NEXT GENERATION STORMWATER MANAGEMENT PLANS: RECENT ADVANCEMENTS UNDER CLEAN WATER ACT REQUIREMENTS IN THE UNITED STATES

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ABSTRACT

The Clean Water Act was enacted in the United States in 1978, representing one of the most significant pieces of environmental protection legislation in the nation's history. Amended several times since, the Act gives the United States Environmental Protection Agency and State regulatory agencies far-reaching authority over facilities that discharge pollutants to waterbodies, including municipal stormwater systems. Within the past five years, particularly in southern California, pollutant discharge permits for municipal stormwater systems have begun to include strict limits for pollutants in discharges to impaired waterbodies. As a "compliance pathway", the stormwater permits in the Los Angeles region have adopted an innovative watershed planning approach based around peer-reviewed, public domain water quality and BMP models. Development of these plans, known as Watershed Management Plans, has provided, for the first time, detailed estimates of the extent and location of stormwater infrastructure required to achieve water quality standards and the associated capital and operation and maintenance costs.

This paper will present an overview and outcome of five (5) major Watershed Management Programs in the Los Angeles area. Each plan covers numerous cities and waterbodies with an "infrastructure recipe" that has reasonable assurance of achieving the water quality standards for those waterbodies. The recipe includes the location and extent of low impact development (LID) projects, green streets, and regional projects that intercept runoff from large drainage areas. The modeling approach is based around two public-domain models – a watershed model known as LSPC and a BMP model known as SUSTAIN – both supported by USEPA. Detailed engineering efforts were used to develop the inputs and assumptions of the BMP model and also to develop cost estimates. By electing to pursue the optional compliance pathway in their Permits, the municipalities have facilitated a robust, integrated approach to stormwater management for their watersheds to address the priority water quality conditions.

KEYWORDS

stormwater, water quality, catchment management plans, modeling

PRESENTER PROFILE

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1 INTRODUCTION

The Clean Water Act legislation in the United States includes requirements for municipalities to control their stormwater discharges. The regulatory requirements for municipal stormwater are administered through Municipal Separate Storm Sewer System (MS4) Permits. One of the most sophisticated MS4 Permits in the U.S. is for the 84-cities in Los Angeles (LA) County, where the stormwater and wastewater systems are separate. Controlling pollutants in stormwater is a major challenge, and the regulated municipalities in LA County have been working towards improving stormwater quality for many years by implementing numerous stormwater capture projects across their watersheds. The Clean Water Act establishes strict compliance timelines to address water quality issues, and the first deadlines impact LA County in 2021. The risk of non-compliance has necessitated a clear "compliance pathway" in the MS4 Permit. In response, in 2012, the Permit was revised to include an innovative approach to Permit compliance through development of "Enhanced Watershed Management Programs" (EWMPs). The vision for development of a each EWMP is to utilize a multiple pollutant approach that maximizes the retention and use of urban runoff as a resource for groundwater recharge and irrigation, while also creating additional benefits for the communities in the watershed. Subsequent to Permit adoption, a total of 11 EWMPs have been developed. Each EWMP presents a toolbox of distributed and regional watershed "control measures" to address the applicable stormwater quality regulations. Distributed control measures include implementation of low impact development (LID) by developers and green street retrofits by municipalites. Regional control measures include infiltration basins that capture stormwater from large drdainage areas (>100 acres). By implementing the control measures as described in the EWMP, the municipalites maintain compliance even if samples from creeks and beaches exceed the applicable water quality criteria.

This paper describes approaches and key outcomes from six of the EWMPs ("example watersheds") in LA County (Figure 1) where modeling was led by the authors, with an emphasis on the methods and key outputs from the modeling used to create the EWMPs. Known as the "reasonable assurance analysis" (RAA), the modeling component of the EWMPs has led to them being next generation stormwater plans, perhaps the most advanced stormwater quality plans developed to date, anywhere.

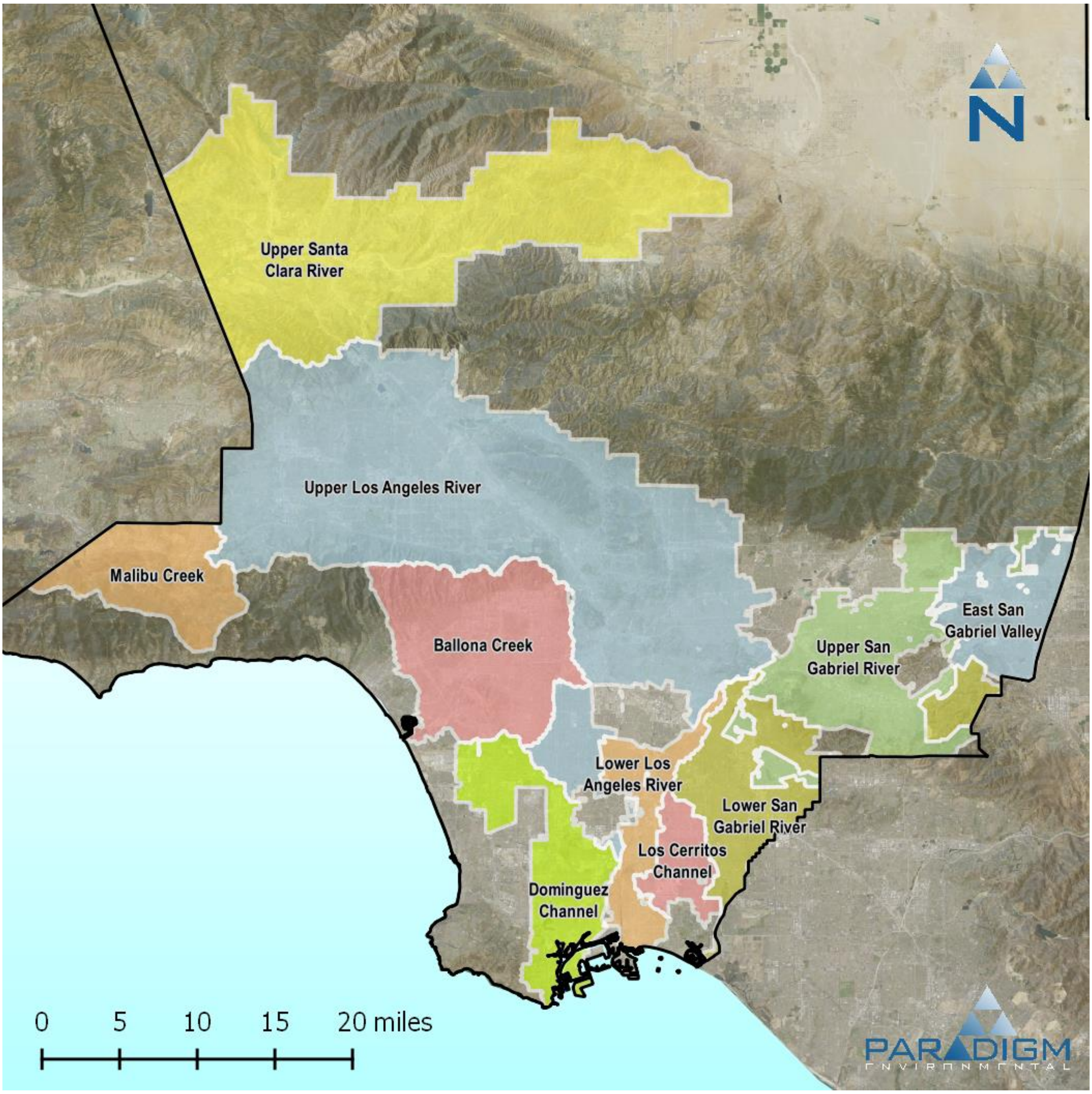

Figure 1: Example Watersheds where Modeling for EWMPs Developed in LA County was led by Authors

2 MODELING APPROACH

A key element of each EWMP is the Reasonable Assurance Analysis (RAA), which was used to quantitatively demonstrate that the overall set of control measures in each EWMP will achieve the applicable water quality standards. While the Permit prescribes the RAA as a "quantitative demonstration that control measures will be effective", the RAA also uses a modeling process to identify and select potential control measures to be implemented by the EWMP. The Watershed Management Modeling System (WMMS) is the basis for the modeling system used to conduct the RAA for the example watersheds. WMMS is specified in the 2012 MS4 Permit as an approved tool to conduct the RAA. The Los Angeles County Flood Control District (LACFCD), through a joint effort with U.S. Environmental Protection Agency (USEPA), developed WMMS specifically to support informed decisions for managing stormwater. The WMMS is a suite of three modeling tools to support BMP planning:

1. A watershed model for prediction of baseline hydrology and pollutant loading (Loading Simulation Program – C+ [LSPC]);

2. A model for simulating the performance of control measures in terms of flow, concentration and load reduction (System for Urban Stormwater Treatment Analysis and Integration [SUSTAIN]); and

3. A tool for running millions of potential scenarios and optimizing/selecting control measures based on cost-effectiveness (also within SUSTAIN).

Key components of the RAA are described in subsections below.

2.1 BASELINE CALIBRATION

Extensive efforts were made to calibrate the LSPC / baseline models across the watersheds, and outputs were generated to demonstrate the calibrated modeling system is able to accurately predict flows and pollutant concentration in each watershed. To encourage accurate representation of existing/baseline conditions, the State of California developed "model calibration criteria" for demonstrating the baseline predictions are accurate and to ensure the "calibrated model properly assesses all the variables and conditions in a watershed system" (Regional Board, 2014). Detailed hydrology and water quality calibrations were performed for the each RAA, as follows (see Figure 6-3 for a map of water quality and hydrology calibration stations):

- **Water quality calibration:** the water quality calibration process for the RAA leveraged two primary monitoring datasets: (1) small-scale, land use-specific water quality monitoring data collected locally and (2) large-scale receiving water monitoring data collected by routine monitoring required by the MS4 Permit.

- **Hydrology calibration:** streamflow gages were used for the hydrology calibration.

Shown in **Table 1** and **Table 2** are example outputs from a baseline calibration to demonstrate model performance. Shown in **Figure 2** are stations used in the example calibration outputs.

Table 1. Summary of Water Quality Calibration Performance by Baseline Model for an Example Watershed

Water Quality Parameter	Sample Count	Modeled vs. Observed Load (% Error)	RAA Guidelines Performance Assessment
Total Suspended Solids	80	9.0%	Very Good
Total Copper	54	-19.7%	Good
Total Zinc	54	-27.2%	Fair
Total Lead	49	-32.1%	Fair
E. coli *	49	-33.4%	Fair
Total Phosphorous	49	-12.9%	Very Good

* *E. coli* was assumed to have a 1:1 translator with fecal coliform.

Table 2. Summary of <u>Hydrology</u> Calibration Performance by Baseline Model for an Example Watershed

Location	Model Period	Hydrology Parameter	Modeled vs. Observed	RAA Guidelines Performance Assessment
Los Angeles River at Wardlow Avenue	10/1/2002 – 9/30/2011	Total Annual Volume	20.1%	Fair
		Highest 10% of Flows	6.0%	Very Good
		Annual Storm Volume	19.6%	Fair
Los Angeles River at Tujunga Wash	10/1/2002 – 9/30/2011	Total Annual Volume	5.2%	Very Good
		Highest 10% of Flows	-22.1%	Fair
		Annual Storm Volume	-2.8%	Very Good
Los Angeles River at Arroyo Seco	10/1/2002 – 9/30/2011	Total Annual Volume	17.9	Fair
		Highest 10% of Flows	-3.8%	Very Good
Santa Anita Wash at Longdem Avenue	10/1/2002 – 9/30/2011	Total Annual Volume	-7.3%	Very Good
		Highest 10% of Flows	-22.9%	Fair
		Annual Storm Volume	-1.4%	Very Good
Arcadia Wash Below Grand Avenue	10/1/2002 – 9/30/2011	Total Annual Volume	3.5%	Very Good
		Annual Storm Volume	-8.5%	Very Good
Eaton Wash Below Grand Avenue	10/1/2002 – 9/30/2011	Total Annual Volume	7.9%	Very Good
		Annual Storm Volume	7.5%	Very Good
Verdugo Wash at Estelle Avenue	10/1/2002 – 9/30/2011	Total Annual Volume	-5.8%	Very Good
		Highest 10% of Flows	-9.0%	Very Good
Burbank Western Channel at Riverside Drive	10/1/2002 – 9/30/2011	Total Annual Volume	-16.6%	Fair
		Annual Storm Volume	0.4%	Very Good
Compton Creek Near Spring Street	10/1/2002 – 9/30/2011	Total Annual Volume	0.8%	Very Good
		Highest 10% of Flows	-14.2%	Good
		Annual Storm Volume	-4.8%	Very Good

Note: for each station, at least one of the following calibration metrics achieved an assessment of “Fair” or better: Total Annual Volume, Highest 10% of Flows or Annual Storm Volume.

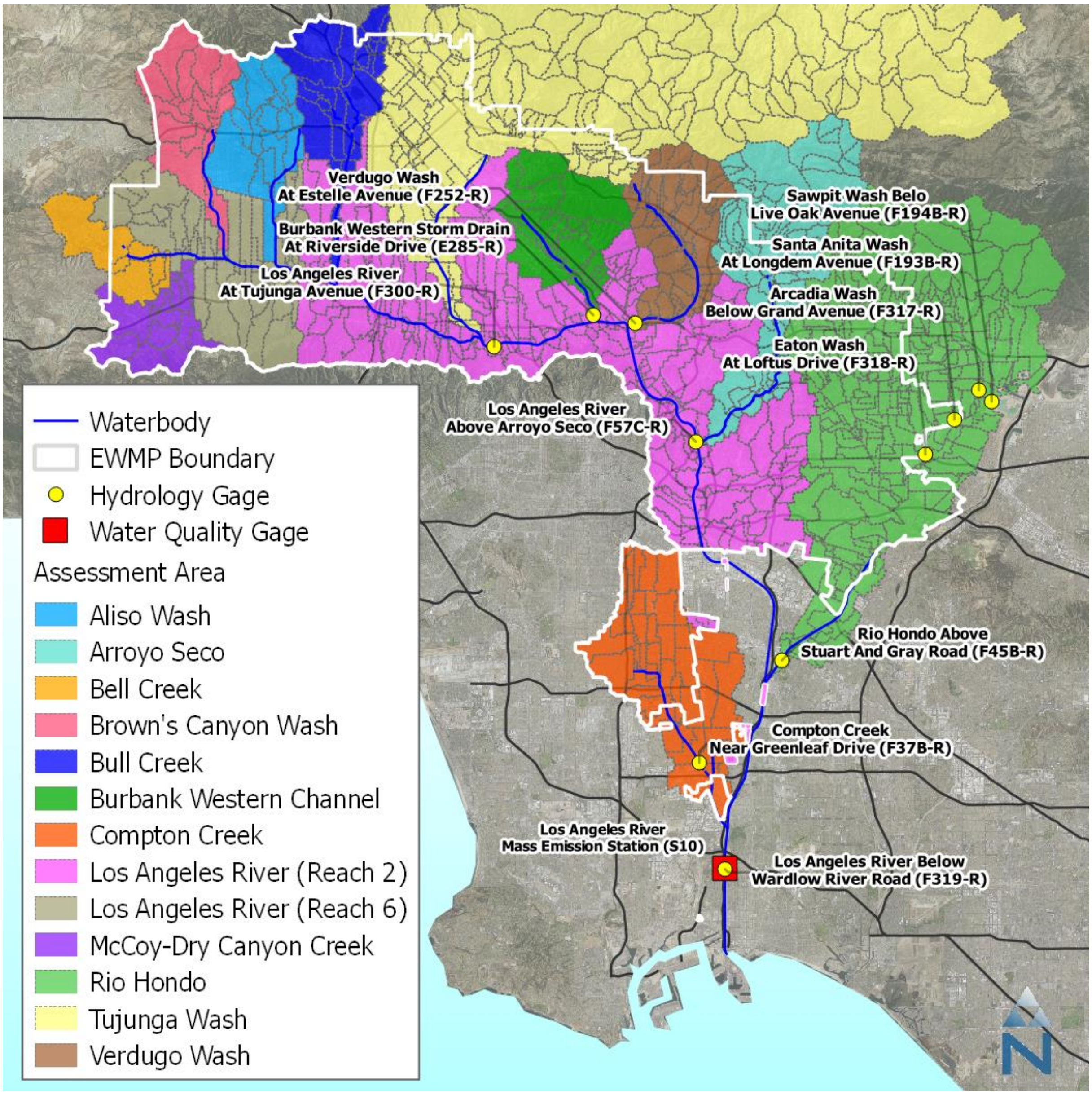

Figure 2. Hydrology and Water Quality Calibration Stations in an Example Watershed

2.2 IDENTIFICATION OF LIMITING POLLUTANTS

The RAA for each watershed was developed based on complying with the applicable criteria for "limiting pollutants" during 90th percentile (critical) storm conditions. As shown in Figure 3, the RAA sequentially addresses the limiting pollutants in stormwater (RAA for rainfall runoff) and non-stormwater (RAA for dry weather runoff [irrigation overspray, car washing, groundwater baseflows, etc.]) based on the limiting pollutant analysis (recall that wastewater is managed in a separate system in LA County). Limiting pollutants are the pollutants that drive BMP capacity (i.e., control measures that address the limiting pollutant will also address other pollutants). The limiting pollutants for most of the example watersheds were as follows:

- **Wet weather** – zinc and *E. coli*: according to the modeling analysis and review of monitoring data, control of zinc and *E. coli* required the largest amount of BMP storage, and thus control of zinc and E. coli has assurance of addressing the water quality standards for other pollutants. Each RAA for the example watersheds first identified the control measures to attain zinc standards (during the zinc critical condition) and then identifies additional capacity, if any, needed to achieve E.coli limits.

- **Dry weather** – *E. coli*: among all the pollutants monitored during dry weather at mass emission stations in LA County, *E. coli* most frequently exceeds receiving water limitation (RWLs). For example, during monitoring "snapshots" of over 100 outfalls along the LA River, over 85 percent of samples exceeded limits for *E. coli*. Among the dry weather WQP pollutants, achievement of dry weather RWLs for *E. coli* will be the most challenging.

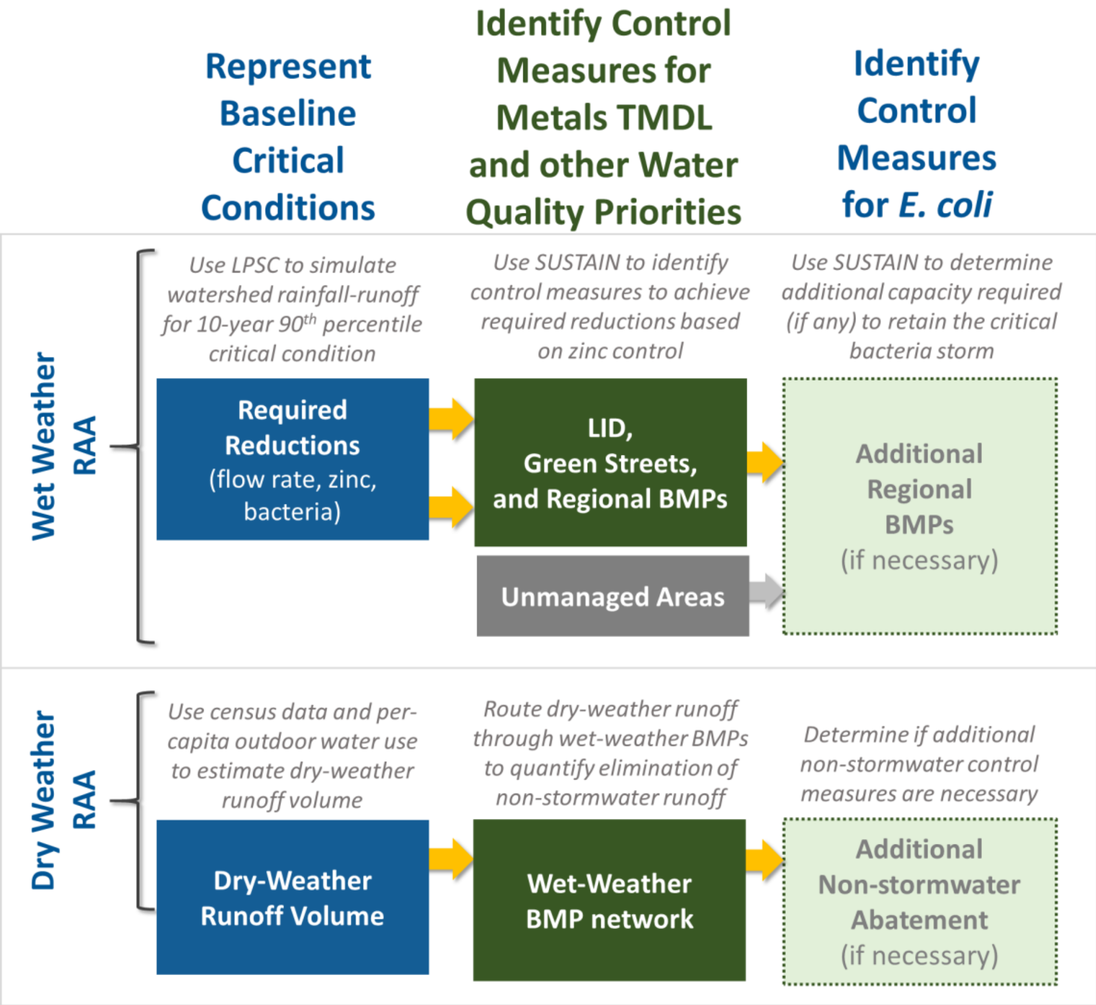

Figure 3. RAA Process for Establishing Critical Conditions and Achieving Water Quality Standards by Addressing Limiting Pollutants

2.3 SIMULATION OF EFFECTIVENESS OF STORMWATER CONTROL MEASURES

Once the model is set up to accurately simulate baseline hydrology and water quality conditions and the required reductions have been estimated, the next stage of the RAA determines the optimal combination of BMP types to achieve applicable water quality standards. This step requires a robust set of assumptions to define the watershed-wide extent and configuration of each of the types of control measures that make up the each EWMP. The representation of control measures in the model is an important element of the RAA, as it provides the link between future watershed activities, model-predicted water quality improvement, and, ultimately, Clean Water Act compliance. Since the BMP modeling parameters will greatly influence the outcome of the RAA, it is imperative that the suite of BMP assumptions are based on the best available data and represent the opportunity and limitations that will be faced by designers, contractors, and maintenance crews in the field as these BMPs are implemented over time.

The three main categories of control measures (also referred to as best management practices [BMPs]) include low-impact development, green streets, and regional projects, as defined below:

- **Low-Impact Development:** distributed structural practices that capture, infiltrate, and/or treat runoff at the parcel, normally less than 10 tributary acres. Common LID practices include bioretention, permeable pavement, and other infiltration BMPs that prevent runoff from leaving a parcel. Since the vast majority (nearly 70 percent) of runoff from the developed portion of the watershed is generated from impervious areas on parcels, LID is a natural choice as a key EWMP strategy to treat runoff from parcel-based impervious areas. LID can be viewed as the "first line of defense" due to the fact that the water is treated on-site before it runs off from the parcel and travels downstream.

- **Green Streets:** distributed structural practices that are typically implemented as linear bioretention/ biofiltration installed parallel to roadways. These systems receive runoff from the gutter via curb cuts or curb extensions (sometimes called bump outs) and infiltrate it through native or engineered soil media. Permeable pavement can also be implemented in tandem or as a standalone practice, such as in parking lanes of roads. Green streets have been demonstrated to provide "complete streets" benefits in addition to stormwater management, including pedestrian safety and traffic calming, street tree canopy and heat island effect mitigation, increased property values, and even reduced crime rates.

- **Regional projects:** Regional projects are centralized facilities located near the downstream ends of large drainage areas (typically treating 10s to 100s of acres). Regional projects receive large volumes of runoff from extensive upstream areas and can provide a cost-effective mechanism for infiltration and pollutant reduction. Runoff is typically diverted to regional projects after it has already entered storm drains. Regional BMPs are key to recharging groundwater supplies and offsetting demand for potable water. Routing offsite runoff to public parcels (versus treating surface runoff near its source, as with green streets and LID) often allows regional BMPs to be placed in cost-effective locations. The EWMP for largest example watershed includes over 120 regional BMPs, including multi-benefit regional projects that retain the storm water volume from the 85th percentile, 24-hour storm.

The RAA was used to select the BMPs in the EWMP Implementation Strategy based on three primary elements:

- **Opportunity** – Where can these BMPs be located and how many can be accommodated?

- **System Configuration** – How is the runoff routed to and through the BMP and what is the maximum BMP size?

- **Cost Functions** – What is the relationship between BMP volume/footprint/design elements and costs?

Each RAA considered millions of BMP scenarios and the EWMP Implementation Strategy was selected based on the most cost-effective scenarios, while incorporating the input from the EWMP Group related to the needs and opportunities within the communities. Figure 4 shows an optimization output for a single subwatershed – each dot is a potential implementation plan for an entire watershed. A similar curve was generated for each of the thousands of subwatersheds in the example watersheds (each example watershed is comprised of between approximately 100 and 1000 subwatersheds). In the end, each EWMP is based on an optimization routine that searches through those curves and selects the combination of solutions in each assessment area / watershed that provides the greatest cost-benefit for the required pollutant reduction.

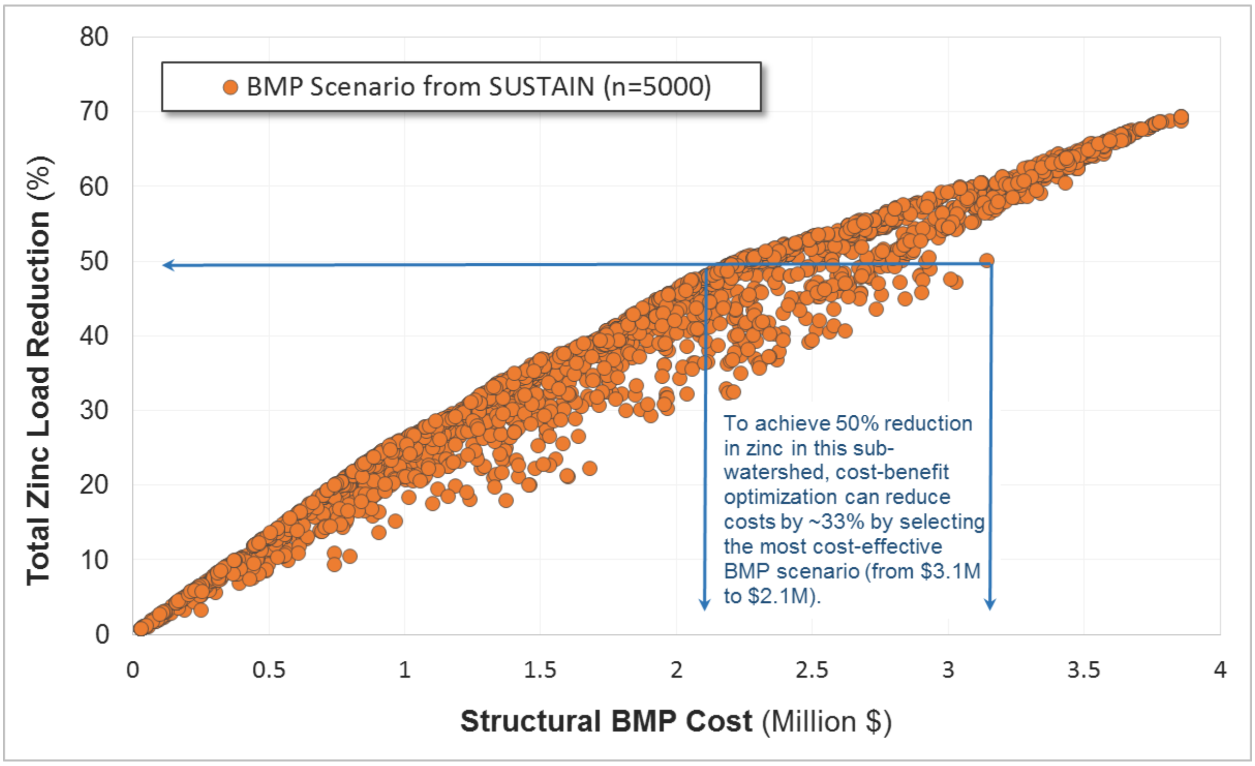

Figure 4. Set of Potential Solutions that were used for Cost-Benefit Optimization of an Example Watershed

3 SELECTED EWMP STRATEGIES BASED ON MODELING

The EWMP is the "recipe for compliance" of each municipality to achieve water quality standards and comply with the provisions of the MS4 Permit. Through the RAA, a series of quantitative analyses were used to identify the capacities of LID, green streets and regional BMPs that comprise the EWMP and assure those control measures will achieve water quality standards. Each EWMP includes individual recipes for each of the municipalities (the number of municipalities in each example watershed range from two to 18) and each waterbody/ tributary. Implementation of the EWMP will provide a BMP-based compliance pathway for each municipality under the MS4 Permit. Each EWMP will guide stormwater management in its watershed for the coming decades, and the LID, green streets and regional BMPs to be implemented by the EWMP have the potential to transform communities.

The EWMP Implementation Strategy is expressed in terms of [1] the volumes[1] of stormwater and non-stormwater to be managed by each jurisdiction to address Water Quality Priorities and [2] the control measures that will be implemented to achieve those volume reductions. The two primary elements of the Pollutant Reduction are as follows:

- **Compliance Targets**: for MS4 compliance determination purposes, the primary metric for EWMP implementation is the volume of stormwater managed by implemented control measures. The stormwater volume to be managed[2] is considered the BMP performance goal for the EWMP. To support future compliance determination and adaptive management, the volume of stormwater to be managed is reported along with the capacities of control measures to be implemented by each jurisdiction in the EWMP Implementation Strategy.
- **EWMP Implementation Strategy**: the network of LID, green streets and regional BMPs that has reasonable assurance of achieving the Compliance Targets is referred to as the EWMP Implementation Strategy. The identified BMPs (and BMP preferences) will likely evolve over the course of adaptive management in response to "lessons learned." As such, it is anticipated the BMP capacities within the various subcategories will be reported to the Regional Board but *not* tracked explicitly by the Regional Board for compliance determination. As BMPs are substituted over the course of EWMP implementation (e.g., replace green street capacity in a subwatershed with additional regional BMP capacity), the Group will show equivalency for achieving the corresponding Compliance Target.

Example core model outputs that comprise the EWMP are presented as follows:

- **Summary of total capacity of control measures for each jurisdiction across the entire EWMP area:** bar graphs are used to summarize the control measure capacities that comprise the EWMP Implementation Strategy. BMP capacity is the amount of storage or void space inside the control measures. The example shown in Figure 5 includes the various subcategories of LID, green streets and regional BMPs for each jurisdiction across the entire EWMP area by the compliance deadline.
- **Detailed recipe for compliance including volumes of stormwater to be managed and control measure capacities:** the EWMP is detailed for each subwatershed in the EWMP area (generally 1 to 2 square mile drainages). Shown in Figure 6 is an example map of the "density" of control measure capacities to achieve water quality standards. The same results are shown as detailed tables in the appendices to the EWMPs. Figure 7 shows the relative capacities of control measures need to achieve zinc and E. coli criteria.

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[1] Volume is used rather than pollutant loading because volume reduction is more readily tracked and reported by MS4 agencies. The volume reductions are actually a *water quality* improvement target based on required pollutant reductions.

[2] The reported volume is determined by tracking the amount of water that is be retained (infiltrated) by BMPs over the course of a 24-hour period under the critical 90th percentile storm condition. Additional volume would be *treated* by these BMPs, but that additional treatment is *implici*t to the reported Compliance Targets. For compliance purposes the volume in the Compliance Target can either be retained and/or treated. Both would result in compliance.

[2] While the EWMP reports the *total* BMP capacity to be implemented, that capacity is not a compliance target because some BMP capacities are sized to reflect a BMP program rather than sized to achieve the required reduction. For example, the BMPs implemented by the LID ordinance and the residential LID program were sized to retain the 85th percentile, 24-hour storm but that volume may be larger than is needed to achieve zinc RWLs. If those BMPs were replaced by a different type of BMP (e.g., regional BMP), the total BMP capacity may be smaller but just as effective.

- **Detailed scheduling for each jurisdiction including volumes of stormwater to be managed and control measure capacities:** an example of the LID, green streets and regional BMP capacities that will be implemented over time to achieve compliance deadlines are shown in Figure 8.

Each municipality receives a unique recipe for compliance and thus, while collaboration is highly encouraged, compliance is determined on a city-by-city basis.

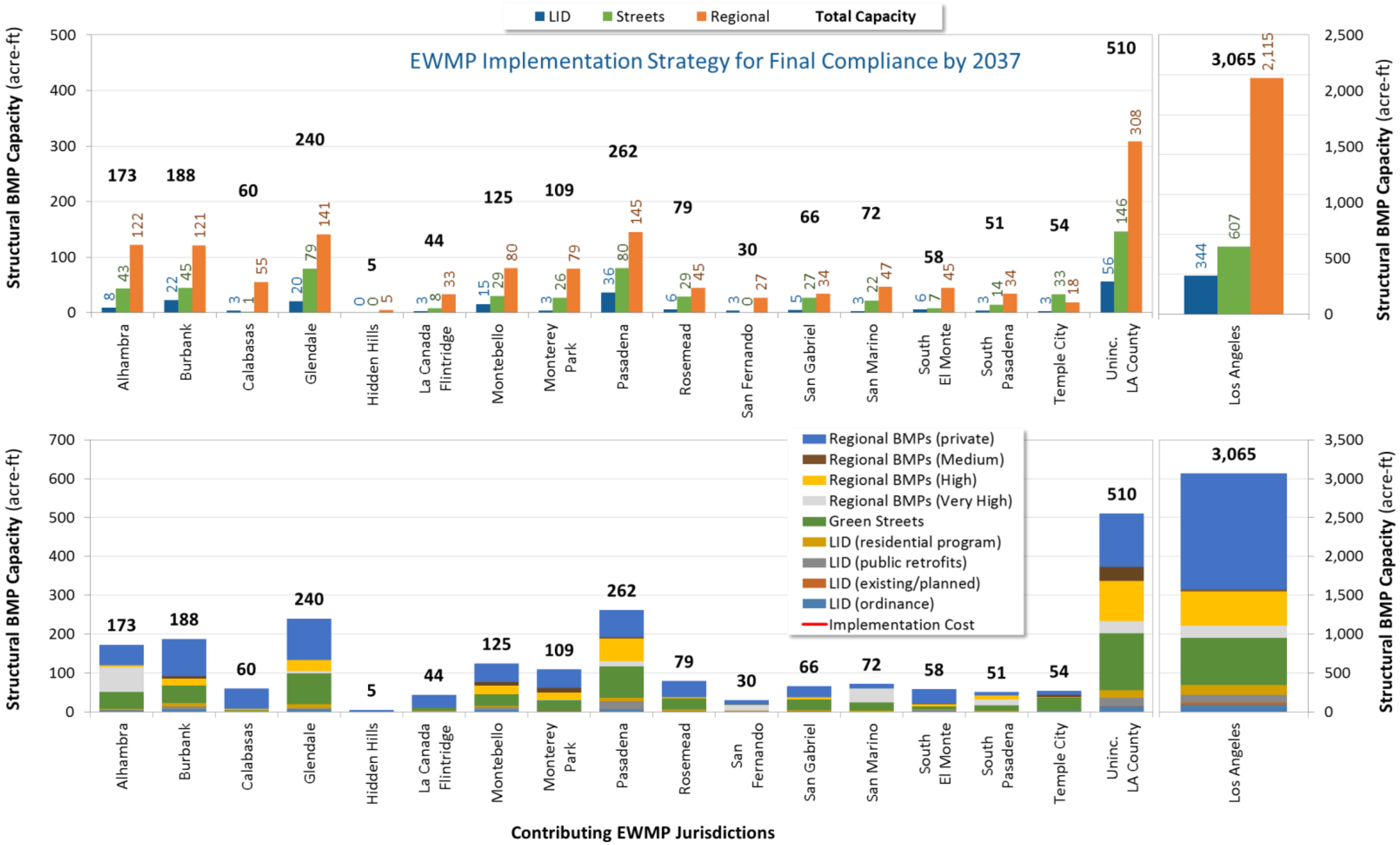

Figure 5. Example Core Modeling Output that Comprises each EWMP

The two panels show the total structural BMP capacity required for each municipality to address water quality standards. The top panel groups the BMP types into LID, green streets and regional BMPs, while the bottom panel provides more resolution for the BMP sub-categories.

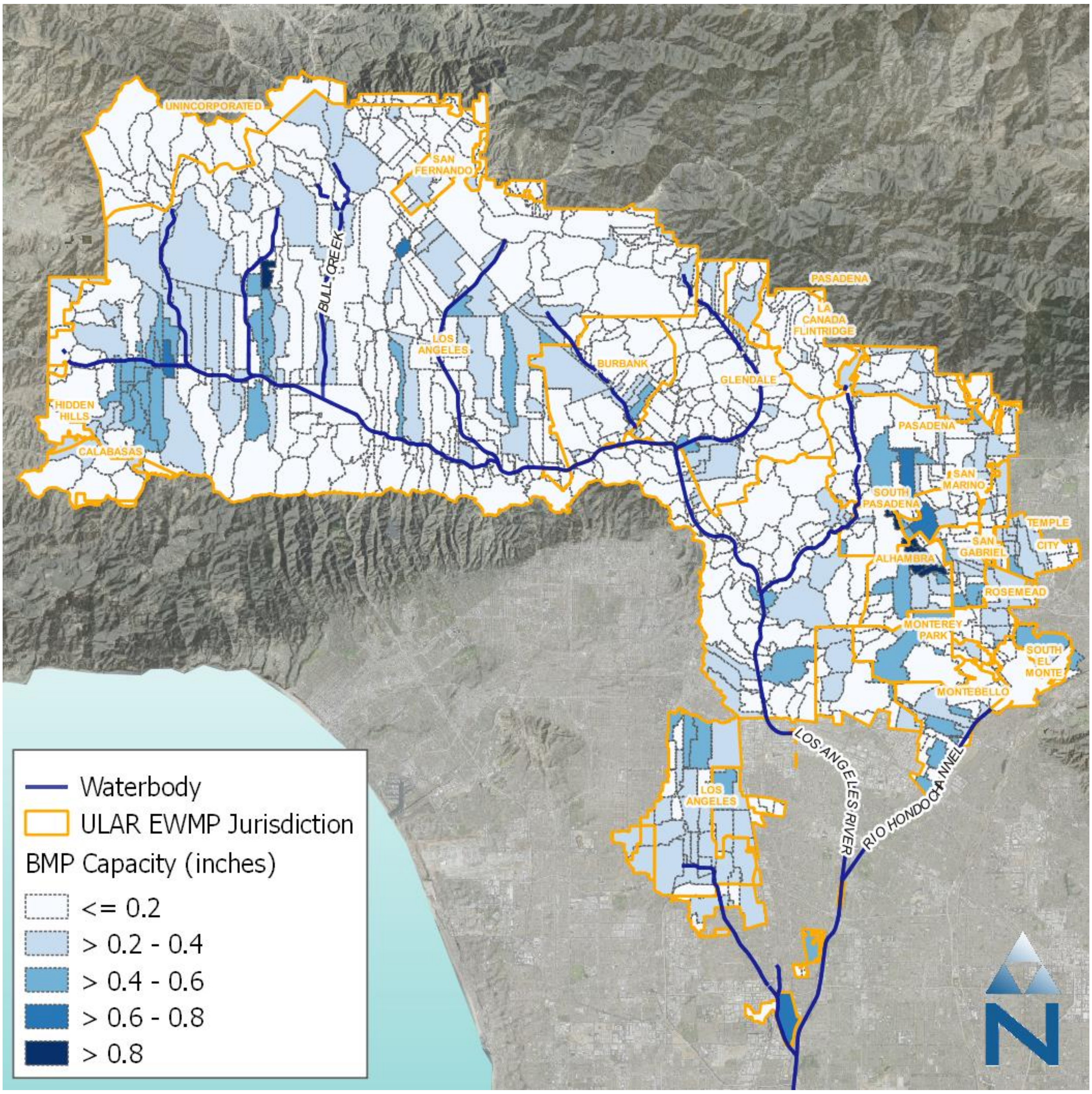

Figure 6. Example BMP Density Map Generated for each EWMP

This map presents an EWMP as control measure "density" by subwatershed. The BMP density is higher in some areas [dark blue] because either [1] relatively high pollutant load reductions are required or [2] BMPs in those areas were relatively cost-effective (e.g., due to high soil infiltration rates). The BMP capacities are normalized by area (i.e., the BMP capacity for each subwatershed [in units of acre-feet] was divided by the subwatershed area [in units of acres] to express the BMP capacity in units of depth [feet or inches]). Note that while all jurisdictions in an assessment area/watershed are held to an equivalent % reduction, subwatersheds within a jurisdiction may have variable reductions based on cost-benefit optimization (another reason why some subwatersheds within a jurisdiction are dark blue while others are light blue).

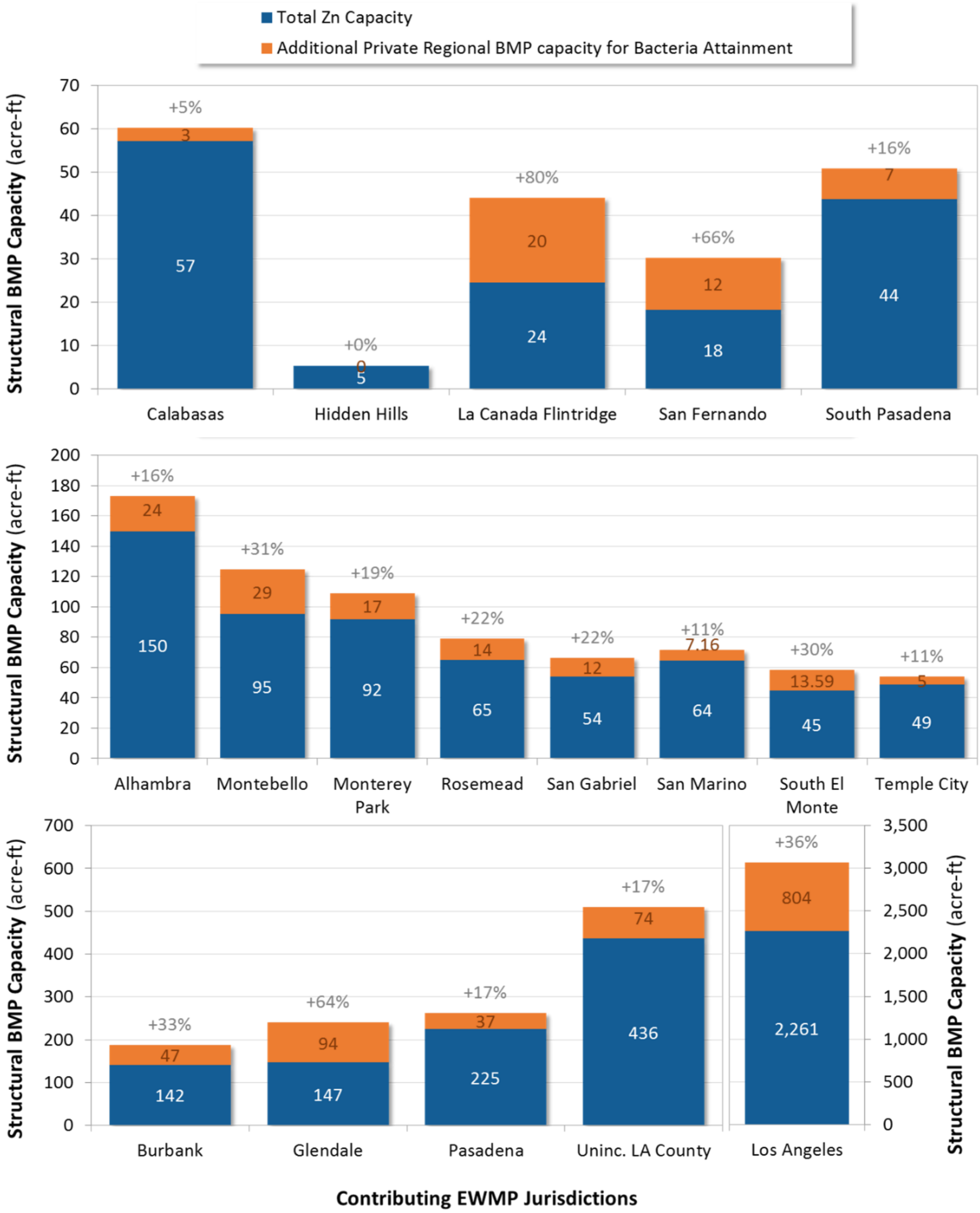

Figure 7. Relative Control Measure Capacities to Address Zinc and E. coli

The bars represent the total control measure capacity in each municipality, and the percentages at the top of each bar report the percent increase in BMP capacity required by the RAA to control *E. coli* beyond the control measures needed for zinc. Note that the y-axis scale differ in each of the three panels.

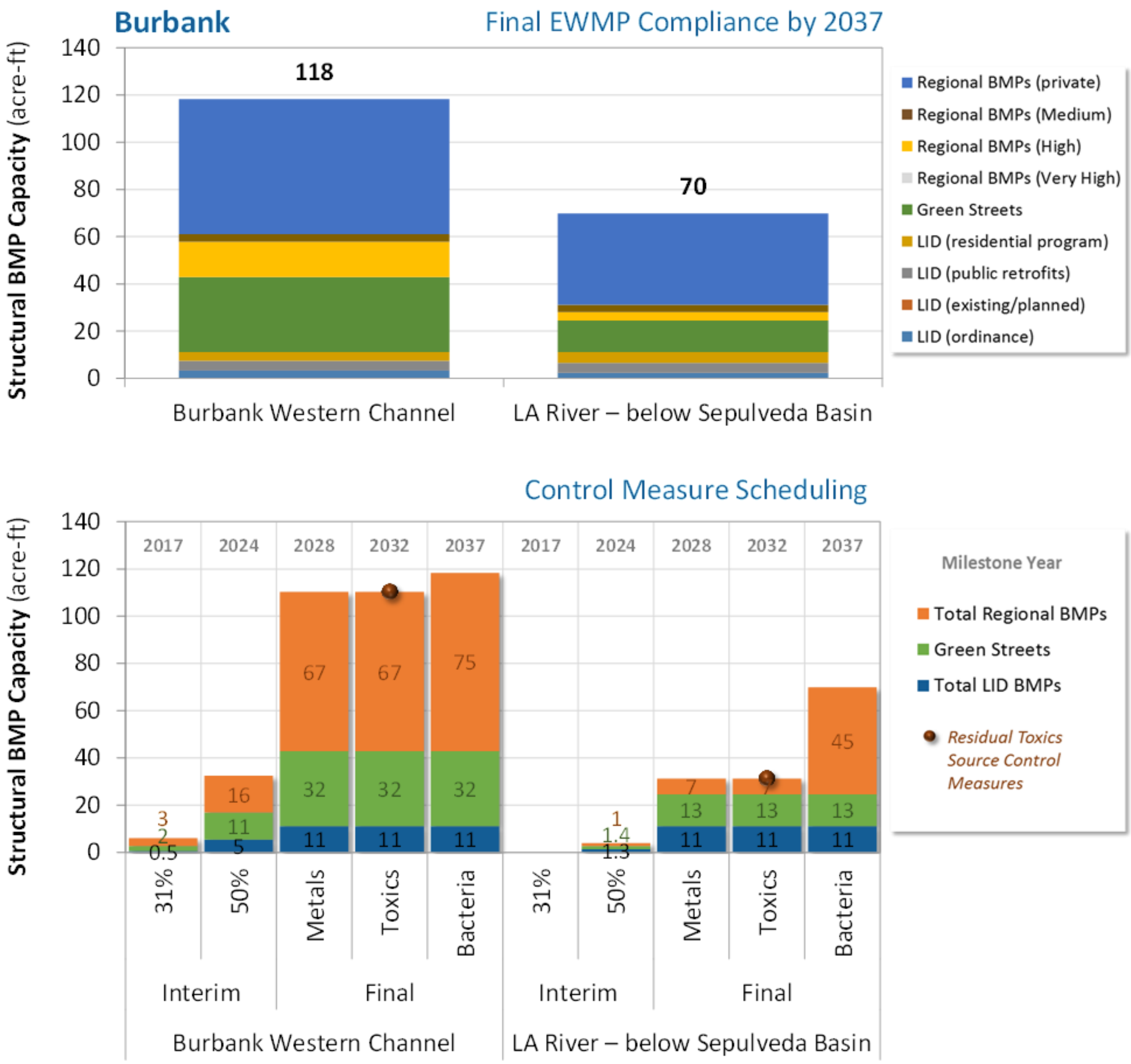

Figure 8. Scheduling of Control Measures for an Example Municipality

The bars represent the LID, green street and regional BMP capacity to achieve each EWMP deadline. The top panel represents the BMPs to achieve "final" compliance in 2037; the bottom panel schedules them through 2037.

4 CONCLUSIONS

Each EWMP will guide stormwater management in its watershed for the coming decades, and the LID, green streets and regional BMPs to be implemented by the EWMP have the potential to transform communities. The intercepted stormwater will greatly increase water supplies, by infiltrating water volumes that equate to the amount consumed annually by millions of people. Implementation of such a large network of control measures will represent a sea change in how stormwater is managed in LA County, but will also require orders of magnitude increases in stormwater funding. Public acceptance will be a key element for achieving the required funding levels. With the advanced modeling / RAAs used to develop the EWMPs, municipalities can assure the public that the money will be used as cost-effectively as possible and that the plans will ultimately be successful in achieving water quality standards.