	0.10	25%
D	34871.15	755	16.03%	12%	0.012	0.15	0.05	0.10	25%

Table A-15: San Luis Rey River Developed & Non-Developable Lands.

HSG	Area (ac)	Width (ft)	Slope	% Imperv	N-IMP	N-Perv	D store-Imperv (in)	D store-Perv (in)	%Zero-Imperv
A	26968.00	584	15.40%	26%	0.012	0.15	0.05	0.10	25%
B	8036.86	174	15.21%	28%	0.012	0.15	0.05	0.10	25%
C	45902.52	993	15.58%	24%	0.012	0.15	0.05	0.10	25%
D	66408.60	1437	14.87%	29%	0.012	0.15	0.05	0.10	25%

Table A-16: San Luis Rey River Dammed Lands.

HSG	Area (ac)	Width (ft)	Slope	% Imperv	N-IMP	N-Perv	D store-Imperv (in)	D store-Perv (in)	%Zero-Imperv
A	45012.92	974	19.29%	15%	0.012	0.15	0.05	0.10	25%
B	440.52	10	18.73%	12%	0.012	0.15	0.05	0.10	25%
C	20690.04	448	24.13%	8%	0.012	0.15	0.05	0.10	25%
D	65878.92	1426	20.82%	15%	0.012	0.15	0.05	0.10	25%

Sweetwater Watershed SWMM Parameters

Table A-17: Sweetwater Project Lands.

HSG	Area (ac)	Width (ft)	Slope	% Imperv	N-IMP	N-Perv	D store-Imperv (in)	D store-Perv (in)	%Zero-Imperv
A	10.91	0.33	3.6%	48%	0.012	0.15	0.05	0.10	25%
B	0.25	0.01	3.3%	42%	0.012	0.15	0.05	0.10	25%
C	133.69	4	5.8%	45%	0.012	0.15	0.05	0.10	25%
D	109.99	3	5.2%	47%	0.012	0.15	0.05	0.10	25%

Table A-18: Sweetwater Non-Exempt Developable Lands.

HSG	Area (ac)	Width (ft)	Slope	% Imperv	N-IMP	N-Perv	D store-Imperv (in)	D store-Perv (in)	%Zero-Imperv
A	4.60	0.1	3.6%	45%	0.012	0.15	0.05	0.10	25%
B	58.00	2	3.9%	40%	0.012	0.15	0.05	0.10	25%
C	141.55	4	5.6%	37%	0.012	0.15	0.05	0.10	25%
D	735.80	22	4.5%	42%	0.012	0.15	0.05	0.10	25%

Table A-19: Sweetwater Developed & Non-Developable Lands.

HSG	Area (ac)	Width (ft)	Slope	% Imperv	N-IMP	N-Perv	D store-Imperv (in)	D store-Perv (in)	%Zero-Imperv
A	850.76	26	13.6%	29%	0.012	0.15	0.05	0.10	25%
B	748.45	23	10.1%	44%	0.012	0.15	0.05	0.10	25%
C	4827.23	147	13.0%	40%	0.012	0.15	0.05	0.10	25%
D	16715.79	511	12.1%	42%	0.012	0.15	0.05	0.10	25%

Table A-20: Sweetwater Dammed Lands.

HSG	Area (ac)	Width (ft)	Slope	% Imperv	N-IMP	N-Perv	D store-Imperv (in)	D store-Perv (in)	%Zero-Imperv
A	10871.62	332	15.7%	16%	0.012	0.15	0.05	0.10	25%
B	9974.55	305	16.6%	16%	0.012	0.15	0.05	0.10	25%
C	24732.95	756	18.7%	14%	0.012	0.15	0.05	0.10	25%
D	70655.14	2160	21.5%	11%	0.012	0.15	0.05	0.10	25%