# *EAST CONTRA COSTA METHYLMERCURY CONTROL MEASURE PLAN AND REASONABLE ASSURANCE ANALYSIS*

***Submitted in Compliance with Provision C.19.d.ii(1)***

***Municipal Regional Stormwater Permit***
***NPDES Permit No. CAS612008***
***Order No. R2-2022-0018***

## *Final Draft October 2022*

***The Contra Costa Clean Water Program – A Municipal Stormwater Program consisting of Contra Costa County, its 19 Incorporated Cities/Towns, and the Contra Costa County Flood & Water Conservation District***

This report is submitted by the agencies of the

CONTRA COSTA CLEAN WATER PROGRAM

**Program Participants:**

- Cities of Antioch, Brentwood, Clayton, Concord, Danville (Town), El Cerrito, Hercules, Lafayette, Martinez, Moraga (Town), Oakley, Orinda, Pinole, Pittsburg, Pleasant Hill, Richmond, San Pablo, San Ramon, and Walnut Creek
- Contra Costa County
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# LIST OF ACRONYMS

| | |
|---|---|
| BASMAA | Bay Area Stormwater Management Agencies Association |
| BMP | Best Management Practices |
| CCCWP | Contra Costa Clean Water Program |
| DMCP | Delta Mercury Control Program |
| g | gram |
| GSI | Green Stormwater Infrastructure |
| GIS | Geographic Information System |
| mg | milligram |
| MRP | Municipal Regional Permit |
| MS4 | Municipal Separate Storm Sewer System |
| MTC | Metropolitan Transportation Commission |
| ng | nanogram |
| NPDES | National Pollutant Discharge Elimination System |
| O&M | Operations and Maintenance |
| RAA | Reasonable Assurance Analysis |
| ROW | Right-of-Way |
| RWSM | Regional Watershed Spreadsheet Model |
| SFBRWQCB | San Francisco Bay Regional Water Quality Control Board |
| SFEI | San Francisco Estuary Institute |
| TMDL | Total Maximum Daily Load |
| WLA | Wasteload Allocation |

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## Executive Summary

This report presents the implementation plan for the Contra Costa County Clean Water Program (CCCWP or Program) Permittees within Region 5[1] to meet the methylmercury load reductions required by the Delta mercury Total Maximum Daily Load (TMDL). The plan is required by the San Francisco Bay Regional Water Quality Control Board (Water Board) through the Municipal Regional Stormwater NPDES Permit (MRP) for urban stormwater. This report fulfills the requirements of MRP Provision C.19.d.ii.(1) for providing a methylmercury control measure implementation plan and corresponding reasonable assurance analysis (RAA).

CCCWP Permittees recommend a programmatic approach for reducing mercury loads from urban stormwater discharges, whereby compliance is assessed based on implementing and documenting a regionally agreed-on program of control measures, which include:

- Green stormwater infrastructure (GSI),
- Full trash capture devices, and
- Enhanced operation and maintenance, such as enhanced inlet cleaning.

As part of implementing MRP Provisions C.11 and C.19.d, CCCWP Permittees have worked diligently with peer stormwater programs through the Bay Area Municipal Stormwater Collaborative (BAMSC)[2] to define the actions and quantifiable benefits of mercury control measures. The programmatic approach includes feasible implementation actions that will move the Permittees forward towards the TMDL load reduction goals. Commitment to the programmatic actions provide Permittees with planning certainty needed for compliance while addressing the public interest in measurable progress towards achieving water quality standards.

[1] Permittees within Region 5 include the cities of Antioch, Brentwood, Oakley, and the eastern portions of unincorporated Contra Costa County and the Contra Costa County Flood Control & Water Conservation District.

[2] In April 2021, the Bay Area Stormwater Municipal Agencies Association (BASMAA) dissolved. The coordination efforts of BASMAA have been replaced by the Bay Area Municipal Stormwater Collaborative (BAMSC), which is a less formal organization without cost sharing abilities. BAMSC continues to serve as a consortium of municipal stormwater programs, representing 79 agencies (cities, towns, counties, and districts), focusing on regional challenges and opportunities to improve the quality of stormwater that flows to our local creeks, San Francisco Bay and Delta, and the Ocean.

This TMDL Control Measure Plan presents an estimate of the load reductions resulting from mercury control programs, along with an objective assessment of how inherent uncertainties affect forecast outcomes. It is important to emphasize that the projected pace of control measure implementation and the resultant predicted load reductions are based on current and projected business practices, which are subject to change. Economic or socio-economic impacts and political shifts may affect future implementation scenarios, causing increases or decreases in the amount of private investment and public funds available for development and control measure implementation, and/or changes in the ability to provide maintenance services that are needed for implementation.

**Mercury Control Measures**

Control measures discussed in Section 2 of this report focus on mercury and methylmercury. Accounting methodologies are summarized in the RAA Report (Appendix A).

The RAA analysis shows that based on current assumptions, the load reduction needed to achieve the methylmercury goals assigned to East Contra Costa County permittees in Marsh Creek cannot be achieved with reasonable, foreseeable control measures in this century. The Centra Delta and West Delta subareas are currently achieving the TMDL wasteload allocations. When East Contra Costa County is considered as a whole, the combined subareas achieve the combined TMDL wasteload allocations in 2030.

However, Provision C.19.d states that this report should describe scenarios showing a path to compliance by January 1, 2030, or any revised final compliance date adopted by the Central Valley Water Board as part of the Delta Mercury Control Program review. The analysis in Appendix A shows that it is technically and economically infeasible to achieve the TMDL wasteload allocation by 2030 in the March Creek subarea.

The discussion by control measure below includes the elements of each control measure, ramifications for Permittees, and an assessment of the level of effort or change of assumptions that would result in compliance by 2030.

Source Control Measures

Source control measures include mercury load avoidance through recycling waste materials and enhanced operations and maintenance (O&M) practices. Enhanced O&M generally means increasing the frequency of sediment removal from storm drain catch basin inserts or increasing street sweeping frequencies. Permittees began enhanced O&M measures in the MRP 2.0 permit term. Permittees will continue to perform enhanced O&M at current levels and, if financially feasible, will consider expanding enhanced O&M to control sediment and prevent methylating conditions in the MS4.

Green Stormwater Infrastructure

As required by MRP Provision C.3, Permittees will continue to implement their Green Infrastructure plans. This will encumber municipal time and attention at current levels, or potentially increased levels, depending on new development and redevelopment activity. Permittees will continue tracking GSI implementation in an ArcGIS online (AGOL) database (or a suitable replacement system). The Program will continue to gather data to assess mercury loads reduced. The rate of implementing this control measure is constrained by the rate of private new development, private redevelopment, and municipal capital project implementation.

Green stormwater infrastructure (GSI) is designed to improve water quality through particle settling and filtration, thereby reducing the potential for mercury methylation as well as lowering the overall load through runoff volume reduction. GSI will continue to be designed to be well draining to avoid suboxic or anoxic conditions that promote methylation. The standard bioretention design criteria in the CCCWP Stormwater C.3 Guidebook should achieve this goal.

Full Trash Capture Treatment Control Measures

Permittees will continue tracking full trash capture devices in AGOL. The Program will continue to gather AGOL data to assess mercury loads reduced. The opportunities to accelerate this or expand the benefit are limited, as there are a finite number of full trash capture opportunities available to Permittees due to funding or existing drainage infrastructure constraints.

**Schedule for Implementation**

The East Contra Costa County Permittees will continue to implement the control measures in perpetuity. For example, GSI provides multiple benefits, addresses other urban pollutants, and is an MRP requirement, so would continue to be implemented as long as that requirement is in place. The source control measure Mercury Load Avoidance and Reduction, which began during MRP 1.0, is assumed to continue indefinitely.

**Evaluation of Costs**

The estimate of public agency costs for implementing planned GSI control measures ranges from $10,000,000 to $55,000,000 within East Contra Costa County. The estimated cost for implementing source control programs is negligible in comparison to the estimated costs for implementing GSI measures. An analysis of cost effectiveness demonstrates that source control measures are much more cost efficient than treatment control measures at reducing loads of mercury in urban runoff.

Public project implementation will depend on funding availability. Funding for implementation of projects included in the Permittees' Green Infrastructure Plans would be obtained by the municipal agency, partnerships of agencies, or other stakeholder project sponsors working to implement the identified projects. Economic or socio-economic impacts and political shifts may affect future implementation scenarios, causing increases or decreases in the amount of private investment and public funds available for development and control measure implementation, and/or changes in the ability to provide services that are needed for implementation.

**Uncertainty Analysis**

There are two types of uncertainty in this analysis: modeling uncertainty and planning uncertainty. The RAA Report (provided in Appendix A) discusses modeling uncertainty, which is caused by the scientific soundness of the model, and the reliability and applicability of the data used in the model. Modeling uncertainties were addressed through a peer review that is documented along with the RAA modeling approach in Appendix C. Modeling uncertainty is not as much of a limiting factor on the ability to forecast change as compared to planning uncertainties that result from input assumptions.

The estimate of achieving the methylmercury TMDL wasteload allocation in the Marsh Creek subarea is based on several assumptions that introduce planning uncertainties. The RAA result is reasonably certain (i.e., not likely to change as a result of changed assumptions). Examples of planning uncertainties leading to uncertainty in the RAA results include:

- Climate change, long-term meteorological patterns, and large seismic events could each significantly affect watershed transport of polluted sediments.
- Large scale economic or socio-economic and political shifts, which may be either planned (e.g., the Federal Bipartisan Infrastructure Law grants that create GSI funding opportunities) or unplanned, (e.g., the 2020 COVID-19 pandemic), can affect the rate of GSI implementation.

# 1. INTRODUCTION

## 1.1 Purpose

This *Methylmercury TMDL Control Measure Plan and Reasonable Assurance Analysis* report was prepared by the Contra Costa Clean Water Program (CCCWP) as required by the Municipal Regional Permit (MRP) for urban stormwater issued by the San Francisco Bay Regional Water Quality Control Board (SFBRWQCB; Order No. R2-2022-0018). This report fulfills the requirements of MRP Provision C.19.d.ii.(1) for providing a methylmercury control measure implementation plan and corresponding reasonable assurance analysis (RAA).

The following MRP reporting requirements are addressed within this report:

> The Plan shall include a corresponding RAA for total mercury and methylmercury demonstrating that sufficient control measures will be implemented during this Permit term to attain the methylmercury Delta Mercury Control Plan (DMCP) wasteload allocations by January 1, 2030, or any revised final compliance date adopted by the Central Valley Regional Water Quality Control Board (Central Valley Water Board) as part of the DMCP review. The Control Measure Plan, including RAA, shall comply with the following:

- The Plan shall identify all technically and economically feasible mercury and methylmercury municipal separate storm sewer system (MS4) control measures to be implemented (including green stormwater infrastructure (GSI) projects).
- The Plan shall include a schedule according to which these technically and economically feasible control measures will be fully implemented.
- The Plan shall provide an evaluation and quantification of mercury and methylmercury load reductions of such measures as well as an evaluation of costs, control measure efficiency, and significant environmental impacts resulting from their implementation.
- The RAA for total mercury must be evaluated using the California Toxics Rule for mercury (0.05 µg/L).
- The RAA for methylmercury must be evaluated using the methylmercury load allocations specific to each Delta subarea within Contra Costa County subject to the DMCP (i.e., the Central Delta, Marsh Creek, and West Delta subareas).
- The RAA shall demonstrate quantitatively that the plan will result in mercury and methylmercury load reductions sufficient to attain the methylmercury wasteload

allocations by January 1, 2030 (or any revised final compliance date adopted by the Central Valley Water Board as part of the DMCP review) and address the following questions:

1. What are the annual mercury and methylmercury loads from the MS4 discharge to the Central Delta, Marsh Creek, and West Delta subareas?
2. Do the mercury and methylmercury load to each subarea meet the assigned methylmercury wasteload allocations?
3. What is the achievable mercury and methylmercury load reduction in discharges from the MS4 by implementation of reasonable, foreseeable control measures?
4. What controllable MS4 water quality factors affect methylmercury production and transport in the MS4 discharge and in the receiving waters draining to the Delta?
5. Are there MS4 design features that increase or decrease mercury methylation?
6. Are there reasonable and foreseeable management actions to reduce methylmercury concentrations within the MS4 boundary?

This report is organized into the following sections:

1. Introduction and Background – Section 1 describes requirements for managing methylmercury per the Total Maximum Daily Load (TMDL) and the MRP.
2. Methylmercury Control Measure Plan – Section 2 describes the technically and economically feasible methylmercury control measures that are currently being implemented or will be implemented by the East County Permittees during the current and future permit terms.
3. Schedule of Implementation – the schedule of implementation for the methylmercury control measures is provided in Section 3.
4. Costs, Efficiency, and Environmental Impacts – Section 4 provides an evaluation of costs, control measure efficiency, and significant environmental impacts resulting from the implementation of the methylmercury control measures.
5. Conclusion – the final section summarizes the findings of the report.

The RAA Report provided in Appendix A presents estimates of the total mercury and methylmercury loads that will be reduced through implementation of the control measures described in the Methylmercury Control Measure Plan presented in Section 2. The RAA summarizes the data used, describes the model and model inputs, and documents peer review.

## 1.2 Background

### 1.2.1 Delta Mercury Control Program

The Central Valley Board has determined that mercury concentrations in fish species found in the Sacramento-San Joaquin River Delta (the Delta) exceed acceptable levels for the protection of human health and wildlife that depend on fish for food (CVRWQCB, 2010a). The sources of mercury contamination include legacy mining, industrial activities, and global atmospheric mercury, in addition to smaller contributions from urban stormwater and publicly owned treatment works. Methylmercury is a form of mercury of heightened environmental concern because it tightly binds to proteins in fish tissues and, therefore, bioaccumulates in organisms and biomagnifies at successively higher levels of the food chain. No cooking or fish cleaning method will reduce the amount of mercury in a meal.

In April 2010, the Central Valley Water Board amended the Water Quality Control Plan for the Sacramento and San Joaquin River Basins (Basin Plan) to include the Delta Mercury Control Program. The TMDL is being implemented through a phased approach; Phase 1 began on October 20, 2011. At the end of Phase 1, the Basin Plan requires the Central Valley Water Board to review the Phase 1 requirements and consider revising the DMCP and future requirements before starting Phase 2. If the Central Valley Water Board does not review and/or revise the DMCP by October 2022, the current load and waste load allocations would become immediately effective with a compliance date of 2030.

A phased TMDL approach was selected because additional information about methylmercury source control methods was needed to determine how and if dischargers can attain the current interim load and waste load allocations listed in the TMDL (CVRWQCB, 2010b). Information was also needed about the methylmercury control methods' potential benefits and adverse impacts on humans, wildlife, and the environment. Therefore, Phase 1 emphasized studies and pilot projects to develop and evaluate management practices to control methylmercury.

Central Valley Water Board staff are currently reviewing and, if necessary, will consider proposing modifications to the following TMDL components: aqueous methylmercury and inorganic mercury goals; site-specific water quality objectives, currently established to protect Commercial and Sport Fishing (COMM) and Wildlife Habitat (WILD) beneficial uses; linkage analysis; allocations; the final compliance date; and requirements and schedules for implementation of methylmercury management practices. Central Valley Water Board staff is also evaluating other potential public and environmental benefits and negative impacts (e.g., habitat restoration, flood protection, water supply, fish consumption) of implementing methylmercury management practices. Modifications to the DMCP were based on the findings of the Phase 1 control studies and other recent information (CVRWQCB, 2021).

### 1.2.2 Municipal Regional Permit

NPDES permit requirements associated with Phase I municipal stormwater programs and Permittees in the Bay area are included in the MRP, which was issued to 76 cities, counties, and flood control districts in 2009 and revised in 2015, 2019, and 2022.

The MRP was amended on February 13, 2019, to add the cities of Antioch, Brentwood, Oakley, and the eastern portions of unincorporated Contra Costa County and the Contra Costa County Flood Control & Water Conservation District (the East County Permittees), which are located within the jurisdiction of the Central Valley Water Board (Region 5) and were previously covered under a separate Joint Municipal NPDES Permit titled "East Contra Costa County Municipal NPDES Permit." This report summarizes the control measures implemented and the mercury loads reduced within the Central Valley Water Board Region 5 boundary for unincorporated Contra Costa County.

The current MRP (i.e., MRP 3.0; Order No. R2-2022-0018) was adopted on May 11, 2022 and was effective on July 1, 2022.

The East County Permittees are not subject to the San Francisco Bay PCBs and mercury TMDLs, although they have been implementing PCBs and mercury control measures. The MRP specifically exempts the East County Permittees from MRP Provisions C.11 and C.12 but does incorporate requirements for the Sacramento-San Joaquin Delta Estuary Methylmercury TMDL in Provision C.19. Therefore, this plan does not report on PCBs control measure implementation or RAA results for the East County Permittees.

MRP 2.0 Provision C.16.5 required the cities of Antioch, Brentwood, and Oakley to submit a Green Infrastructure Plan on December 31, 2020. Contra Costa County submitted a Green Infrastructure Plan for the entire unincorporated area with the 2019 Annual Report. CCCWP developed, and each of the Permittees used, a mechanism to prioritize and map areas for potential and planned green infrastructure projects, both public and private, on a drainage-area-specific basis, for implementation by 2020, 2030, and 2040.

MRP 3.0 Provision C.19.e lists the minimum BMPs to address mercury. These BMPs include inorganic mercury reduction BMPs as well as provide ongoing education and outreach to address mercury pollution prevention and risk reduction. East County Permittee BMP implementation is discussed in Section 2.

### 1.2.3 Bay Area RAA Guidance

From a regulatory perspective, reasonable assurance is defined as the demonstration that the implementation of control measures will, in combination with operation of existing or proposed storm drain system infrastructure and management programs, result in sufficient pollutant reductions over time to meet total maximum daily load (TMDL) wasteload allocations, water quality-based effluent limits (WQBELs), or other water quality targets specified in a municipal separate storm sewer system (MS4) permit (USEPA, 2017). From the perspective of a stakeholder in the watershed who is focused on the improvement of water quality or restoration of a beneficial use of a waterbody, reasonable assurance is the demonstration and a commitment that specific management practices are identified with sufficient detail (and with an implementation schedule) to establish that necessary improvements in the receiving water quality will occur. From the perspective of an MS4 Permittee, reasonable assurance is a detailed analysis of TMDL WLAs, associated permit limitations, and the extent of stormwater management actions needed to achieve TMDL WLAs and address receiving water limitations. RAAs may also assist in evaluating the financial resources necessary to meet pollutant reductions based on schedules identified in the permit, TMDL, or stormwater management plan and in preparing associated capital improvement plans.

As defined in the *Bay Area RAA Guidance Document* (BASMAA, 2017), an RAA is a demonstration that the control measures proposed in the Green Infrastructure Plans and TMDL Control Measure Implementation Plan, as required by the MRP, will meet TMDL wasteload allocations for urban stormwater runoff over the defined period.

The MRP provides flexibility for Permittees to define what constitutes an acceptable RAA; however, the RAAs developed in compliance with the MRP must be peer-reviewed. The RAA presented in this report is consistent with the guidance provided in the *Bay Area RAA Guidance Document* (BASMAA, 2017).

# 2. MERCURY AND METHYLMERCURY CONTROL MEASURE PLAN

This section describes sources of mercury and methylmercury in urban runoff and the control measures that are currently being implemented or will be implemented by the Permittees during this and future permit terms to control methylmercury in urban runoff.

## 2.1 Mercury Sources and Transport in the MS4

Mercury is a naturally-occurring, persistent, bioaccumulative metal that can be present in the environment in elemental, inorganic, or organic mercury. It is both a legacy pollutant and a contemporary pollutant. Historically, mercury has been used in a variety of products. Among the over 3,000 historical industrial uses in the U.S. were battery manufacturing and chlorine-alkali production. Paints and industrial instruments have also been among the major uses. It is also used in laboratories for making thermometers, barometers, diffusion pumps, and many other instruments, including mercury switches and other electrical apparatuses. Mercury is used as an electrode in some types of electrolysis and some types of batteries (mercury cells). Gaseous mercury is used in mercury-vapor lamps (e.g., fluorescent tubes) and advertising signs. Mercury is also the basis of dental amalgams and preparations and can be a byproduct of burning fossil fuels and refining petroleum (BASMAA, 2017).

Mercury was mined from the California Coast Range mainly from source rocks called serpentinite (the state rock of California). In some areas, the serpentine geology was so enriched with mercuric sulphide (HgS, called cinnabar) that extracting it was economically profitable (SFEI, 2010). The upper Marsh Creek watershed includes the Mount Diablo Mercury Mine. The mine site, located on privately owned lands, contains historic mining buildings, piles of exposed waste rock with mercury-containing calcines (processed mercury ore), and residual acidic drainage (CCCWP, 2020). This legacy mine acts as a source to Lower Marsh Creek and the Delta but is outside the MS4 boundary.

Atmospheric deposition on urban areas is a significant source of mercury (BASMAA, 2017). Mercury is transported globally in the atmosphere and is found in lakes, glacial ice, and soils far from manufacturing, mining, or urban areas. Local sources include off-gassing from contaminated sites; dust rising into the atmosphere; vegetation fires; industrial fires; combustion of fossil fuels (coal, gas, gasoline, diesel, and oil) for heating, manufacturing cement, and oil refining; incineration; and cremation (SFEI, 2010). Some of the mercury released from these local sources is deposited locally down wind and the rest is lost to the Central Valley area further east or to the global cycle.

Mercury that falls on surfaces from global or local atmospheric sources gradually builds up on impervious surfaces, and wind and vehicle traffic can move mercury from source areas onto impervious surfaces (SFEI, 2010). Soil and sediment with associated mercury from pervious areas that has been transported to the MS4 may accumulate in roadway curbs and gutters, storm drain inlets/catch basins, storm drain pipelines, and other structures (e.g., stormwater pump stations). These storage locations are potential places to implement enhanced operation and maintenance activities that remove sediment.

While mercury released into the environment is typically in an inorganic form, concerns about human and wildlife exposure are mostly related to methylmercury that accumulates in fish and other food. Methylmercury is produced in ecosystems through naturally occurring processes that convert inorganic mercury to methylmercury. These processes and the extent of methylmercury bioaccumulation depend on a number of site-specific conditions (Hsu-Kim, et al., 2018). Mercury released to waterways is generally strongly chelated (i.e., attached to natural organic matter) or associated with particles (both particulate natural organic matter and mineral particles). The conversion of inorganic mercury to methylmercury in the environment is primarily a microbially driven process commonly present in anaerobic sediments, saturated soils, and anoxic conditions. Methylmercury can also be degraded by biotic and abiotic processes.

### 2.1.1 Controllable MS4 Water Quality Factors and MS4 Design Features

Urban stormwater management generally focuses on the rapid conveyance of water away from the built environment, thus reducing water stagnation and the formation of anoxic conditions. With increased peak flows and erosion in urban waterways, MS4 conditions are significantly less favorable for methylation by anaerobic microbes than in depositional environments (Hsu-Kim, et al., 2018). Higher nitrogen and lower dissolved natural organic matter may also contribute to a lower methylation potential in urban environments. Finally, the bioavailability of inorganic mercury for methylation in urban environments may be lower due to a higher proportion of inorganic mercury bound to particles (Hsu-Kim, et al., 2018).

A study conducted by the San Francisco Estuary Institute (SFEI) on a City of El Cerrito green street bioretention cell showed that methylmercury decreased at the outlet by 50% on average relative to the influent over a five years (Gilbreath, et al., 2019). This bioretention cell was constructed consistent with the *Stormwater C.3 Guidebook* bioretention design standards. Native soils at the site have a high clay content; therefore, an underdrain was installed directly below the engineered media layer and the facility was well-drained. Outlet mercury concentrations were also significantly lower than inlet concentrations, with a mean difference of 37%.

A similar study conducted by the City of Citrus Heights (LWA, 2015) found that a parking lot treated with permeable pavement, bioswales, and bioretention areas reduced methylmercury loads by 85% and total mercury by 57%. These studies show that GSI is an effective control measure for controlling mercury and methylmercury in urban runoff.

Thousands of scientific publications over the past several decades provide detailed insights into the complex environmental factors affecting how mercury is converted to methylmercury (i.e., methylated) and how methylmercury is converted back to inorganic mercury (i.e., demethylated). The key points about mercury methylation and demethylation most relevant to controllable MS4 water quality factors and MS4 design features include:

- Mercury methylation is a microbially mediated process in which bacteria take up inorganic mercury and add carbon to make methylmercury.
- The bacteria that methylate mercury thrive under low oxygen (suboxic) or no oxygen (anoxic) conditions; therefore, slow moving, or stagnant water is a risk factor for increased mercury methylation.
- Cyclical wetting and drying, such as in tidal systems or small streams with intermittent discharge, is also a risk factor for increased mercury methylation
- Methylation and demethylation constantly occur in natural waters. Methylmercury concentration reflects the balance between the forward (methylation) and reverse (demethylation) reactions at any given time and location.
- Mercury and methylmercury tend to adhere to sediment particles. Thus, suspended sediment concentrations (SSC) in water directly affect mercury and methylmercury concentrations in water.

GSI is designed to improve water quality through particle settling and filtration, thereby reducing the potential for mercury methylation as well as lowering the overall load through runoff volume reduction. GSI should be designed to be well draining to avoid suboxic or anoxic conditions that promote methylation. The standard bioretention design criteria in the CCCWP *Stormwater C.3 Guidebook* should achieve this goal.

## 2.2 Source Control Measures

### 2.2.1 Mercury Load Avoidance and Reduction

Mercury load avoidance and reduction include several source control measures listed in the California Mercury Reduction Act adopted by the State of California in 2001. These source controls include material bans, reductions of the amount of mercury allowed for commercial uses, and mercury device recycling. The following source controls bans consists of:

- Sale of cars that have light switches containing mercury;
- Sale or distribution of fever thermometers containing mercury without a prescription;
- Sale of mercury thermostats; and,
- Manufacturing, sale, or distribution of mercury-added novelty items.

In addition, manufacturers continue to reduce the amount of mercury in fluorescent lamps sold in the U.S. as well as have significantly reduced the amount of mercury in fluorescent linear tube lamps.

Mercury Device Recycling Programs resulting in mercury load reduction generally include three types of programs that promote and facilitate the collection and recycling of mercury–containing devices and products:

- Permittee-managed household hazardous waste (HHW) drop-off facilities and curbside or door-to-door pickup;
- Private business take-back and recycling programs (e.g., Home Depot); and,
- Private waste management services for small- and large-size generating businesses.

The CCCWP coordinates with Permittees and local household hazardous waste collection facilities to raise awareness of and implement mercury collection and recycling in accordance with MRP Provisions C.11.d. and C.19.e.ii.(1).

CCCWP Permittees collect household hazardous waste at three regional facilities in the County:

- Central Contra Costa Sanitary District (CCCSD);
- Delta Diablo Sanitation District (DDSD); and,

- West Contra Costa Integrated Waste Management District (WCCIWMA).

CCCSD serves the communities of Concord, Clayton, Martinez, Pleasant Hill, Orinda, Lafayette, Moraga, Walnut Creek, Danville, San Ramon, and unincorporated County. DDSD serves Pittsburg, Antioch, Oakley, and Bay Point. WCCIWMA serves Richmond, Pinole, El Sobrante, El Cerrito, San Pablo, and unincorporated areas of Contra Costa County.

The types of data collected at each facility vary slightly, as do the level of differentiation between types of mercury containing devices and the level of detail in reporting the data.

#### 2.2.2 Enhanced Municipal Management Practices to Reduce Sediment Discharges

The East County Permittees are implementing BMPs to minimize sediment discharges during municipal operations and maintenance activities such as storm drain drop inlet and pipeline cleaning, landscaping, road construction, road repair, and pump station cleaning.

*Street Sweeping and Street Flushing*

Each of the East County Permittees has a jurisdiction-wide street sweeping program. These municipalities enhanced their street sweeping program under MRP 2.0 as part of their Long-Term Trash Load Reduction plans. The City of Antioch sweeps once a month on residential roads and twice a month on busy arterials. The City of Brentwood currently sweeps most streets twice a month and downtown areas once a week. The City of Oakley sweeps its downtown core areas twice a week and after street festivals. Unincorporated Contra Costa County sweeps residential areas in East County that have curb and gutter on a monthly basis. Existing street sweeping frequencies for each municipality along with other enhanced sediment management practices are summarized in Table 2-1.

Street flushing, another potential method for managing sediment, uses pressure washing to remove sediment, trash, and other pollutants from the street, then collecting and properly disposing of the wash water and pollutants. Street flushing and wastewater capture are not currently routine O&M activities in the in the Bay Area. Pilot tests of street flushing performed in the City of San Carlos found several barriers to using street flushing as a mercury control measure (BASMA, 2017). Some encountered challenges included locating appropriate sites where street flushing could be conducted while minimizing disturbances to parking, traffic flow, and business activities, and addressing wastewater disposal issues, which requires a special discharge permit from the local sanitary sewer and complying with permit requirements for wastewater quality testing. In addition, the current statewide water conservation mandate restricts the implementation of street flushing. For these reasons, street flushing is not considered a feasible enhanced municipal maintenance practice.

*Storm Drain Line Cleanout*

Municipalities occasionally clean out storm drain lines to remove sediment blockages and alleviate localized flooding hazards. Storm drain line cleanout removes mercury associated with the sediment and eliminates stagnant pools of water in the storm drain line that may lead to mercury methylation.

*Storm Drain Inlet Cleaning*

The East County Permittees conduct periodic inspections of their publicly owned storm drain inlets and perform maintenance (cleaning and repair) according to an established maintenance schedule. The activities involved include removing trash and sediment from the storm drain inlet, documenting the amount of materials removed, and occasionally performing repairs (i.e., replacing missing bolts or repairing damaged structures).

The East County Permittees, except the City of Antioch, inspect their storm drain inlets annually.[3] In recent years, the Permittees have increased the cleaning frequency of the inlets with inlet-based full trash capture devices. The City of Antioch inspects and cleans over 120 inlet-based full trash capture devices monthly. Contra Costa County owns over 6,000 storm drain inlets and prioritizes frequent cleaning of those posing flooding hazards. The City of Brentwood completes the inspections of all public storm drain inlets in October and prioritizes its maintenance activities based on the results.

*Channel Maintenance*

The East County Permittees regularly perform channel and ditch maintenance in addition to storm drain inlet cleaning and storm line flushing to remove sediment, organic materials, and trash. While the City of Antioch has an annual inspection and maintenance of most drainage channels within the city, it maintains Lindsey Basin monthly. Both Contra Costa County and the

[3] The City of Antioch is currently on a two-year inspection schedule of its 47 maintenance routes (zones). The City recently added staff to assist with storm drain and sewer system maintenance.

cities of Brentwood and Oakley inspect their drainage channels annually and schedule cleaning accordingly. The City of Brentwood uses goats to control weeds before cleaning the channels. None of the East County Permittees performs significant channel desilting on a routine basis.

*Other Enhanced Maintenance Opportunities*

The East County Permittees may require other entities within its jurisdiction to perform enhanced maintenance. To reduce the ongoing contribution of mercury-containing sediment to the Permittee's MS4 that originates from private properties (e.g., railroad right-of-way, old industrial sites, etc.), a municipality may require street sweeping to be implemented on public roads fronting such properties as an interim measure or storm line flushing be performed from the subject property laterals to the main line in the public right-of-way. Fencing may be required along the railroad right-of-way to eliminate tracking sediment to public roads by vehicles. A municipality may consider installing full trash capture devices to treat stormwater runoff from adjacent mercury-concentrated properties.

No East County Permittee has implemented other enhanced maintenance opportunities in their jurisdiction to-date but may use this tool if a specific opportunity arises.

**Table 2-1. Enhanced Municipal Management Practices**

| Municipality | Municipal Maintenance Control Measures | | | | | |
|---|---|---|---|---|---|---|
| | Street Sweeping | Street Flushing | Storm Drain Flushing | Storm Drain Inlet Cleaning | Channel Maintenance | Other Opportunity |
| City of Antioch | E | O | O | E/P | E | O |
| City of Brentwood | E | O | O | E | E | O |
| City of Oakley | E | O | O | E | E | O |
| Contra Costa County | E | O | O | E | E | O |

E – Existing P – Planned enhancement O – Not performed

### 2.2.3 Public Education and Risk Reduction

The East County Permittees continue to implement risk reduction activities to increase awareness of the risks of mercury contamination when consuming fish caught in the San Francisco Bay/Delta.

The Fish Risk Reduction Program was designed to raise awareness and address public health impacts from mercury in San Francisco Bay and Central and South Sacramento-San Joaquin River Delta fish by:

- Taking action to reduce actual and potential health risks in people and communities most likely to consume San Francisco Bay/Delta-caught fish, such as subsistence fishers, recreational anglers, and their families.
- Working with local health departments, regional parks, and Permittees to coordinate resources for the program to target at-risk populations.

As part of this program, the CCCWP works with the East Bay Regional Parks District to post, inspect, and maintain fish consumption warning signs at fishing piers and harbor/marina kiosks around the county. CCCWP funds the replacement of signs when they are vandalized or when fish consumption information needs to be updated. The CCCWP also works with marinas and local fishing supply stores throughout the county to make fish consumption warning information available to the public through displaying multi-lingual signage and brochures. The outreach locations are contacted twice annually to provide each location with the appropriate type and quantity of flyers or posters. Leaflets and posters are then displayed at marina informational kiosks and storefront countertops. CCCWP estimates that the Fish Risk Reduction Program has the potential to reach well over the program's minimum target of 3,000 individuals annually (CCCWP, 2022). In addition, CCCWP has applied for an EPA Water Quality Improvement Fund grant that would expand this outreach. EPA expects to announce the grant awards in winter 2023.

## 2.3 Treatment Control Measures

Treatment control measures that address mercury and methylmercury in stormwater include GSI and full trash capture devices. The RAA Report provided in Appendix A of this report estimates the mercury and methylmercury load reductions that would be achieved by implementing these treatment control measures.

### 2.3.1 Green Stormwater Infrastructure

Green stormwater infrastructure refers to constructing and retrofitting storm drainage systems to mimic natural processes by slowing runoff, dispersing it to vegetated areas, harvesting and using runoff, promoting infiltration and evapotranspiration, and using bioretention to filter stormwater runoff. This control measure includes implementation of GSI in new development and redevelopment projects that are under the Permittees' planning and building authority, as well as retrofit of existing infrastructure in public right-of-way (ROW) areas and on publicly owned parcels.

MRP Provision C.3 mandates implementation of a comprehensive program of stormwater control measures and actions designed to limit contributions of urban runoff pollutants to receiving waters, including mercury. GSI has been incorporated into new development and redevelopment projects in Contra Costa County since 2005. The first edition of the CCCWP *Stormwater C.3 Guidebook* was published in 2005. The current 7th Edition of the *Stormwater C.3 Guidebook* was published in 2017. Ancillary support documents, such as example projects, design details, and reporting templates, are continually being developed by the CCCWP to assist the Permittees in C.3 implementation. All of these documents are available on the CCCWP website[4].

Permittees track C.3 project implementation in an ArcGIS Online (AGOL) database. CCCWP developed the countywide GIS database to assist with maintaining, analyzing, interpreting, displaying, and reporting relevant municipal stormwater program data and information related to MRP Provision C.3, Provision C.10 (i.e., trash load reduction activities), and Provisions C.11/C.12 (i.e., mercury and PCBs TMDL implementation activities).

The East County Permittees have developed Green Infrastructure Plans that map and prioritize areas for potential and planned public and private GSI projects for implementation by 2020, 2030, and 2040. The RAA provided in Appendix A of this report estimates the mercury and methylmercury load reductions that would be achieved through implementation of the Permittees' Green Infrastructure Plans.

Additional actions that the Permittees have taken or will take to promote the implementation of GSI include:

- Incorporate GSI requirements into planning documents such as General Plans, Specific Plans, Complete Streets Plans, Active Transportation Plans, Storm Drain Master Plans, Pavement Work Plans, Urban Forestry Plans, Flood Control or Flood Management Plans, and other plans that may affect the future alignment, configuration, or design of impervious surfaces within the Permittee's jurisdiction;

[4] See: https://www.cccleanwater.org/development-infrastructure/

- Evaluate funding options for GSI projects;
- Adopt policies, ordinances, and/or other appropriate legal mechanisms to ensure implementation of their Green Infrastructure Plans;
- Conduct public outreach, train Permittee staff, and educate elected officials on the MRP GSI requirements and methods of implementation; and
- Maintain a list of public infrastructure improvement projects that have a potential for incorporating GSI.

2.3.2 Full Trash Capture Treatment Control Measures

MRP Provision C.10 requires Permittees to implement trash prevention and control actions, including full trash capture systems, to reduce trash generation. Full trash capture systems remove sediment along with trash that may be contaminated with mercury. Permittees have installed both large and inlet-based full trash capture devices in response to MRP Provision C.10 requirements. Large full trash capture devices, including hydrodynamic separators (HDS), gross solids removal devices (GSRDs), and baffle boxes, capture and treat urban runoff from large drainage areas, ranging from 10's to 100's of acres. Inlet-based devices in roadways enhance the removal of sediment from smaller, localized drainage areas. In addition, these inlets are typically cleaned more frequently because of the full trash capture device installation. Trash capture device implementation is described in each Permittee's Trash Load Reduction Plan. Permittees track installed trash capture devices in the AGOL database and use the database to run scenarios to guide future locations for these devices.

The City of Antioch inspects its full trash capture devices monthly and, for certain locations, before and after a significant rain event. The City has identified one suitable area for the future installation of a large-size full trash capture device. Each East County Permittees will review their Long-Term Trash Reduction plans, identify locations to install additional full trash capture devices, and partner with other entities (e.g., Caltrans and the Contra Costa Flood Control District) or seek grant funding to advance implementation of this control measure.

# 3. SCHEDULE OF IMPLEMENTATION

## 3.1 Overall Schedule of Implementation

Table 3-1 below presents the implementation schedule for the control measures described in the Mercury and Methylmercury Control Measure Plan (Section 2). The schedule in Table 3-1 shows when the implementation of each control measure began and will be complete concerning TMDL implementation. The RAA results confirm that although the West and Central Delta subareas are currently below the TMDL wasteload allocation for methylmercury, the MS4 discharges from the Marsh Creek subarea cannot achieve the methylmercury WLA with technically and economically feasible control measures. Therefore, the methylmercury control measures will continue to be implemented in perpetuity.

Implementation of GSI for new development and redevelopment projects is an ongoing MRP requirement, so will continue to be implemented as long as that requirement is in place. In addition, MRP Provision C.3.j requires the East County Permittees to retrofit 16.42 acres with GSI during this permit term.[5] Full trash capture device implementation is assumed to be complete no later than 2030. The source control measure Mercury Load Avoidance and Reduction, which began during MRP 1.0, is assumed to continue indefinitely.

**Table 3-1. Mercury and Methylmercury Control Measure Plan Schedule of Implementation**

| Control Measure | Begin Implementation | Implementation Complete |
|---|---|---|
| Mercury Load Avoidance and Reduction | 2011 | Ongoing |
| Enhanced Municipal Management Practices | 2011 | Ongoing |
| Public Education and Risk Reduction | 2011 | Ongoing |
| Green Stormwater Infrastructure | 2011 | Ongoing |
| Full Trash Capture Device Installation | 2015 | 2030 |

[5] By June 30, 2027, the Permittees shall implement, or cause to be implemented, GSI projects within their jurisdictions which are not already defined as Regulated Projects pursuant to Provision C.3.b, such that the impervious surface retrofits listed in Table H-1 of Attachment H are achieved. The Permittees may meet the numeric retrofit requirements listed in Table H-1 of Attachment H on a countywide basis. If Permittees within a given county do not collectively achieve their numeric retrofit requirements, each Permittee within the county shall be separately responsible for achieving its individual retrofit requirement. Each Permittee shall implement, or cause to be implemented, a GSI project or projects treating no less than 0.2 acres of impervious surface within its jurisdiction.

## 3.2 Green Stormwater Infrastructure Schedule of Implementation

### 3.2.1 Methodology

The East County Permittees' Green Infrastructure Plans outline the Permittee's efforts to include sustainable stormwater management systems that reduce runoff volume and disperse and treat runoff through natural processes. A summary of the schedule in each Permittee's Green Infrastructure Plan is provided below.

*Private Redevelopment Area Projection*

To forecast private development, the East County Permittees participated in a regional process coordinated through the CCCWP that utilized the outputs of UrbanSim, a model developed by the Urban Analytics Lab at the University of California under contract to the Bay Area Metropolitan Transportation Commission ("MTC"). UrbanSim is a modeling system developed to support the need for analyzing the potential effects of land use policies and infrastructure investments on the development and character of cities and regions. The Bay Area's application of UrbanSim was developed specifically to support the development of Plan Bay Area, the Bay Area's Sustainable Communities planning effort.

MTC forecasts growth in households and jobs and uses the UrbanSim model to identify development and redevelopment sites to satisfy future demand. Model inputs include parcel-specific zoning and real estate data; model outputs show increases in households or jobs attributable to specific parcels. The methods and results of the Bay Area UrbanSim model have been approved by both MTC and the Association of Bay Area Governments ("ABAG") Committees for use in transportation projections and the regional Plan Bay Area development process.

The CCCWP process used outputs from the Bay Area UrbanSim model to map parcels predicted to undergo development or redevelopment in each Contra Costa jurisdiction at each time increment specified in the MRP (2020, 2030, and 2040). The resulting maps were reviewed by Permittee staff to ensure consistency with local planning and economic development initiatives. The maps were revised, and each revision was documented.

It is assumed that multifamily residential and commercial/industrial developments will incorporate stormwater treatment facilities (typically bioretention) in accordance with MRP Provisions C.3.b., C.3.c., and C.3.d. Because of high land values, it is expected that more than 50% of the existing impervious area in each parcel will be replaced if a parcel is developed and, therefore, the entire parcel will be subject to Provision C.3 requirements (i.e., will be retrofit with GSI), consistent with the "50% rule" requirements of MRP Provision C.3.b.

*Public GSI Project Area Projection*

Publicly owned parcels and ROWs that could potentially be retrofitted to include multi-benefit stormwater capture facilities were identified as part of the Contra Costa Watersheds Stormwater Resource Plan (SWRP) (CCCWP, 2019). These potential project locations were used to identify potential public retrofit locations within each Permittee's jurisdiction based on local knowledge and priorities. Each Permittee selected projects, largely from the SWRP list, to be incorporated into their Green Infrastructure Plan. Projects in the Permittees' Green Infrastructure Plans were reviewed to develop the projection herein.

Generally, local knowledge and priorities include judgments of potential neighborhood support for a project, potential integration with transportation projects that can be externally funded, [6] and potential integration with storm drainage infrastructure projects, including drainage improvement projects funded by local special assessments and/or state and Federal grants. In addition, some identified public ROW retrofit projects could potentially be implemented as street frontage improvements and funded through development agreements.

For nearly all public projects identified in the Permittees' Green Infrastructure Plans, implementation is dependent on funding or other support that is not within the Permittees' control. It can be expected that the pace of implementation in any given jurisdiction will vary considerably from year to year (with more variability among smaller jurisdictions, because they have fewer projects). Progress will best be assessed as a multi-year average over the region or countywide. The regional or countywide pace of implementation will be affected by economic conditions and by the general availability of state and Federal infrastructure grants.

[6] See the "Roadmap of Funding for Sustainable Streets" prepared by BASMAA for the Urban Greening Bay Area Initiative (2018)

### 3.2.2 City of Antioch

Table 3-2 lists the private development project area treated with GSI through 2022 and the cumulative area predicted to be treated by 2030 and 2040 within the City of Antioch (City of Antioch, 2021). Table 3-3 lists the public retrofit project treatment area for 2022, 2030, and 2040.

**Table 3-2. Estimate of Cumulative Area Treated via Private Development in the City of Antioch**

| Year | Total Acres |
|---|---|
| 2022[1] | 21.6 |
| 2030[2] | 107.9 |
| 2040[2] | 173.9 |

1 Total acres treated obtained from the AGOL database entered by the City of Antioch through FY 2021-2022.

2 Estimated treatment acres via communication with City of Antioch, October 2022.

**Table 3-3. Estimate of Cumulative Public Retrofit Project Treatment Area in the City of Antioch**

| Year | Total Acres |
|---|---|
| 2022[1] | 5.4 |
| 2030[2] | 8.4 |
| 2040[2] | TBD |

1 Total acres treated obtained from the AGOL database entered by the City of Antioch through FY 2021-2022.

2 Estimated treated area via communication with City of Antioch, October 2022.

### 3.2.3 City of Brentwood

Table 3-4 lists the private development project area treated with GSI through 2022 and the cumulative area predicted to be treated by 2030 and 2040 within the City of Brentwood (City of Brentwood, 2020). Table 3-5 lists the public retrofit project treatment area for 2022, 2030, and 2040.

**Table 3-4. Estimate of Cumulative Area Treated via Private Development in the City of Brentwood**

| Year | Total Acres |
|---|---|
| 2022[1] | 164.1 |
| 2030[2] | 620.2 |
| 2040[2] | 1,297.0 |

1 Total acres treated obtained from the AGOL database entered by the City of Brentwood through FY 2021-2022.

2 Estimated private project area from RAA model.

**Table 3-5. Estimate of Cumulative Public Retrofit Project Treatment Area in the City of Brentwood**

| Year | Total Acres |
|---|---|
| 2022[1] | 0.0 |
| 2030[2] | 44.5 |
| 2040[2] | 49.9 |

1 Total acres treated obtained from the AGOL database entered by the City of Brentwood through FY 2021-2022.

2 Estimated public project area from RAA model.

### 3.2.4 City of Oakley

Table 3-6 lists the private development project area treated with GSI through 2022 and the cumulative area predicted to be treated by 2030 and 2040 within the City of Oakley (City of Oakley, 2020). Table 3-7 lists the public retrofit project treatment area for 2022, 2030, and 2040.

**Table 3-6. Estimate of Cumulative Area Treated via Private Development in the City of Oakley**

| Year | Total Acres |
|---|---|
| 2022[1] | 45.1 |
| 2030[2] | 2,408.8 |
| 2040[2] | 2,591.9 |

1 Total acres treated obtained from the AGOL database entered by the City of Oakley through FY 2021-2022.

2 Estimated private project area from RAA model.

**Table 3-7. Estimate of Cumulative Public Retrofit Project Treatment Area in the City of Oakley**

| Year | Total Acres |
|---|---|
| 2022[1] | 3.7 |
| 2030[2] | 6.3 |
| 2040[3] | 110.5 |

1 Total acres treated obtained from the AGOL database entered by the City of Oakley through FY 2021-2022.

2 Includes the numeric retrofit requirement in MRP 3.0 Attachment H (2.55 acres of impervious area).

3 Estimated public project area from RAA model.

### 3.2.5 Unincorporated Contra Costa County

Table 3-8 lists the private development project area treated with GSI through 2022 and the cumulative area predicted to be treated by 2030 and 2040 within the Region 5 area of Unincorporated Contra Costa County (Contra Costa County, 2019). Table 3-9 lists the public retrofit project treatment area within Region 5 for 2022, 2030, and 2040.

**Table 3-8. Estimate of Cumulative Area Treated via Private Development in Unincorporated Contra Costa County within Region 5**

| Year | Total Acres |
|---|---|
| 2022[1] | 635.3 |
| 2030[2] | 800.5 |
| 2040[3] | 827.4 |

1 Total acres treated obtained from the AGOL database entered by Unincorporated Contra Costa County through FY 2021-2022.

2 Total acres treated obtained from the AGOL database for projects with future construction dates entered by Unincorporated Contra Costa County through FY 2021-2022 and estimated private project area from RAA model.

3 Estimated private project area from RAA model.

**Table 3-9. Estimate of Cumulative Public Retrofit Project Treatment Area in Unincorporated Contra Costa County within Region 5**

| Year | Total Acres |
|---|---|
| 2022[1] | 64.9 |
| 2030[2] | 75.8 |
| 2040[3] | 83.0 |

1 Total acres treated obtained from the AGOL database entered by Unincorporated Contra Costa County through FY 2021-2022.

2 Total acres treated obtained from the AGOL database for projects with future construction dates entered by Unincorporated Contra Costa County through FY 2021-2022 and estimated public project area from RAA model.

3 Estimated public project area from RAA model.

## 3.3 Full Trash Capture Schedule of Implementation

Table 3-10 lists the estimated drainage area treated by full trash capture devices in Eastern Contra Costa County by 2022 and 2030. MRP 3.0 Provision C.10 requires 100 percent trash load reduction or no adverse impacts to receiving waters from trash by June 30, 2025.

**Table 3-10. Estimate of Cumulative Area Treated with Full Trash Capture Devices in Eastern Contra Costa County**

| Year | Total Acres |
|---|---|
| 2022[1] | 2,894 |
| 2030[2] | 3,685 |

1 Total acres treated obtained from the AGOL database entered through FY 2021-2022.

2 Assumes all remaining areas mapped as Very High and High baseline trash generation rate would be treated with Full Trash Capture Devices.

# 4. EVALUATION OF COSTS, CONTROL MEASURE EFFICIENCY, AND SIGNIFICANT ENVIRONMENTAL IMPACTS

## 4.1 Cost Analysis

### 4.1.1 Source Control Measure Cost Analysis

A regionally consistent approach to estimating source control program enhanced operations and maintenance implementation costs developed through collaboration with the other Bay Area stormwater programs is summarized in Table 4-1 below.

**Table 4-1: Planning Level Cost Estimate Values for Enhanced Operations and Maintenance Source Control Measures**

| Control Measure | Unit of Implementation | Estimated Unit Costs[1] | | | |
|---|---|---|---|---|---|
| | | Initial[2] | | Ongoing[3] | |
| | | Cost | Unit | Cost | Unit |
| Enhanced Street Sweeping - mechanical broom | Acres addressed | $48 / curb-mile swept (lifecycle cost) | | | |
| Enhanced Street Sweeping - Regenerative Air or Vacuum Assisted | Acres addressed | $80 / curb-mile swept (lifecycle cost) | | | |
| Street Flushing | Linear mile of street flushed | $193,139 | $ / linear mile of street flushed | NA | NA |
| Enhanced Inlet Cleanout | Number of inlets cleaned out | NA | NA | $100 | $ per cleanout |
| Enhanced Pump Station Cleanout | Additional annual cleanouts | $82,200 | $/cleanout | NA | NA |
| Storm Drain Piping Cleanout | Annual cleanouts | $146,062 | $/cleanout | NA | NA |

1. The unit costs are rough planning level estimates that do not consider net present worth cost adjustments or other complexities.
2. Initial costs generally include planning, design, capital, and other initial one-time costs.
3. Ongoing costs include operation & maintenance and other ongoing costs.

### 4.1.2 Green Stormwater Infrastructure Cost Methodology

GSI project cost data were gathered from several Bay Area and Southern California sources to develop relationships between project size or project area (tributary drainage area) and total capital cost (construction and design). Likewise, O&M cost data were gathered from these sources and through literature review. A technical memorandum summarizing this cost analysis is provided in Appendix B. The results of this analysis for project capital costs, in 2022 dollars[7], are presented in Table 4-2 below. Actual GSI project implementation costs will vary and may be greater than those listed in Table 4-2.

**Table 4-2: Statistical Summary of Unit Capital Cost for Green Street, Parcel-Based, and Regional GSI Project Types**

| Project Category | No. of Projects (n) | Unit Capital Cost ($/ac treated) in 2022 Dollars[1] | | | | | |
|---|---|---|---|---|---|---|---|
| | | Minimum | 25th-percentile | Median | 75th-percentile | Maximum | Mean |
| Green Street | 19 | $30,000 | $83,000 | $162,000 | $315,000 | $1,522,000 | $251,000 |
| Distributed Green Infrastructure | 21 | $19,000 | $106,000 | $143,000 | $208,000 | $491,000 | $181,000 |
| Regional Stormwater Control | 11 | $18,000 | $30,000 | $72,000 | $150,000 | $504,000 | $119,000 |

1 Values have been rounded to the nearest $1,000.

As can be seen by comparing Table 4-1 and Table 4-2, the estimated unit cost for implementing source control programs is negligible compared to the estimated unit costs for implementing GSI projects.

Annual O&M costs are intended to account for activities necessary to maintain the effectiveness of a project that recur regularly, such as routine maintenance on an annual basis or repairs following a large storm event. For this cost analysis, annual O&M costs do not include replacement (of portions) or rehabilitation of GSI facilities, which occurs approximately every 20 to 30 years. For planning purposes, annual O&M costs are often assumed to be a percentage of the capital (design and construction) costs. Annual O&M costs range from approximately 1% to 6% of the capital costs, with an average of 4% of capital costs for the data sources reviewed.

The estimated capital cost, including both the design and construction costs, for the public GSI project acres included in the RAA model is provided in Table 4-3 below. This cost was estimated by applying the Green Street unit cost to the right-of-way area, and the Distributed Green Infrastructure unit cost to the parcel area within the total estimated public GSI project area each year. The low, medium, and high-cost estimates were calculated using the 25$^{th}$ percentile,

[7] The cost estimate assumes 18% inflation on 2018 dollars.

median, and 75th percentile unit costs. The annual O&M cost was calculated by multiplying the capital cost by an estimated fixed O&M cost factor of 4%. The total project cost includes the capital costs and the annual O&M costs over the project's design life. For the purposes of this analysis, a 20-year design life and a 3% inflation rate were used to calculate the total present value of the annualized O&M costs.

**Table 4-3: Cost to Treat the Estimated Public GSI Project Area by 2020, 2030, and 2040 within Contra Costa County**

| Year | Total Capital Cost ($1,000) | | | Annual O&M Cost ($1,000) | | | Total Project Cost ($1,000) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Low | Medium | High | Low | Medium | High | Low | Medium | High |
| 2020 | $4,310 | $5,815 | $8,458 | $172 | $233 | $338 | $6,952 | $9,379 | $13,642 |
| 2030 | $5,421 | $8,659 | $14,732 | $217 | $346 | $589 | $8,744 | $13,967 | $23,762 |
| 2040 | $10,284 | $18,730 | $34,939 | $411 | $749 | $1,398 | $16,588 | $30,211 | $56,355 |
| **Total** | $20,015 | $33,204 | $58,129 | $800 | $1,328 | $2,325 | $32,284 | $53,557 | $93,759 |

Public project implementation will depend on funding availability and allocation. Funding for project implementation included in the Permittees' Green Infrastructure Plans would be obtained by the municipal agency, partnerships of agencies, or other stakeholder project sponsors working to implement the identified projects. Economic or socio-economic impacts and political shifts may affect future implementation scenarios, causing increases or decreases in the amount of private investment and public funds available for development and control measure implementation, and/or changes in the ability to provide services that are needed for implementation.

The Cities of San Pablo, Walnut Creek, and Richmond and Contra Costa County have partnered for an EPA San Francisco Bay Water Quality Improvement Fund grant to develop and pilot a Regional Alternative Compliance System in Contra Costa County. The objective of the project is to develop a Regional Alternative Compliance System that will efficiently and cost-effectively improve surface water quality, achieve multiple benefits, and reduce compliance pressures on jurisdictions and entities subject to MRP requirements. It is intended that the system will help facilitate implementation of GSI across Contra Costa County with the potential for substantial cost savings, while meeting MRP and TMDL water quality goals.

### 4.1.3 Full Trash Capture Cost Analysis

Table 4-4 presents the regionally consistent unit costs for implementing full trash capture devices. Table 4-5 lists the cost to treat the areas presented in Table 3-10 with full trash capture using these unit costs.

**Table 4-4: Planning Level Cost Estimate Values for Full Trash Capture Devices**

| Control Measure | Unit of Implementation | Estimated Unit Costs[1] | | | |
|---|---|---|---|---|---|
| | | Initial[2] | | Ongoing[3] | |
| | | Cost | Unit | Cost | Unit |
| FTC Implementation - Large Devices | Acres treated | $4,500 | $/acre | $6,000 | $ per year |
| FTC Implementation – Inlet-Based Devices | Acres treated | $1,000 | $/acre | $400 | $ per year |

1. The unit costs are rough planning level estimates that do not consider net present worth cost adjustments or other complexities.
2. Initial costs generally include planning, design, capital, and other initial one-time costs.
3. Ongoing costs include operation & maintenance and other ongoing costs.

**Table 4-5: Full Trash Capture Implementation Cost by 2022 and 2030 within Eastern Contra Costa County**

| Full Trash Capture Device Type | Total Implementation Cost ($1,000) | | |
|---|---|---|---|
| | 2022[1] | 2023-2030[2] | Total |
| Large Devices | $11,861 | -- | $11,861 |
| Inlet-Based Devices | $1,970 | $1,081 | $3,051 |
| Total | $13,831 | $1,081 | $14,912 |

1. Cost for the total area treated in the AGOL database through FY 2021-2022.
2. Assumes all remaining very high and high trash generation areas would be treated with inlet-based devices by 2030.

## 4.2 Control Measure Efficiency

In general, as discussed above, source control measures are much more cost efficient to implement than structural treatment control measures.

There are several factors to consider when selecting control measures to address mercury for a specific area. Cost effectiveness (i.e., the cost per mass of pollutant reduced), while an important factor, is not sufficient when considering which type of control measure to implement at the site scale. Different types of control measures may be more appropriate in some situations than others. Additionally, the potential load reduction available for each type of control measure varies; some control measures may be effective but not have much opportunity for implementation (such as public GSI projects), while others may be less effective but have much more opportunity (such as full trash capture devices).

Factors that help identify optimal implementation for a given location are listed below; site- or catchment-specific characteristics may increase or decrease the importance of any of these factors at a given location:

- *Costs*: includes all life cycle (i.e., including maintenance) costs associated with planning and implementing a given control measure.
- *Load Reduction Potential*: includes the load reduction potential at the site, catchment, or municipal scale.
- *Opportunity*: includes the current and future opportunities and feasibility to implement a given control measure successfully.
- *Safety*: includes consideration of the potential to cause a safety hazard and the need for any additional measures to avoid creating a safety hazard. Safety hazards may include slip, trip, or fall hazards; drowning hazards; visual impairments (i.e., overgrowth into a roadway); vector concerns; chemical hazards; or flooding concerns.
- *Implementation Challenges*: includes consideration of potential implementation challenges due to local ordinances or regulations, resistance from the local community, major utility conflicts, or ability to obtain adequate funding.

### 4.2.1 Clean Watersheds for a Clean Bay

The Clean Watersheds for a Clean Bay (CW4CB) project was a collaboration among the BASMAA member agencies funded by a San Francisco Bay Water Quality Improvement Fund grant from the United States Environmental Protection Agency and matching funds from Bay Area countywide stormwater management programs and member agencies. The CW4CB project was designed to evaluate the effectiveness of stormwater controls for PCBs and mercury in response to the San Francisco Bay polychlorinated biphenyls (PCBs) and mercury TMDLs. The CW4CB project pilot-tested methods to control discharges of PCBs and mercury in urban stormwater runoff and developed and implemented a regional risk reduction program that focused on targeted education on the health risks of consuming certain species of Bay fish that contain relatively high levels of mercury and PCBs. The results of the CW4CB project are available on the CW4CB website (http://basmaa.org/Clean-Watersheds-for-a-Clean-Bay-Project).

A significant finding from the project highlighted source control measures to be much more cost effective for controlling PCBs and mercury than treatment control measures.

Table 4-6 lists the estimated cost per unit pollutant load reduced by source property identification and abatement[8] and the bioretention treatment control retrofit pilot projects. The source property identification and referral cost per unit load reductions represent the cost of pollutant loads reduced per acre of watershed investigated. Costs are in 2016 dollars.

**Table 4-6: Estimated Cost Effectiveness for the CW4CB Source Property Identification and Abatement and Treatment Control Retrofit Pilot Projects**

| Pilot Project Type | Estimated Cost per Mercury Unit Load Reduced[1] ($/(mg/year)) |
|---|---|
| Source Area Identification and Abatement[2] | $53 |
| Treatment Control Retrofit – Bioretention[3] | $372,500 |

1. Assigns the pilot project total design and construction costs to each pollutant independently. Treatment control retrofit project costs are not annualized. Costs are in 2016 dollars.
2. Average for all five pilot watersheds of cost of loads reduced per acre of watershed area investigated ($/acre) divided by the unit load reduced ((mg/yr)/acre).
3. Average of cost per acre treated ($/acre) divided by unit load reductions ((mg/yr)/acre) for the El Cerrito Green Streets, Bransten Road, and PGE 1st and Cutting projects.

## 4.3 Significant Environmental Impacts

The California Environmental Quality Act (CEQA) establishes requirements and procedures for state and local agency review of the environmental effects of projects proposed within their jurisdictions. It further requires that agencies, when feasible, avoid or reduce the significant environmental impacts of their decisions. The applicable statutes are contained in California Public Resources Code, Sections 21000 - 21189, and Title 14 CCR, Division 6, Chapter 3, Sections 15000 – 15387.

CEQA applies to all California public agencies that carry out or approve projects. CEQA compliance is only required if a lead agency is considering approval of a proposed "project." The distinction between the normal and the specific CEQA meaning of "project" is very important, as it can

[8] Source property referral and abatement is a source control measure that is focused on parcel-based sources of PCBs into the MS4.

determine whether an action is subject to CEQA compliance or not. Section 15378 of the State CEQA Guidelines provides the following definition of a project:

1. "Project" means the whole of an action, which has the potential for resulting in either a direct physical change in the environment or a reasonably foreseeable indirect physical change in the environment, and that is any of the following:
    a. An activity directly undertaken by a public agency including but not limited to public works construction and clearing or grading of land, improvement to existing public structures, enactment and amendment of zoning ordinances, and the adoption and amendment of local General Plans or elements thereof pursuant to Government Code Sections 65100-65700.
    b. An activity undertaken by a person which is supported in whole or in part through public agency contacts, grants subsidies, or other forms of assistance from one or more public agencies.
    c. An activity involving the issuance to a person of a lease, permit, license, certificate, or other entitlement for use by one or more public agencies.

CEQA requires the preparation of an Initial Study to determine if a project may result in significant effects on the environment. If substantial evidence in the record supports a fair argument that significant effects may occur, an Environmental Impact Report will be prepared. A Negative Declaration or Mitigated Negative Declaration must be prepared if there is no substantial evidence that the project may have a significant effect on the environment or if revisions to the project would avoid or mitigate the effects that would result in no significant impact.

The CEQA Guidelines stipulate that a public agency shall prepare or have prepared a proposed Negative Declaration or Mitigated Negative Declaration for a project subject to CEQA when:

- The initial study shows that there is no substantial evidence, in light of the whole record before the agency, that the project may have a significant effect on the environment, or
- The initial study identifies potentially significant effects, but:
    - Revisions in the project plans or proposals made by, or agreed to by the applicant before a proposed mitigated negative declaration and initial study are released

for public review would avoid the effects or mitigate the effects to a point where clearly no significant effects would occur; and

- There is no substantial evidence, in light of the whole record before the agency, that the project, as revised, may have a significant effect on the environment.

CEQA requires that reasonable alternatives to implement a proposed project should be considered during the planning process, and potential environmental effects should be included in the evaluation of the project. CEQA also requires state and local agencies to disclose and consider the environmental impacts of their actions. It further requires that agencies, when feasible, avoid or reduce the significant environmental impacts of implementing their action.

This TMDL Control Measure Plan is statutorily exempted under Public Resources Code (California Administrative Code Sec. 15262 et seq.) because it involves feasibility or planning studies for possible future actions that the Permittees have not approved or adopted. Any future projects to be constructed as recommended by this Plan will either be determined to be exempt from CEQA, or an initial study to determine potential environmental impacts will be prepared. In general, this TMDL Control Measure Plan has been determined to have no potential to generate significant adverse impacts on the environment. Instead, it will lessen adverse water quality impacts by reducing loads of mercury and methylmercury into the Delta.

# 5. REASONABLE ASSURANCE ANALYSIS SUMMARY

This section provides a summary of the results of the reasonable assurance analysis. Further detail on the RAA modeling is provided in Appendix A.

## 5.1 RAA Results

Planned GSI implementation was modeled for the three subareas, within Region 5 and the Urban Growth Boundary, using both subarea boundary definitions for the years 2030 and 2040. This scenario helps to address the question "what is the achievable mercury and methylmercury load reduction in discharges from the MS4 by implementation of reasonable, foreseeable control measures" for the Marsh Creek subarea. The future loads for all subareas within Contra Costa County were modeled, even though the baseline conditions for all TMDL defined subareas are below the CTR for mercury, and the baseline conditions for the West and Central Delta subareas are below the TMDL wasteload allocation for methylmercury.

### 5.1.1 Total Mercury

Table 5-1 lists the predicted wet weather loads and concentrations for mercury in urban runoff by 2030 and 2040, given the planned GSI implementation. Loads and concentrations are predicted to decrease for all subareas in future conditions relative to the modeled baseline. In future conditions, predicted mercury concentrations are below the CTR of 0.05 µg/L (50 ng/L) in all subareas.

**Table 5-1: Predicted Mercury Loads and Concentrations with GSI Implementation**

| Subarea within Contra Costa County | 2030 Mercury Load (g/year) | 2040 Mercury Load (g/year) | 2030 Mercury Concentration (ng/L)[1] | 2040 Mercury Concentration (ng/L)[1] | Exceeds California Toxics Rule for Mercury (50 ng/L) |
|---|---|---|---|---|---|
| **TMDL Subarea** | | | | | |
| West Delta | 225.9 | 223.8 | 33.8 | 32.9 | No |
| Central Delta | 65.2 | 65.2 | 45.2 | 45.2 | No |
| Marsh Creek | 61.4 | 56.8 | 20.5 | 16.9 | No |
| **Watershed Atlas Subarea** | | | | | |
| West Delta | 257.5 | 255.6 | 36.1 | 35.5 | No |
| Central Delta | 87.6 | 87.2 | 32.3 | 32.0 | No |
| Marsh Creek | 90.9 | 85.5 | 19.7 | 16.1 | No |

1. (Wet Weather Mercury Load in RAA Development Scenario / Average Annual Wet Weather Runoff Volume) * unit conversions.

Additional mercury load reductions will occur due to full trash capture implementation. Table 5-2 summarizes the predicted mercury load reductions as a result of full trash capture implementation.

**Table 5-2. Predicted Mercury Load Reduction by Full Trash Capture Devices**

| Control Measure | Total Mercury Reduction[1] (g/year) |
|---|---|
| FTC Implementation - Large Devices | 6.6 |
| FTC Implementation – Inlet-Based Devices | 10.8 |
| Future Inlet-Based Devices on Very High and High Trash Generation Rate Areas | 6.4 |
| Total | 23.8 |

1. Mercury load reduction is estimated as catchment area x area-weighted land-use based mercury yield x efficiency factor (20% for large FTC and 18% for inlet-based devices) per BASMAA, 2022.

### 5.1.2 Methylmercury

Geosyntec modeled two GSI scenarios for the methylmercury RAA:

- Scenario 1 assumed that methylmercury entrained within infiltrated runoff is 100% reduced and, conservatively, no methylmercury reductions occur in treated runoff.

- Scenario 2 assumed methylmercury load is 100% reduced for infiltrated runoff and 85% reduced for treated runoff, based on the City of Citrus Heights study results (LWA, 2015).

*Scenario 1: No Load Reduction in Methylmercury Except through Infiltration*

The results of the RAA modeling for methylmercury for the TMDL and Watershed Atlas subareas for Scenario 1 are summarized in Table 5-3 (concentration results) and Table 5-4 (load results) below.

**Table 5-3: Scenario 1 Methylmercury Concentration Results from the RAA Model**

| Subarea within Contra Costa County | Baseline Methylmercury Concentration[1] (ng/L) | 2030 Methylmercury Concentration[1,2] (ng/L) | 2040 Methylmercury Concentration[1,2] (ng/L) |
|---|---|---|---|
| **TMDL Subarea** | | | |
| West Delta | 0.18 | 0.16 | 0.15 |
| Central Delta | 0.19 | 0.19 | 0.19 |
| Marsh Creek | 0.18 | 0.17 | 0.16 |
| **Watershed Atlas Subarea** | | | |
| West Delta | 0.18 | 0.17 | 0.17 |
| Central Delta | 0.20 | 0.15 | 0.15 |
| Marsh Creek | 0.18 | 0.16 | 0.15 |

1. (Wet Weather Methylmercury Load in RAA Development Scenario / Average Annual Wet Weather Runoff Volume) * unit conversions.
2. The methylmercury concentration used to calculate the TMDL wasteload allocation is 0.24 ng/L.

Methylmercury concentrations are predicted to decrease with implementation of GSI from the baseline concentration in both 2030 and 2040 in the three subareas. The predicted concentrations are less than the methylmercury concentration used to calculate the TMDL wasteload allocations (0.24 ng/L).

**Table 5-4: Scenario 1 Methylmercury Load Results from the RAA Model**

| Subarea within Contra Costa County | CVRWQCB (2010a) Wasteload Allocation (g/year) | 2030 Methylmercury Load (g/year) | 2030 Difference Between Wasteload Allocation and Predicted Load (g/year)[1] | 2040 Methylmercury Load (g/year) | 2040 Difference Between Predicted Load and Wasteload Allocation (g/year)[1] |
|---|---|---|---|---|---|
| **TMDL Subarea** | | | | | |
| West Delta | 3.2 | 1.05 | 2.15 | 1.05 | 2.15 |
| Central Delta | 0.75 | 0.27 | 0.48 | 0.27 | 0.48 |
| Marsh Creek | 0.3 | 0.50 | -0.20 | 0.54 | -0.24 |
| Total East Contra Costa County MS4 Area | 4.25 | 1.82 | 2.43 | 1.86 | 2.39 |
| **Watershed Atlas Subarea** | | | | | |
| West Delta | 3.2 | 1.23 | 1.97 | 1.23 | 1.97 |
| Central Delta | 0.75 | 0.41 | 0.34 | 0.41 | 0.34 |
| Marsh Creek | 0.3 | 0.74 | -0.44 | 0.81 | -0.51 |
| Total East Contra Costa County MS4 Area | 4.25 | 2.38 | 1.87 | 2.45 | 1.8 |

1. A positive difference between wasteload allocation and predicted load indicates that the wasteload allocation has been achieved. A negative value indicates that the wasteload allocation has not been achieved.

Methylmercury loads are predicted to increase slightly for Marsh Creek and West Delta in future conditions relative to the modeled baseline due to increased runoff from new impervious areas with projected development[9]. The overall loads are larger for the Watershed Atlas subareas relative to the TMDL subareas because the total watershed areas are larger. As in the baseline condition, future West Delta and Central Delta conditions are predicted to be less than the

[9] Runoff volumes are projected to increase even though new impervious area was modeled to be treated per the required water quality design standards (80% capture of average annual runoff volume) and infiltration was supported by underlying soils, see Appendix A.

wasteload allocation. However, the predicted methylmercury load in stormwater runoff from the Marsh Creek subarea exceeds the wasteload allocation by 0.20 g/year in 2030 and 0.24 g/year in 2040 for the TMDL subareas, and by 0.44 g/year in 2030 and 0.51 g/year in 2040 for the Watershed Atlas subareas. The combined East Contra Costa County MS4 discharges (i.e., the total of the three subareas) are predicted to achieve the methylmercury wasteload allocation in 2030.

*Scenario 2: 85% GSI Methylmercury Load Reduction through Treatment*

The results of the RAA modeling for methylmercury for the TMDL and Watershed Atlas subareas for Scenario 2 are summarized in Table 5-5 (concentration results) and Table 5-6 (load results) below.

**Table 5-5: Scenario 2 Methylmercury Concentration Results from the RAA Model**

| Subarea within Contra Costa County | Baseline Methylmercury Concentration[1] (ng/L) | 2030 Methylmercury Concentration[1,2] (ng/L) | 2040 Methylmercury Concentration[1,2] (ng/L) |
|---|---|---|---|
| **TMDL Subarea** | | | |
| West Delta | 0.18 | 0.15 | 0.15 |
| Central Delta | 0.19 | 0.18 | 0.18 |
| Marsh Creek | 0.18 | 0.16 | 0.14 |
| **Watershed Atlas Subarea** | | | |
| West Delta | 0.18 | 0.17 | 0.17 |
| Central Delta | 0.20 | 0.13 | 0.13 |
| Marsh Creek | 0.18 | 0.15 | 0.13 |

1. (Wet Weather Methylmercury Load in RAA Development Scenario / Average Annual Wet Weather Runoff Volume) * unit conversions.
2. The methylmercury concentration used to calculate the TMDL wasteload allocation is 0.24 ng/L.

As with Scenario 1, methylmercury concentrations are predicted to decrease with implementation of GSI from the baseline concentration in both 2030 and 2040 in the three subareas. The predicted concentrations are less than the methylmercury concentration used to calculate the TMDL wasteload allocations (0.24 ng/L).

**Table 5-6: Scenario 2 Methylmercury Load Results from the RAA Model**

| Subarea within Contra Costa County | CVRWQCB (2010a) Wasteload Allocation (g/year) | 2030 Methylmercury Load (g/year) | 2030 Difference Between Wasteload Allocation and Predicted Load (g/year)[1] | 2040 Methylmercury Load (g/year) | 2040 Difference Between Predicted Load and Wasteload Allocation (g/year)[1] |
|---|---|---|---|---|---|
| **TMDL Subarea** | | | | | |
| West Delta | 3.2 | 1.01 | 2.19 | 1.00 | 2.20 |
| Central Delta | 0.75 | 0.26 | 0.49 | 0.26 | 0.49 |
| Marsh Creek | 0.3 | 0.48 | -0.18 | 0.47 | -0.17 |
| Total East Contra Costa County MS4 Area | 4.25 | 1.75 | 3.21 | 1.73 | 2.52 |
| **Watershed Atlas Subarea** | | | | | |
| West Delta | 3.2 | 1.22 | 1.98 | 1.21 | 1.99 |
| Central Delta | 0.75 | 0.37 | 0.38 | 0.36 | 0.39 |
| Marsh Creek | 0.3 | 0.69 | -0.39 | 0.69 | -0.39 |
| Total East Contra Costa County MS4 Area | 4.25 | 2.28 | 1.97 | 2.26 | 1.99 |

1. A positive difference between wasteload allocation and predicted load indicates that the wasteload allocation has been achieved. A negative value indicates that the wasteload allocation has not been achieved.

Loads are predicted to decrease slightly for West, Central, and Marsh Creek subareas in future conditions relative to the modeled baseline due to the increased assumed load reductions in the treated runoff. As in the baseline condition, future West Delta and Central Delta conditions are predicted to be well under the wasteload allocation. However, the estimated methylmercury load in stormwater runoff from the Marsh Creek subarea is predicted to exceed the wasteload allocation by 0.18 g/year in 2030 and 0.17 g/year in 2040 for the TMDL subareas, and by 0.39 g/year in both 2030 and 2040 for the Watershed Atlas subareas. As with Scenario 1, the combined East Contra Costa County MS4 discharges (i.e., the total of the three subareas) are predicted to achieve the methylmercury wasteload allocation in 2030.

The projected rate of methylmercury load reduction within the Marsh Creek subarea between 2020 and 2040 in Scenario 2 was extrapolated into the future to estimate when the wasteload allocation could be achieved within the Marsh Creek subarea. The projected rate of methylmercury load reduction through GSI implementation within this subarea is approximately 0.003 g/yr per decade. Maintaining this load reduction rate into the future would require approximately 56 decades (560 years) to achieve the Marsh Creek wasteload allocation.

## 5.2 Uncertainty Analysis

There are two types of uncertainty in this analysis: modeling uncertainty and planning uncertainty. The RAA (Appendix A) discusses modeling uncertainty, whereas planning uncertainties are summarized in this section. The estimate of achieving the methylmercury wasteload allocation is based on several assumptions that introduce planning uncertainties. Although the RAA result that the East Contra Costa County Permittees will not achieve the methylmercury wasteload allocation is reasonably certain (i.e., not likely to change due to changed assumptions), a discussion of planning uncertainties that lead to uncertainty in the RAA results is provided below.

Changes in large-scale processes can be difficult to predict and can introduce substantial planning uncertainties. Climate change, long-term meteorological patterns, and large seismic events could each significantly affect the watershed transport of polluted sediments. These can also include economic or socio-economic, and political shifts, which may be either planned (e.g., Federal Infrastructure Projects that create GSI funding opportunities) or unplanned (e.g., the 2020 COVID-19 pandemic).

Major changes in large-scale processes can impact the actuality of some of the assumptions in the pollutant loading model as well as the future implementation scenarios. These may include changes to total area contributing to loading, for example, as a result of sea level rise; changes to annual loading due to increases or decreases in average annual stormwater runoff volume as a result of precipitation or flooding changes caused by long-term meteorological patterns and/or climate change; or changes to loading and/or redevelopment rates as a result of a seismic event. Economic or socio-economic impacts and political shifts can also affect future implementation scenarios, causing increases or decreases in the amount of private investment and public funds for development and control measure implementation and/or changes in the ability to provide services that are needed for implementation. The examples provided represent just a small fraction of the range of possibilities; many of these large-scale phenomena are very challenging to predict. As such, they are even more difficult to model and, in many cases, represent scenarios that may not happen, and/or the timeframe for when they occur cannot be estimated.

## 6. CONCLUSIONS

This report answers the questions from MRP Provision C.19.d.ii.(1)(f):

- What are the annual mercury and methylmercury loads from the MS4 discharge to the Central Delta, Marsh Creek, and West Delta subareas?
- Do the mercury and methylmercury load from each subarea meet the assigned methylmercury wasteload allocations?
- What is the achievable mercury and methylmercury load reduction in discharges from the MS4 by implementation of reasonable, foreseeable control measures?
- What controllable MS4 water quality factors affect methylmercury production and transport in the MS4 discharge and in the receiving waters draining to the Delta?
- Are there MS4 design features that increase or decrease mercury methylation?
- Are there reasonable and foreseeable management actions to reduce methylmercury concentrations within the MS4 boundary?

The Central Delta and West Delta subareas comply with the TMDL wasteload allocations. Achieving the TMDL-required methylmercury wasteload allocation for urban stormwater in the Marsh Creek subarea by 2030 is infeasible. Achieving this wasteload allocation within this century would require capital and labor resources beyond the means of the Permittees. The foreseeable time frame for achieving the required methylmercury load reductions using reasonable, foreseeable control measures in the Marsh Creek subarea is 56 decades. When considered as a whole, the combined East Contra Costa County MS4 discharges are predicted to achieve the methylmercury wasteload allocation in 2030.

Dividing load reduction control measures into categories of “scalable” and “fixed” benefits helps evaluate alternatives for compliance. Control measures with fixed benefits cannot practically be increased in scope to achieve load reductions sooner or in greater measure. Scalable control measures (e.g., GSI or enhanced O&M) increase load reduction in proportion to implementation – more acres treated leads to more loads reduced. Scaling up the number of GSI projects is practically and economically infeasible. Redevelopment creates the most likely path to achieving methylmercury load reduction goals; however, the schedule for redevelopment is cyclic and cannot be foreseen, leading to planning uncertainty about when methylmercury load reduction goals will be achieved. Municipalities lack the funding and opportunity areas to implement GSI in the public right-of-way at a rate that would close the gap in TMDL attainment. The $10 million to $55 million in total costs associated with the full implementation of the public projects in the Permittees' GSI plans would not be procured for the single purpose of achieving methylmercury TMDL goals but rather as an outcome of community development for multiple benefits.

In summary, this TMDL Control Measure Plan presents a programmatic approach to implementing known and effective mercury and methylmercury control measures. The programmatic approach will lead to ongoing mercury and methylmercury load reductions over time, depending on the rate of GSI implementation achieved. This quantitative analysis showing the linkage between schedule and feasibility supports the finding that the TMDL wasteload allocation assigned to the East Contra Costa County Permittees in the Marsh Creek watershed is unachievable in this century.

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# APPENDIX A

## Contra Costa Clean Water Program Reasonable Assurance Analysis Report

CONTRA COSTA CLEAN WATER PROGRAM

# *EAST CONTRA COSTA REASONABLE ASSURANCE ANALYSIS FOR TOTAL MERCURY AND METHYLMERCURY*

***Submitted in Compliance with Provision C.19.d.ii(1)***

***Municipal Regional Stormwater Permit***
***NPDES Permit No. CAS612008***
***Order No. R2-2022-0018***

## *Final Draft October 2022*

***The Contra Costa Clean Water Program – A Municipal Stormwater Program consisting of Contra Costa County, its 19 Incorporated Cities/Towns, and the Contra Costa County Flood & Water Conservation District***

This report is submitted by the agencies of the

**Program Participants:**

- Cities of: Antioch, Brentwood, Clayton, Concord, Danville (Town), El Cerrito, Hercules, Lafayette, Martinez, Moraga (Town), Oakley, Orinda, Pinole, Pittsburg, Pleasant Hill, Richmond, San Pablo, San Ramon and Walnut Creek
- Contra Costa County
- Contra Costa County Flood Control & Water Conservation District


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Contra Costa Clean Water Program

## LIST OF ACRONYMS

| | |
|---|---|
| ac-ft | acre-feet |
| BASMAA | Bay Area Stormwater Management Agencies Association |
| BMP | Best Management Practices |
| CCCWP | Contra Costa Clean Water Program |
| CVRWQCB | Central Valley Regional Water Quality Control Board |
| DMCP | Delta Mercury Control Program |
| g | gram |
| GSI | Green Stormwater Infrastructure |
| GIS | Geographic Information System |
| HRU | Hydrologic Response Unit |
| L | liter |
| MeHg | methylmercury |
| mg | milligram |
| mg/kg | milligram per kilogram |
| MRP | Municipal Regional Permit |
| MS4 | Municipal Separate Storm Sewer System |
| ng | nanogram |
| NPDES | National Pollutant Discharge Elimination System |
| RAA | Reasonable Assurance Analysis |
| SFBRWQCB | San Francisco Bay Regional Water Quality Control Board |
| SWMM | Stormwater Management Model |
| TMDL | Total Maximum Daily Load |
| µg | microgram |
| WLA | Wasteload Allocation |
| WY | Water Year |

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## Executive Summary

This report summarizes the results of the mercury and methylmercury reasonable assurance analysis (RAA) modeling conducted by Geosyntec Consultants (Geosyntec) for the Contra Costa Clean Water Program (CCCWP) on behalf of the East Contra Costa County (East County) Permittees[1]. Provision C.19.d.ii.(1) of the revised Municipal Regional Stormwater Permit (MRP, NPDES Permit No. CAS612088, Order No. R2-2022-0018) requires the East County Permittees to prepare a plan and schedule for total mercury and methylmercury control measure implementation and a corresponding reasonable assurance analysis.

The RAA analysis addresses the following questions in MRP Provision C.19.d.ii.(1)(f):

- What are the annual mercury and methylmercury loads from the municipal separate storm sewer system (MS4) discharge to the Central Delta, Marsh Creek, and West Delta subareas?
- Do the mercury and methylmercury load to each subarea meet the assigned methylmercury wasteload allocations?
- What is the achievable mercury and methylmercury load reduction in discharges from the MS4 by implementation of reasonable, foreseeable control measures?

To address these questions, Geosyntec performed RAA modeling to estimate mercury and methylmercury pollutant loads discharged from the East County Permittees' MS4s for the three scenarios described below.

The **Baseline Scenario** models the existing condition corresponding to water years 2000 - 2009 for the three TMDL subareas in Eastern Contra Costa County (i.e., the West Delta, Central Delta, and Marsh Creek subareas, see Figure 1). The Baseline Scenario estimated that the West and Central Delta urban stormwater methylmercury loads are approximately 1.02 grams per year (g/yr) and 0.27 g/yr. These results are less than the respective TMDL wasteload allocations of 3.2 and 0.75 g/yr. The baseline urban stormwater methylmercury load for the Marsh Creek subarea, 0.48 g/yr, is greater than the wasteload allocation of 0.3 g/yr. The baseline East County RAA results for mercury indicate that estimated pollutant concentrations are below the California Toxics Rule (CTR) criteria of 0.05 ug/L (or 50 ng/L) as required by the permit.

[1] The East County Permittees include the cities of Antioch, Brentwood, Oakley, and the eastern portions of unincorporated Contra Costa County and the Contra Costa County Flood Control & Water Conservation District.

To address whether reasonable, foreseeable control measures can help achieve the target load, the **Green Stormwater Infrastructure (GSI) Implementation Scenario** included projected private new development and redevelopment and planned public GSI retrofit implementation by 2030 and 2040. The estimated future methylmercury loads in stormwater runoff from the Marsh Creek subarea with GSI was estimated to exceed the wasteload allocation in 2030 and 2040. Future condition loads for West and Central Delta were found to be well under the respective wasteload allocations. The GSI Implementation Scenario for mercury indicated that all urban stormwater in all the subareas have mercury concentrations that are below the threshold CTR mercury concentration.

Geosyntec performed a third modeling scenario (the **GSI Treatment Reduction Scenario**) to further address whether reasonable, foreseeable control measures could be implemented to achieve the methylmercury wasteload allocation for Marsh Creek. For this scenario, the model incorporated an 85% methylmercury load reduction for treated runoff based on the results from a City of Citrus Heights stormwater treatment effectiveness study (LWA, 2015). In contrast, the GSI Implementation Scenario conservatively reduced methylmercury loads through infiltration only and assumed no methylmercury reduction through treatment. The GSI Reduction Scenario resulted in an approximate 5% reduction in methylmercury loads in urban stormwater within the Marsh Creek subarea relative to the GSI Implementation Scenario. However, the total estimated future methylmercury load, at 0.48 g/yr for 2030 and 0.47 g/yr for 2040, was still greater than the wasteload allocation of 0.3 g/yr. Extrapolating the projected rates of redevelopment and associated methylmercury load reductions in the Marsh Creek subarea, it would take approximately 56 decades (560 years) to achieve the wasteload allocation of 0.3 g/yr.

The East County RAA results demonstrate that with reasonable, foreseeable control measures, mercury concentrations are below the CTR for mercury in all subareas. Based on the assumptions and outcomes of the RAA, while the West and Central Delta methylmercury TMDL wasteload allocations can be met with reasonable, foreseeable control measures, it is infeasible to meet the Marsh Creek wasteload allocation through GSI implementation.

Although the Marsh Creek wasteload allocation is infeasible, the predicted methylmercury loads for all three subareas combined for 2030 and 2040 in the GSI Treatment Reduction Scenario are less than the combined methylmercury wasteload allocation.

# 1. INTRODUCTION

## 1.1 Purpose

This *Reasonable Assurance Analysis for Total Mercury and Methylmercury* report was prepared by the Contra Costa Clean Water Program (CCCWP) as required by the Municipal Regional Permit (MRP) for urban stormwater issued by the San Francisco Bay Regional Water Quality Control Board (SFBRWQCB; Order No. R2-2022-0018). This report fulfills the requirements of MRP Provision C.19.d.ii.(1) for providing a reasonable assurance analysis (RAA) for total mercury and methylmercury corresponding with the *East Contra Costa Methylmercury Control Measure Plan and Reasonable Assurance Analysis* (Geosyntec, 2022).

The following MRP Provision C.19.d.ii.(1) requirements are addressed within this report:

- The RAA for total mercury must be evaluated using the California Toxics Rule for mercury (0.05 µg/L).
- The RAA for methylmercury must be evaluated using the methylmercury load allocations specific to each Delta subarea within Contra Costa County subject to the Delta Mercury Control Plan (DMCP) (i.e., the Central Delta, Marsh Creek, and West Delta subareas).
- The RAA shall demonstrate quantitatively that the plan will result in mercury and methylmercury load reductions sufficient to attain the methylmercury wasteload allocations by January 1, 2030, (or any revised final compliance date adopted by the Central Valley Regional Water Quality Control Board (Central Valley Water Board) as part of the DMCP review) and address the following questions:
    i. What are the annual mercury and methylmercury loads from the MS4 discharge to the Central Delta, Marsh Creek, and West Delta subareas?
    ii. Do the mercury and methylmercury loads to each subarea meet the assigned methylmercury wasteload allocations?
    iii. What is the achievable mercury and methylmercury load reduction in discharges from the MS4 by implementation of reasonable, foreseeable control measures?
    iv. Are there reasonable and foreseeable management actions to reduce methylmercury concentrations within the MS4 boundary?"

This RAA Report describes the East County RAA model methodology and inputs used to answer the questions listed above. It is a companion report to the *East Contra Costa Methylmercury Control Measure Plan and Reasonable Assurance Analysis* (Geosyntec, 2022). Using the East

County RAA approach, this report presents estimates of the total mercury and methylmercury loads within MS4 discharges from the Central Delta, Marsh Creek, and West Delta subareas within the boundary of the Central Valley Regional Water Quality Control Board (CVRWQCB; Region 5) and estimates of load reductions through implementation of the control measures described in Section 2 of the *East Contra Costa Methylmercury Control Measure Plan*. This RAA Report also compares the model output with the methylmercury TMDL wasteload allocations included in the DMCP.

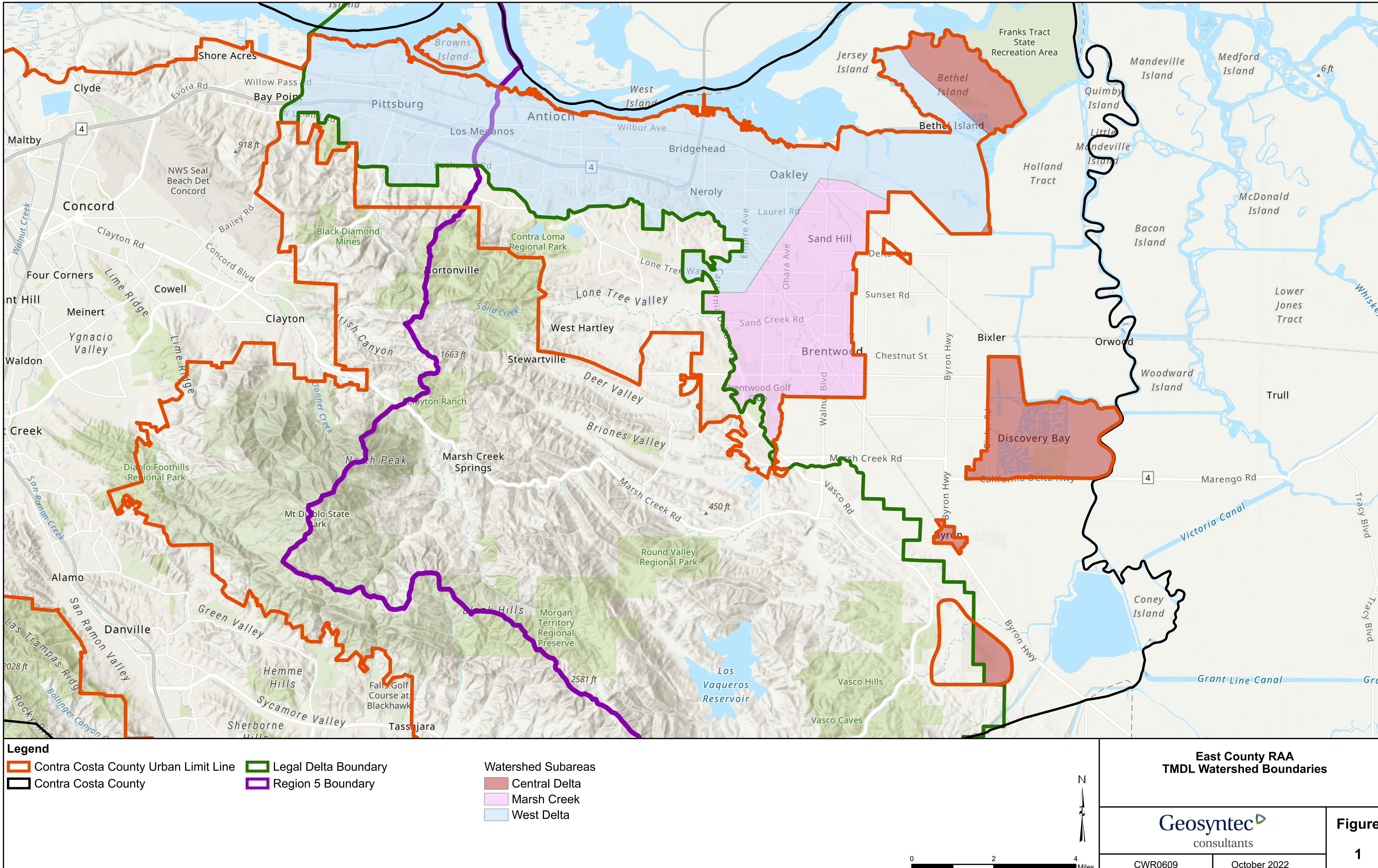
### 1.2 Geographic Scope

The East County RAA focuses on East County Permittee urban stormwater drainage areas (i.e., the areas within the East County Permittees' jurisdictional boundaries that are also within Region 5 and the urban limit line (Contra Costa County, 2021)). Figure 1 illustrates this area. The TMDL subareas, which are within the Legal Delta Boundary, do not match the hydrologically defined watersheds as delineated by the Contra Costa Watershed Atlas (Contra Costa County, 2004) (Figure 2). In this report, the combined area of analysis is referred to as the "East County Urban Stormwater Area of Analysis" or “Area of Analysis.” Results are reported for both the TMDL defined subarea boundaries as well as the hydrologic “Watershed Atlas subareas” within Region 5. This report provides an estimate of stormwater runoff volumes, pollutant loads, and pollutant concentrations associated with the individual subareas.

### 1.3 Delta Mercury Control Program

In April 2010, the Central Valley Water Board amended the Basin Plan to include the Sacramento-San Joaquin Delta Estuary (Delta) Mercury Control Program. The DMCP and the associated methylmercury Total Maximum Daily Load (TMDL) is being implemented through a phased approach; Phase 1 began October 20, 2011. At the end of Phase 1, the Basin Plan requires the CVRWQCB to review the Phase 1 requirements and to consider revising the DMCP and future requirements before starting Phase 2. If the CVRWQCB does not review and/or revise the DMCP by October 2022, the current load and waste load allocations would become immediately effective with a compliance date of 2030.

A phased approach was selected because additional information about methylmercury source control methods was needed to determine how and if dischargers can attain the current interim load and wasteload allocations listed in the TMDL (CVRWQCB, 2010b). Information was also needed about the methylmercury control methods' potential benefits and adverse impacts to humans, wildlife, and the environment. Therefore, Phase 1 emphasized studies and pilot projects to develop and evaluate management practices to control methylmercury.

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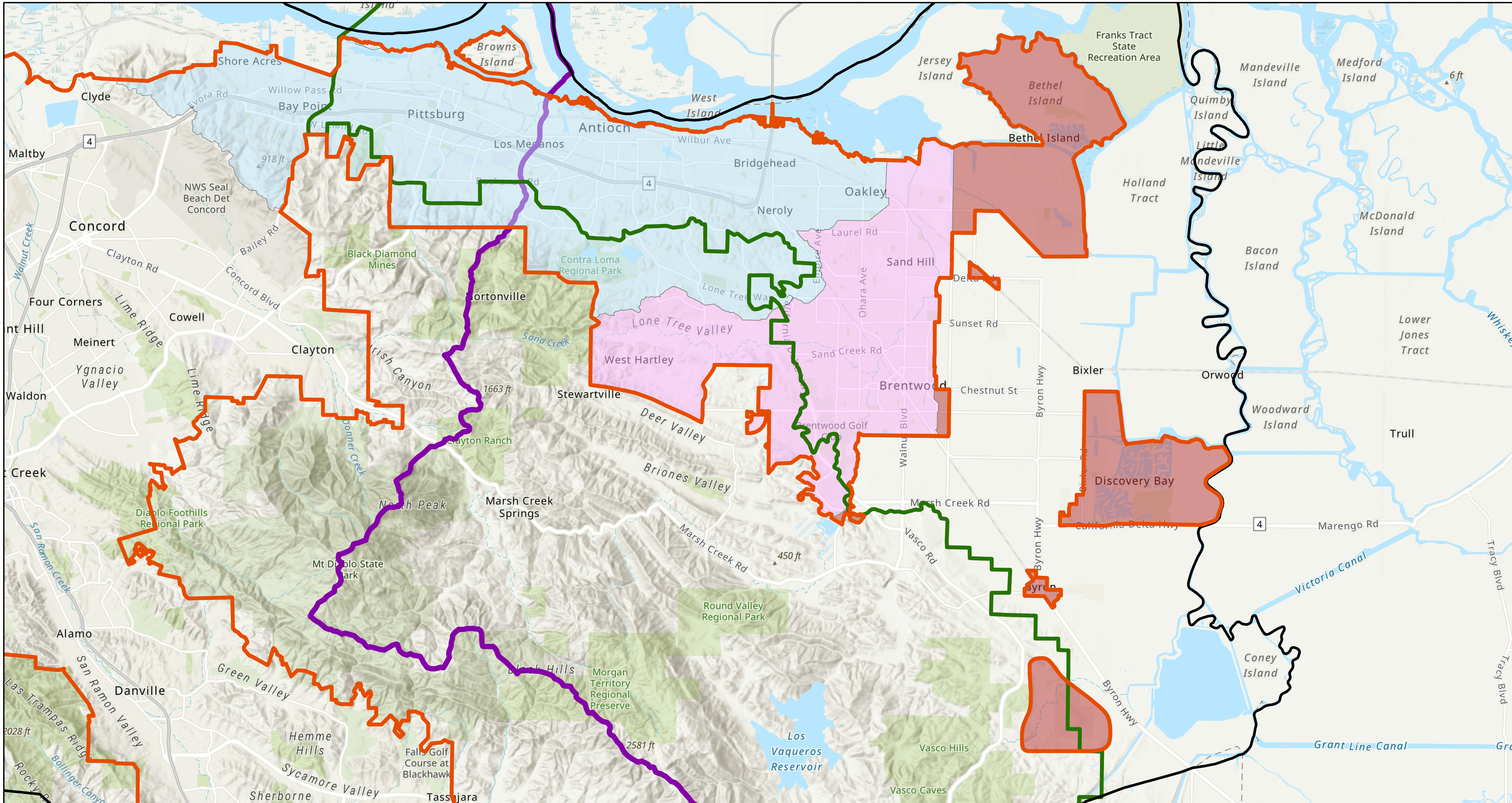


**Legend**

- Contra Costa County Urban Limit Line
- Contra Costa County
- Legal Delta Boundary
- Region 5 Boundary

Watershed Subareas

- Central Delta
- Marsh Creek
- West Delta

Note: Watershed delineation according to the Contra Costa Watershed Atlas (https://www.cccleanwater.org/userfiles/kcfinder/files/Watershed%20Atlas.pdf)

N

0 2 4 Miles

**East County RAA Watershed Atlas Boundaries**

Geosyntec consultants

CWR0609 | October 2022

**Figure 2**

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CVRWQCB staff are currently (as of Fall 2022) reviewing and, if necessary, will consider proposing modifications to the following DMCP components: aqueous methylmercury and inorganic mercury goals; site-specific water quality objectives, currently established to protect Commercial and Sport Fishing (COMM) and Wildlife Habitat (WILD) beneficial uses; linkage analysis; allocations; the final compliance date; and requirements and schedules for implementation of methylmercury management practices. CVRWQCB staff are also evaluating other potential public and environmental benefits and negative impacts (e.g., habitat restoration, flood protection, water supply, fish consumption) of implementing methylmercury management practices. Modifications to the DMCP will be based on the findings of the Phase 1 control studies and other recent information (CVRWQCB, 2021).

### 1.3.1 TMDL Baseline Load and Concentration

Section 8 of the Delta Methylmercury TMDL Staff Report (TMDL Staff Report; CVRWQCB, 2010b) includes an estimated baseline average annual methylmercury load (in grams per year (g/yr)) and concentration (in nanograms per liter (ng/L)) in urban runoff for the TMDL subareas. Table 1 below lists the baseline annual average methylmercury load and concentration in MS4 discharges from the TMDL Staff Report (CVRWQCB, 2010b). Geosyntec calculated the average annual MS4 runoff volume (acre-feet per year (ac-ft/yr)) in Table 1 using these values, as the TMDL Staff Report (CVRWQCB, 2010b) does not provide the average annual runoff volume directly.

**Table 1: Baseline Average Annual MS4 Methylmercury Load, Concentration, and Runoff Volume by TMDL Subarea in Contra Costa County**

| Subarea within Contra Costa County | Baseline Average MS4 MeHg Load (g/yr)[1] | Baseline Average MS4 MeHg Concentration (ng/L)[1] | Baseline Annual MS4 Volume (ac-ft/yr)[2] |
|---|---|---|---|
| West Delta | 3.2 | 0.24 | 10,810 |
| Central Delta | 0.75 | 0.24 | 2,533 |
| Marsh Creek | 1.2 | 0.24 | 4,054 |

1. From Tables 8.4a, 8.4b, and 8.4f of CVRWQCB (2010).
2. Calculated as (Existing MeHg Load (g/yr) / Existing Average MeHg Concentration (ng/L)) * unit conversions.

Geosyntec calculated the average annual dry weather and wet weather urban runoff methylmercury load, concentration, and volume for the portions of the subareas within Contra Costa County using the data and methods provided in the TMDL Staff Report (CVRWQCB, 2010b). Key inputs to the dry weather load calculation are provided in Table 2 below.

**Table 2: Key Inputs to Dry Weather Load Calculation**

| Subarea within Contra Costa County | Urban Area in Contra Costa County (acres)[1] | Dry Weather Runoff Volume (acre-ft/yr)[2] | Average Dry Weather MeHg Concentration in Urban Runoff (ng/L)[3] | Dry Weather MeHg Load (g/yr)[4] |
|---|---|---|---|---|
| West Delta | 9,518 | 2,263 | 0.363 | 1.0 |
| Central Delta | 2,181 | 519 | 0.363 | 0.23 |
| Marsh Creek | 3,427 | 815 | 0.363 | 0.36 |

1. From Table 6.10 of CVRWQCB, 2010b.
2. Calculated as (234 gallons/acre/day * 305 dry days/year for the WY 1984-2003 period * urban area (acres) * unit conversions) per calculation summarized in Appendix E.2.3 of CVRWQCB, 2010b.
3. As presented in Section 6.2.5 of CVRWQCB, 2010b.
4. Calculated as (Dry Weather MeHg Concentration (ng/L) * Dry Weather Runoff Volume (ac-ft/yr)) * unit conversions.

The baseline wet weather runoff volume and load were calculated as the difference between the total average annual runoff load and volume minus the dry weather load and volume, respectively, (calculated per data and methods presented in the TMDL Staff Report (CVRWQCB, 2010b)) and are presented in Table 3 below.

**Table 3: Existing Average Annual Wet Weather Methylmercury Load by TMDL Subarea**

| Subarea within Contra Costa County | Wet Weather Runoff Volume (ac-ft/yr)[1] | Wet Weather MeHg Load (g/yr)[2] | Calculated MeHg Concentration (ng/L)[3] |
|---|---|---|---|
| West Delta | 8,547 | 2.2 | 0.21 |
| Central Delta | 2,015 | 0.52 | 0.21 |
| Marsh Creek | 3,239 | 0.84 | 0.21 |

1. Total Average Annual Runoff Volume (ac-ft/year) from Table 1 – Average Annual Dry Weather Runoff Volume (ac-ft/year) from Table 2.
2. Total Average Annual MeHg Load (g/year) from Table 1 – Average Annual Dry Weather MeHg Load (g/year) from Table 2.
3. The average urban runoff methylmercury concentration reported in the TMDL Staff Report (CVRWQCB, 2010), Table 6.11, is 0.241 ng/L.

Most inputs to the wet weather runoff volume and load calculation are summarized within Appendix E of the TMDL Staff Report (CVRWQCB, 2010b); although the estimated runoff coefficients specific to the Contra Costa County portions of the subareas are not reported. Per Appendix E of the TMDL Staff Report, runoff volume was calculated using average annual precipitation at the Stockton Fire Station 4 rain gauge for water years (WY) 2000 to 2003 and the rational method[2]. Key inputs and estimates for average annual wet weather methylmercury load and runoff volume as described in Appendix E of the TMDL Staff Report are provided in Table 4 below.

**Table 4: Existing Average Annual Wet Weather Estimates by TMDL Subarea per TMDL Staff Report Appendix E**

| Subarea within Contra Costa County | Wet Weather Runoff Volume (ac-ft/yr)[1] | Annual Precipitation (inches)[2] | Runoff Generating Area (acres)[3] | Urban Area (acres)[4] | Calculated Runoff Coefficient[5] |
|---|---|---|---|---|---|
| West Delta | 8,547 | 16.6 | 6,178 | 9,518 | 0.65 |
| Central Delta | 2,015 | 16.6 | 1,457 | 2,181 | 0.67 |
| Marsh Creek | 3,239 | 16.6 | 2,341 | 3,427 | 0.68 |

1. See Table 3.
2. From Table E.3 of CVRWQCB, 2010b for WY 2000-2003 at Stockton Fire Station 4.
3. Calculated as Wet Weather Runoff Volume/ Average Annual Precipitation * unit conversions (i.e., equivalent to C*A)
4. From Table 6.10 of CVRWQCB, 2010b.
5. Calculated as (Runoff Generating Area / Total Area (acres)).

## 2. RAA METHODOLOGY

This section describes the East County RAA hydrologic and water quality modeling. The methodology includes a hydrologic model, a geospatial computation to estimate associated water quality, and GSI performance models. The methodology builds on the methodology, model files, and outputs developed by the CCCWP for the *Contra Costa PCBs and Mercury TMDL Control Measure Plan and Reasonable Assurance Analysis* report (Countywide RAA) conducted in compliance with the requirements of the previous MRP (NPDES Permit No. CAS612088, Order No. R2-2015-0049) to address the San Francisco Bay PCBs and mercury TMDLs (CCCWP, 2020a). While the Countywide RAA results focused on loading from the Contra Costa watersheds within the San Francisco Bay Regional Water Quality Control Board boundary (Region 2), the RAA model was developed countywide, thus hydrologic results for East County are available for use for the East County RAA.

[2] The rational method is a widely used approach (including in CVRWQCB (2010)) to estimate runoff volume according to the formula: $Q=CiA$, where $C$ is a runoff coefficient, $i$ is the annual rainfall, and $A$ is the sub-catchment area.

The East County RAA model was used to estimate baseline watershed and urban stormwater loads of mercury and methylmercury for the TMDL subareas within East County and the future urban stormwater loads of these pollutants with implementation of GSI measures.

## 2.1 Hydrologic Model

East County RAA hydrology was modeled using the hydrologic response unit (HRU) model developed for the Countywide RAA. An HRU is a unique combination of land surface features (imperviousness, underlying soil characteristics, slope, etc.) expected to give a consistent runoff response to rainfall, no matter where that unique combination is found. The HRU approach involves modeling all possible combinations of land surface features and rainfall present within the model area of interest (in this case, the East County Urban Stormwater Area of Analysis) using a unit area drainage catchment for each HRU and then storing these results in a database. These HRU results can be scaled geospatially across the Area of Analysis without developing a detailed hydrologic model, based on the varying combination of land surface features and rainfall within the Area of Analysis.

The generic HRUs are modeled using USEPA's Stormwater Management Model (SWMM) to obtain an average annual runoff volume per acre for the identified baseline rainfall period of record for each HRU. The average annual runoff volume per acre associated with a specific HRU is then multiplied by the area represented by that HRU within the Area of Analysis. The resulting volumes associated with each represented HRU within the specified Area of Analysis are then summed to obtain the estimated total average annual runoff volume for the baseline period of record.

### 2.1.1 HRU Model Input Parameters

There are several inputs varied in the HRU models to obtain a range of average annual runoff. These inputs include climate data, development status, slope, soil parameters, and imperviousness.

#### *2.1.1.1 Overview of HRU Input Parameters*

HRUs are identified across the Area of Analysis based on the geospatial characteristics matching the parameters defined in **Table 5** below. Details of each HRU variable is provided in the following sections.

**Table 5: Land Surface Feature Inputs for Generic HRU Hydrologic Models**

| Variables | Description | Number of Varying Features | Feature Representations | Source |
|---|---|---|---|---|
| Hourly Annual Precipitation | Rainfall Gauge and Rainfall Zone | 7 | Contra Costa County Gauge IDs: DBF, FCD, LSM | PRISM[1], NCDC/ County-maintained rainfall gauges |
| Daily Evapotranspiration Rate | Evapotranspiration Zone | 5 | CIMIS Zones 8, 14 | CIMIS[2] |
| Slope Zone | Representation of Slope | 3 | <5%, 5-15%, 15%+ | USGS[3] |
| Developed/ Undeveloped Areas | Representation of Compaction of Underlying Soils (Pervious Areas Only) | 2 | Undeveloped (Ksat * 1) Developed (Ksat * 0.75) | ABAG Land Use 2005[4] |
| Hydrologic Soil Group | Representation of Underlying Soil Type (pervious areas only) | 6 | HSG A, B, C, D[5], Rock, Water | NRCS[6] |
| Imperviousness | Representation of Imperviousness | 2 | 0% and 100% | NLCD and ABAG 2005 |

1. PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, 30-year normal mean annual precipitation
2. California Irrigation Management Information System (CIMIS) Reference Evapotranspiration; digitized from http://www.cimis.water.ca.gov/App_Themes/images/etozonemap.jpg
3. U.S. Geological Survey. National Elevation Dataset (NED) 1/3 arc-second. 2013
4. Association of Bay Area Governments (ABAG) land uses are proposed to identify developed and undeveloped conditions and have an imperviousness value assigned based on geospatial analysis of the 2006 NLCD Imperviousness layer.
5. "Urban" representation was re-classified based on the dominant adjacent HSG.
6. U.S. Department of Agriculture, Natural Resources Conservation Service. Soil Survey Geographic (SSURGO) database. 2016

The detailed SWMM model input parameters used for the HRU models are summarized in Table 6 below. Additional information about the RAA model is provided in the *Quantitative Relationship Between Green Infrastructure Implementation and Mercury Load Reductions Report* (CCCWP, 2018) and the *CCCWP RAA Modeling Report and Peer Review Package*, which is included herein in Appendix C. Rainfall data, baseline period, and soils inputs for the East County RAA model are further described below.

## Table 6: SWMM Parameter Input Values

| Parameter | Description & Source[1] | Unit | Value |
|---|---|---|---|
| Infiltration Model | Controls how infiltration of rainfall into the upper soil zone of sub-catchments is modeled in SWMM. | -- | Green Ampt, see parameters in Table 1.H-2 |
| Routing Method | Determines the method used to route flows through the system in SWMM. | -- | Kinematic Wave |
| Reporting Time Step | *Model time step input.* | Minutes | 5 |
| Dry Weather Time Step | *Model time step input.* | Minutes | 240 |
| Wet Weather Time Step | *Model time step input.* | Minutes | 5 |
| Routing Time Step | *Model time step input.* | Seconds | 30 |
| Flow Path Length | Overland flow path length assumed for sheet flow runoff. The selected default inputs represent typical overland sheet flow path lengths for undeveloped/open space areas and developed/urban areas. | Feet | 500 (Existing non-developed condition; development footprint) |
| | | | 250 (Proposed developed condition; development footprint) |
| N-Imperv | Manning's roughness for impervious or pervious surfaces. | -- | 0.012 (corresponds to smooth concrete) |
| N-Perv | | -- | 0.25 (corresponds to dense grass) |
| Dstore-Imperv | Depth of depression storage (i.e., the maximum surface storage provided by ponding, surface wetting, and interception) for impervious and pervious surfaces. | Inches | 0.1, 0.075, and 0.05 for slopes of 3%, 7.5%, and 15%, respectively |
| Dstore-Perv | | Inches | 0.2, 0.15, and 0.1 for slopes of 3%, 7.5%, and 15%, respectively |
| %Zero-Imperv | Percent of the impervious area with no depression storage. | % | 25 |
| Groundwater | -- | - | Not simulated |
| Snowmelt | -- | - | Not simulated |

[1] Source of description and selected model input values obtained from USEPA, 2015 unless otherwise indicated.

### *2.1.1.2 Rainfall Data and Baseline Period*

For the Area of Analysis, three precipitation gauges are used corresponding with different climate zones within the Area of Analysis (see Figure 3). Details of these gauges are provided in **Table 7** below.

**Table 7: East County Urban Stormwater Area of Analysis Precipitation Gauges**

| Gauge ID | Gauge Name | Average Annual Precipitation (inches) WY 2000 - 2009 | Gauge Source |
|---|---|---|---|
| DBF | Dublin Fire Station, San Ramon | 17.3 | CCCFCD[1] |
| FCD | Flood Control District, Martinez | 16.2 | CCCFCD |
| LSM | Los Medanos, Pittsburg | 11.8 | CCCFCD |

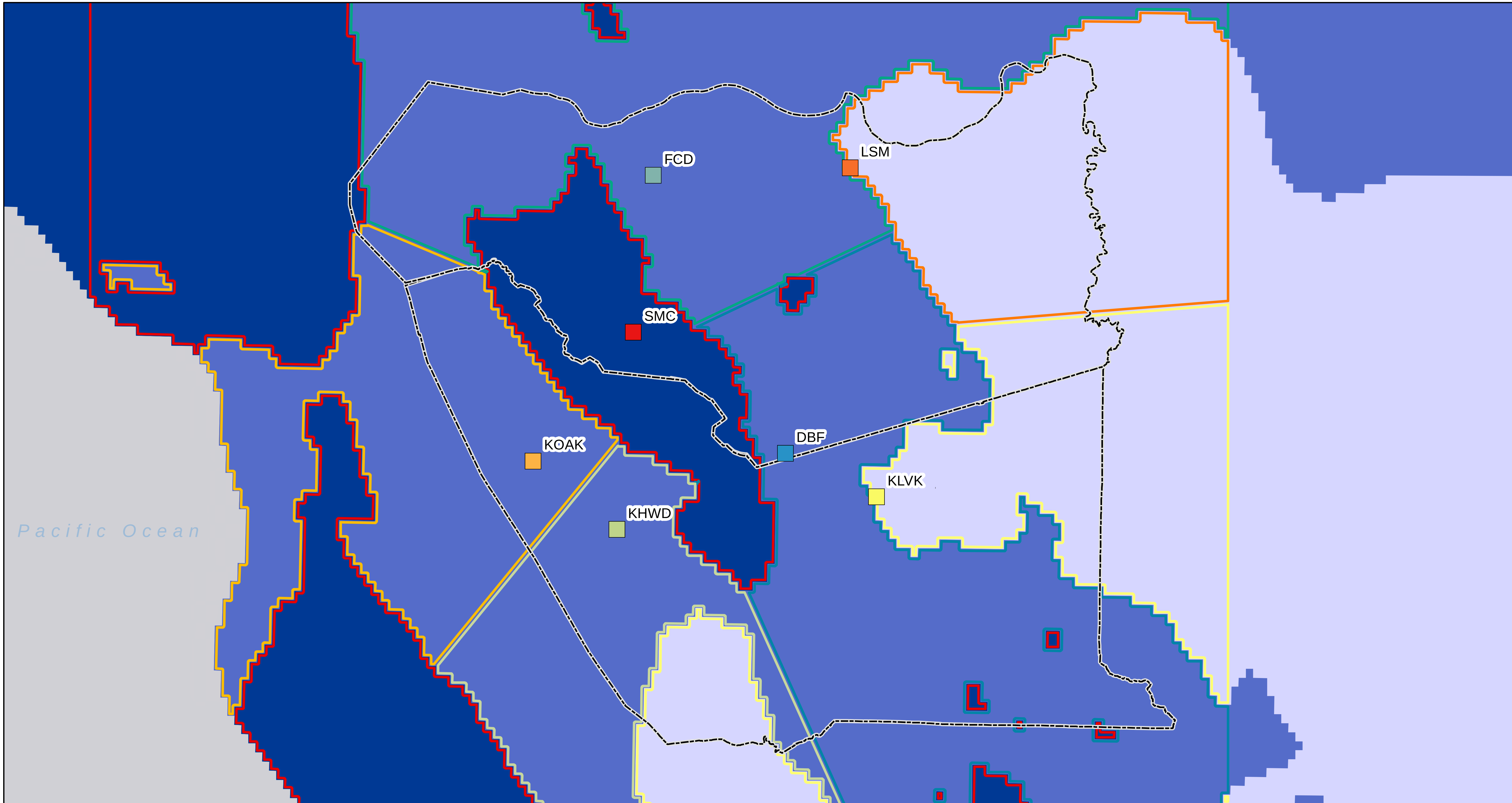
1. Contra Costa County gauge data is collected by the Flood Control District but was provided to Geosyntec by Dubin Engineering.

The Countywide RAA utilized a 10-year period of rainfall data for modeling for WYs 2000 – 2009. This same period of record was used for the East County RAA. This period of record is considered reasonably representative of the baseline period included in the TMDL Staff Report.

The same period of record was used for both the Baseline and Green Infrastructure Plan Scenarios to estimate the load reduction resulting from the implementation of control measures. The modeling allows for isolation of the effect of the GSI control measures on mercury and methylmercury load reductions.

### *2.1.1.3 Soil Parameters*

For the Countywide RAA, the HRU based hydrologic model was calibrated using available flow gauge records for the baseline period of record in Alameda and Contra Costa counties. The variable adjusted for that calibration was the soil infiltration rate corresponding with the hydrologic soil groups present per the National Resource Conservation Service Web Soil Survey. The resulting calibrated soil parameters used in the HRU models are provided in **Table 8** below.




**Rain Gauge ID**

- Rain Gauge ID
- County Boundary

**Mean Annual Precipitation (in)**

- < 16
- 16 - 25
- > 25

**Rain Gauge Zones**

- DBF
- FCD
- KHWD
- KLVK
- KOAK
- LSM
- SMC

N

0 6 12 Miles

**Precipitation Zones for Baseline Runoff Period (WY 2000-2009)**

Alameda County and Contra Costa County
California

Geosyntec consultants

Oakland | October 2022

**Exhibit 1**

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**Table 8: Green-Ampt Soil Parameters**

| Hydrologic Soil Group | Prevalent Soil Texture Class | Saturated Soil Conductivity (in/hr) | | Suction Head[1] (in) | IMD[1] (in/in) |
|---|---|---|---|---|---|
| | | Existing Condition[1] | Developed Condition[2] | | |
| A | Sand, Loamy Sand | 2.5 | 1.88 | 2.61 | 0.34 |
| B | Sandy Loam | 0.3 | 0.23 | 6.02 | 0.22 |
| C | Loam | 0.15 | 0.11 | 10.4 | 0.13 |
| D | Clay | 0.1 | 0.08 | 7.4 | 0.17 |

[1] HSG A and B estimated based on texture class from Rawls et al. (1983); HSG C and D estimated through calibration, see the "Alameda Countywide Clean Water Program and Contra Costa Clean Water Program Reasonable Assurance Analysis Model Calibration and Validation" Memo [PR-5].

[2] Determined based on an assumption of 25% reduction of conductivity due to compaction.

Of the Watershed Atlas-defined watersheds in the Area of Analysis, flow data is only available at the Marsh Creek gauge (USGS Gauge ID: 11337600), located in Lower Marsh Creek. Flow data available for Lower Marsh Creek are heavily influenced by a combination of detention ponds located in the watershed, reservoir flows, and other agricultural dry weather flows. During the countywide RAA development, the Marsh Creek gauge was explored for use along with the other flow gauges located within Alameda and Contra Costa County that were ultimately used for calibration. A variety of baseflow bias corrections were examined for the Marsh Creek gauge and found to not adequately isolate the wet weather response. Therefore, the HRU soil parameters were not recalibrated for the Area of Analysis as part of the East County RAA; the soil parameters listed above were used and considered to be regionally representative.

### 2.1.2 Baseline Urban Stormwater Runoff Volume

Average annual runoff volume output from the identified HRUs within the Area of Analysis were area-weighted and summed across the TMDL subareas. The average annual volume for the TMDL subareas were combined with the geospatial water quality model to estimate baseline mercury and methylmercury loading for the individual subareas.

## 2.2 Water Quality Model

Following extraction of hydrologic results, water quality calculations were performed to estimate the total mercury and methylmercury loading for the TMDL subareas. Total mercury loading was estimated using the approach used for the Countywide RAA and described in the *Quantitative Relationship Between Green Infrastructure Implementation and Mercury Load Reductions Report* (CCCWP, 2018). The *Reasonable Assurance Analysis Peer Review Package* (Geosyntec, 2019), which describes details of the RAA model and includes the *Quantitative Relationship Report*, is provided as Appendix C of this report.

Wet weather watershed methylmercury loading was estimated by applying a methylmercury-to-SSC particle ratio (SSC particle ratio) to estimate sediment loading from Area of Analysis. The regression analysis used to develop the SSC particle ratio presented in the *CCCWP Methylmercury Control Study* (CCCWP, 2020a) was updated to include three additional years of data collected in Marsh Creek. The updated SSC particle ratio for the Area of Analysis was estimated to be 1.7 ng methylmercury per gram SSC (ng/g) for all subareas (combined) and 1.7 ng/g for Marsh Creek only, with an associated $R^2$ of 0.54 and 0.51, respectively. Therefore, the SSC particle ratio of 1.7 ng/g was used for all three subareas. The resulting baseline total mercury and methylmercury load estimates were used to represent the baseline watershed loading, against which future loading (following application of GSI) was compared to examine the resulting load reduction.

Estimated sediment loading from the Area of Analysis was estimated by geospatially combining average annual stormwater volume model output for the baseline period of record, and land use-based sediment average annual concentrations based on the land uses in the Area of Analysis. Land uses within the Area of Analysis were identified using 2005 existing land use data, developed by the Association of Bay Area Governments in 2006 and published by the San Francisco Estuary Institute as part of their Regional Watershed Spreadsheet Model (RWSM).

Though the available methylmercury particle ratios are based on SSC, land use-based SSC data is not readily available in national and regional urban stormwater quality databases. Land use-based total suspended solids[3] (TSS) average annual concentrations were used to calculate sediment load discharged from the Area of Analysis subareas. Land use-based TSS concentration data were obtained from the National Stormwater Quality Database (NSQD), a database developed by the University of Alabama and the Center for Watershed Protection with support from the U.S. Environmental Protection Agency (Pitt, 2015), and statistically analyzed to estimate average annual concentrations. Details on the TSS average annual concentration statistical analysis are provided in Attachment A to this report. Based on the results of the statistical analysis, land uses were grouped into the following three categories with the associated TSS average annual concentration:

- Residential, Commercial, and Institutional: 92 mg TSS/L
- Freeway: 117 mg TSS/L

[3] The difference between TSS and SSC is explained in USGS (2000). Generally, SSC is considered more reliable for surface water assessments, and tends to be somewhat higher compared to TSS measurements made on the same sample. TSS is an acceptable parameter for modeling and estimating loads; when comparing monitored vs. modeled loads, the tendency for TSS to be biased low compared to SSC should be considered in the evaluation.

- Industrial: 166 mg TSS/L
- Open Space: 130 mg TSS/L

To estimate methylmercury loads, the TSS load estimated through the geospatial analysis was multiplied by the methylmercury to SSC ratio of 1.7 ng/g for the three subareas.

The resulting total mercury and methylmercury load estimates were used to represent the baseline watershed loading, against which future loading (following application of control measures, specifically GSI) were compared to examine the potential load reduction.

## 2.3 Future with Green Infrastructure

For the RAA future scenarios, future condition land uses and treatment areas were estimated within the Area of Analysis for 2030 and 2040, as described below.

### 2.3.1 Development Considerations

The East County RAA used development forecasts produced by the Countywide RAA to map areas predicted to undergo new development or redevelopment in each East County jurisdiction at the time increments specified in the previous MRP (i.e., 2020, 2030, and 2040). CCCWP forecasted private development using the output of UrbanSim, a model developed by the Urban Analytics Lab at the University of California under contract to the Bay Area Metropolitan Transportation Commission. The UrbanSim modeling system was designed to support the need for analyzing the potential effects of land use policies and infrastructure investments on the development and character of cities and regions. The Bay Area's application of UrbanSim was developed to support the development of Plan Bay Area, the Bay Area's Regional Transportation Plan/Sustainable Communities Strategy-equivalent planning effort (CCCWP, 2020b). The resulting maps were reviewed by East County Permittee staff for consistency with local knowledge and local planning and economic development initiatives and were revised as needed. The UrbanSim output was used to estimate development through 2030 and updated if needed based on information readily available in East County Permittee GI Plans.

### 2.3.2 GI Plan Data

Locations of GSI facilities and their treatment drainage areas were obtained from the East County Permittees' Green Infrastructure Plans developed in 2020 and 2021. These GI Plans mapped and prioritized areas for potential and planned public and private GSI projects for implementation by 2020, 2030, and 2040. The East County RAA estimates the load reductions that would be achieved through implementation of the GI Plans within the Area of Analysis.

Identified GSI drainage areas were assumed to be treated by bioretention facilities with no, full, or partial subsurface infiltration of the water quality design volume. Infiltration feasibility was obtained from the GI Plans, where available; if this information was not available in the GI Plans, feasibility was established using publicly available underlying hydrologic soil group (HSG) GIS data.

Load reductions estimated for implementation of GSI were applied to future condition East County RAA scenario models based on estimated locations of GSI and the tributary drainage areas to those facilities.

2.3.3 GSI Performance Modeling

Geosyntec modeled two future scenarios with GSI for the East County RAA: the GSI Implementation Scenario and the GSI Treatment Reduction Scenario. GSI performance, including volume reduction (via retention in the GSI facility) and pollutant load reduction (via filtration through media and discharge through an underdrain) were modeled utilizing a combination of hydraulic modeling in SWMM and currently available empirical GSI performance data.

Runoff volume within the areas tributary to the GSI facilities were calculated as the area-weighted sum of the HRU runoff volume within the drainage area. GSI control measure hydraulic performance was estimated using output from HRU-based SWMM models developed as part of the Countywide RAA, applied to the drainage area runoff volume.

The Countywide RAA SWMM models simulated treatment of a 100% impervious tributary area with different HRU variable mixes for three GSI facility types: (1) bioretention[4] with a raised underdrain, (2) bioretention with no underdrain, and (3) lined bioretention. The models were run with varying footprint sizes and varying underlying infiltration rates (i.e., the rate at which treated runoff infiltrates into native soils underlying the BMP facility). Average annual volume retained, volume treated, and volume bypassed by the GSI measure were recorded for each HRU unit GSI model run in SWMM. Volume-based performance[5] corresponding to a generic 100% impervious tributary area for each unit drainage area were applied to the effective impervious area corresponding HRUs within the East County RAA GSI drainage areas. For conservatism, the GSI

[4] The bioretention facility is assumed to include: 6-inch or 12-inch ponding depth, 1.5 ft of filter media with a 5 in/hr flow through rate, and 1 ft of gravel beneath the media.

[5] Volume-based performance refers to how much runoff volume the GSI facility captures and retains or treats and discharges through the underdrain, typically represented as a percentage of the average annual runoff volume.

modeled facility footprints were assumed to be sized to achieve 80% average annual capture from the tributary drainage areas, consistent with the sizing requirements included in MRP Provision C.3, which regulates GSI facility sizing for East County Permittees. The area weighted GSI measure performance was estimated for each modeled GSI facility in the subareas to understand the total volume retained, treated and discharged, and bypassed by the projected future facilities.

All pollutant load associated with retained runoff is assumed to fully controlled (i.e., zero load discharge). Pollutant load reductions in treated runoff was modeled as described in the Countywide RAA for mercury (CCCWP, 2018) and is based on currently available empirical GSI effluent concentration data. There are limited effluent or removal data for methylmercury for lower-SSC influent in stormwater control measures, as evident when examining data from the International Stormwater BMP Database[6] and as described in the *Methylmercury Control Study* (CCCWP, 2020b). In a separate study, monitoring data from the City of Citrus Heights City Hall green parking lot project, which included permeable pavement, bioswales, and rain barrels, found an 85% overall load reduction in methylmercury for the project (LWA, 2015).

Given the data limitations for methylmercury reduction in treated effluent, the following scenarios were modeled:

- GSI Implementation Scenario, which assumed that methylmercury entrained within infiltrated runoff was 100% reduced and, conservatively, no other methylmercury reductions would occur through treatment in the bioretention media.
- Treatment Reduction Scenario, which assumed the methylmercury load reduction was 100% reduced for infiltrated runoff and 85% reduced for treated runoff based on the City of Citrus Heights study.

## 3. RAA RESULTS

### 3.1 Baseline Results

The baseline East County RAA results for the three subareas and the difference between these estimated runoff volumes and methylmercury loads and those identified in the TMDL Staff Report (CVRWQCB, 2010b) are presented below. The baseline East County RAA results for total

[6] http://bmpdatabase.org/

mercury are evaluated using the California Toxics Rule (CTR) for mercury of 0.05 ug/L (or 50 ng/L), per Provision C.19.d.ii.(d).

### 3.1.1 Runoff Volume

The total volume from the three subareas based on output from the East County RAA and the comparison to the TMDL wet weather volume (calculated as described in Section 2.1.2) is summarized in **Table 9**.

**Table 9: Baseline Annual Wet Weather Volume by TMDL Subarea per RAA Model**

| Subarea within Contra Costa County | Average Annual Wet Weather Volume[1] (ac-ft/year) | Average Annual Precipitation[2] (inch) | Runoff Generating Area[3] (acre) | Total Area[4] (acre) | Runoff Coefficient[5] | % Difference in Annual Wet Weather Volume from TMDL[6] |
|---|---|---|---|---|---|---|
| West Delta | 4,520 | 11.8 | 4,638 | 19,218 | 0.24 | -47 % |
| Central Delta | 1,114 | 11.9 | 1,135 | 7,420 | 0.15 | -45 % |
| Marsh Creek | 2,225 | 11.7 | 2,283 | 9,274 | 0.25 | - 31 % |

1. Baseline average annual wet weather runoff volume based on RAA output using precipitation data of WY2000-2009.
2. Area-weighted average annual precipitation for WY2000-2009.
3. Runoff generating area is equivalent to total subarea multiplied by the weighted average runoff coefficient in that subarea.
4. Total sub-watershed area within the urban limit line of Contra Costa County.
5. Weighted average runoff coefficient by subarea.
6. [(Annual Wet Weather Volume per RAA (Table 9) – Estimated Annual Wet Weather Volume from CVRWQCB (2010) (Table 3)) / Annual Wet Weather Volume from CVRWQCB (2010) (Table 3)] * 100%

The difference in estimated wet weather volume is primarily due to differences in annual precipitation inputs and methods for estimating runoff generating area within the TMDL subareas between the East County RAA and the TMDL Staff Report. The precipitation data used for the East County RAA is a continuous hourly rainfall record from one of three rainfall gauges, the Los Medanos (LSM) gauge, Livermore Municipal Airport gauge (KLVK), and the Flood Control District gauge (FCD) in Contra Costa County, for WY 2000-2009 (Geosyntec, 2021). See Figure 3 for gauge locations and the geographic area they were applied to for the East County RAA. These gauges were used based on their proximity to or location within East County and are expected to be more representative of the local climate than the rainfall record for the Stockton Fire Station 4 (SFS) gauge used in CVRWQCB (2010b), which is located on the eastern side of the Delta. The resulting area-weighted average annual precipitation for the TMDL subareas within the Area of Analysis are included in Table 9 and are approximately, depending on the specific subarea, 27 to 30 percent less than the 16.6 inches assumed in the TMDL Staff Report (CVRWQCB, 2010b) (based on the SFS gauge for WY 2000 – 2003).

The urban area modeled for the East County RAA was identified using the Contra Costa County urban limit line (Contra Costa County, 2021) within Region 5, and the baseline imperviousness was developed by geospatially combining the land uses identified by the ABAG with the National Land Cover Dataset (NLCD, 2006) data. Appendix E of the TMDL Staff Report (CVRWQCB, 2010b) does not describe how urban area was identified for the portions of the subareas within Contra Costa County, but the total areas are much smaller than those identified for the East County RAA model. Finally, the runoff coefficient was calculated for the TMDL based on imperviousness values associated with different land uses, rather than geospatial land cover data.

For the loading analysis, the East County RAA uses the total volumes calculated by the RAA. The change in loading from baseline to future scenarios is calculated using East County RAA-calculated volumes for all scenarios, which allows for consistent comparison.

### 3.1.2 Mercury

The East County RAA area-weighted mercury loads and concentrations analysis results for the TMDL subareas and Watershed Atlas subareas boundaries are summarized in **Table 10**.

**Table 10: Baseline Mercury Load by Subarea**

| Subarea within Contra Costa County | Average Annual Wet Weather Runoff Volume[1] (ac-ft/year) | Wet Weather Mercury Load from RAA Baseline (g/year) | Area-weighted Mercury Concentration[2] (ng/L) | Exceeds California Toxics Rule for Mercury (50 ng/L)? |
|---|---|---|---|---|
| **TMDL Subarea** | | | | |
| West Delta | 4,520 | 238.6 | 42.8 | No |
| Central Delta | 1,114 | 67.0 | 48.8 | No |
| Marsh Creek | 2,225 | 64.8 | 23.6 | No |
| **Watershed Atlas Subarea** | | | | |
| West Delta | 5,630 | 264.1 | 38.0 | No |
| Central Delta | 1,453 | 93.5 | 52.2 | Yes |
| Marsh Creek | 3,188 | 98.1 | 25.0 | No |

1. Baseline average annual wet weather runoff volume based on RAA output using precipitation data of WY2000-2009.
2. (Wet Weather Mercury Load in RAA Baseline / Average Annual Wet Weather Runoff Volume) * unit conversions.

Based on the results of the RAA model shown in **Table 10**, baseline wet weather mercury concentrations for all three TMDL subareas are below the CTR concentration for mercury. When the hydrologic Watershed Atlas subarea boundary is used for Central Boundary, the mercury concentration is above the CTR due to the high proportion of open space in the subarea (the subarea has a runoff coefficient of 0.11). As included in the *Quantitative Relationship Between Green Infrastructure Implementation and Mercury Load Reductions Report* (CCCWP, 2018), the mercury concentration used in the model is substantially higher for open space than other land uses.

### 3.1.3 Methylmercury

Section 3.1.1 describes the differences in runoff volume calculations in the East County RAA compared with the TMDL Staff Report (CVRWQCB, 2010b). Similarly, the assumed methylmercury concentrations and resulting loads are computed differently in the East County RAA than in the TMDL Staff Report (CVRWQCB, 2010b). For the East County RAA, methylmercury concentrations were calculated using the modeled runoff volume and the estimated methylmercury loads for the different subareas. See Section 2.2 for details on how the methylmercury loads were derived . The resulting runoff volumes, concentrations, and loads, for the three subareas are summarized in **Table 11**.

**Table 11: Baseline Methylmercury Load by TMDL Subarea**

| Subarea within Contra Costa County | Average Annual Wet Weather Runoff Volume[1] (ac-ft/year) | Area-weighted Methylmercury Concentration[2] (ng/L) | Wet Weather Methylmercury Load from RAA Baseline (g/year) | % Difference between RAA Baseline and CVRWQCB (2010)[3] | CVRWQCB (2010a) Wasteload Allocation[4] (g/year) |
|---|---|---|---|---|---|
| **TMDL Subarea** | | | | | |
| West Delta | 4,520 | 0.18 | 1.02 | - 53.4 % | 3.2 |
| Central Delta | 1,114 | 0.19 | 0.27 | - 48.5 % | 0.75 |
| Marsh Creek | 2,225 | 0.18 | 0.48 | - 42.4 % | 0.3 |
| **Watershed Atlas Subarea** | | | | | |
| West Delta | 5,630 | 0.18 | 1.24 | -43.2% | 3.2 |
| Central Delta | 1,453 | 0.20 | 0.36 | -31.3% | 0.75 |
| Marsh Creek | 3,188 | 0.18 | 0.69 | -17.1% | 0.3 |

1. Baseline average annual wet weather runoff volume based on RAA output using precipitation data of WY2000-2009.
2. (Wet Weather Methylmercury Load in RAA Baseline / Average Annual Wet Weather Runoff Volume) * unit conversions.
3. [(Total Methylmercury Load in Baseline per RAA Output (Table 11) – Total Methylmercury Load in Baseline per from CVRWQCB (2010b) (Table 3)) / Total Methylmercury Load in Baseline from CVRWQCB (2010b) (Table 3)] * 100%.
4. From TMDL Staff Report (CVRWQCB, 2010b) Table 8.4a, 8.4b, 8.4f.

Based on the results of the RAA model shown in **Table 11**, baseline wet weather concentrations and loads of methylmercury for West Delta and Central Delta subareas are below the respective wasteload allocations. For the Marsh Creek subarea, however, the wet weather baseline load exceeds the required wasteload allocation by approximately 0.2 g/year – 0.4 g/year, depending on the subarea boundary used.

## 3.2 RAA Future Scenario Modeling

### 3.2.1 <u>GSI Implementation Scenario</u>

GSI implementation from the East County Permittees' GI Plans was modeled for the three subareas in Region 5 using both subarea boundary definitions. The East County RAA modeled projected private development and public retrofit GSI implementation for the years 2030 and 2040. This scenario helps to address the question "what is the achievable mercury and methylmercury load reduction in discharges from the MS4 by implementation of reasonable, foreseeable control measures" for the Marsh Creek subarea. The future loads for all three subareas within Contra Costa County were modeled, even though the baseline conditions for all TMDL defined subareas are below the CTR for mercury and the West and Central Delta subareas are below the TMDL wasteload allocation for methylmercury.

#### *3.2.1.1 Mercury*

The results of the GSI Implementation Scenario for mercury for the TMDL and Watershed Atlas subareas are summarized in **Table 12** below.

**Table 12: GSI Implementation Scenario Mercury Results**

| Subarea within Contra Costa County | 2030 Mercury Load (g/year) | 2040 Mercury Load (g/year) | 2030 Mercury Concentration (ng/L)[1] | 2040 Mercury Concentration (ng/L)[1] | Exceeds California Toxics Rule for Mercury (50 ng/L)? |
|---|---|---|---|---|---|
| **TMDL Subarea** | | | | | |
| West Delta | 225.9 | 223.8 | 33.8 | 32.9 | No |
| Central Delta | 65.2 | 65.2 | 45.2 | 45.2 | No |
| Marsh Creek | 61.4 | 56.8 | 20.5 | 16.9 | No |
| **Watershed Atlas Subarea** | | | | | |
| West Delta | 257.5 | 255.6 | 36.1 | 35.5 | No |
| Central Delta | 87.6 | 87.2 | 32.3 | 32.0 | No |
| Marsh Creek | 90.9 | 85.5 | 19.7 | 16.1 | No |

1. (Wet Weather Mercury Load in RAA Development Scenario / Average Annual Wet Weather Runoff Volume) * unit conversions.

Loads and concentrations are predicted to decrease for all subareas in future conditions relative to the modeled baseline. In future conditions, mercury concentrations are below the CTR criterion of 0.05 µg/L (50 ng/L) in all subareas.

*3.2.1.2 Methylmercury*

The results of the East County RAA modeling for methylmercury for the TMDL and Watershed Atlas subareas are summarized in **Table 13** below.

**Table 13: GSI Implementation Scenario Methylmercury Results**

| Subarea within Contra Costa County | CVRWQCB (2010a) Wasteload Allocation (g/year) | 2030 Methylmercury Load (g/year) | 2040 Methylmercury Load (g/year) | 2030 Methylmercury Concentration (ng/L)[1] | 2040 Methylmercury Concentration (ng/L)[1] |
|---|---|---|---|---|---|
| **TMDL Subarea** | | | | | |
| West Delta | 3.2 | 1.05 | 1.05 | 0.16 | 0.15 |
| Central Delta | 0.75 | 0.27 | 0.27 | 0.19 | 0.19 |
| Marsh Creek | 0.3 | 0.50 | 0.54 | 0.17 | 0.16 |
| **Watershed Atlas Subarea** | | | | | |
| West Delta | 3.2 | 1.23 | 1.23 | 0.17 | 0.17 |
| Central Delta | 0.75 | 0.41 | 0.41 | 0.15 | 0.15 |
| Marsh Creek | 0.3 | 0.74 | 0.81 | 0.16 | 0.15 |

1. (Wet Weather Methylmercury Load in RAA Development Scenario / Average Annual Wet Weather Runoff Volume) * unit conversions.

Loads increase slightly for Marsh Creek and West Delta in future conditions relative to the modeled baseline due to increased runoff from new impervious areas with projected development[7]. The overall loads are larger for the Watershed Atlas subareas relative to the TMDL subareas because the areas are larger. As in the baseline condition, future conditions for West Delta and Central Delta are still well under the wasteload allocation. However, the estimated methylmercury load in stormwater runoff from the Marsh Creek subarea exceeds the wasteload allocation by 0.20 g/year in 2030 and 0.24 g/year in 2040 for the TMDL subareas, and by 0.44 g/year in 2030 and 0.51 g/year in 2040 for the Watershed Atlas subareas.

[7] Runoff volumes are projected to increase even though new impervious area was modeled to be treated per the required water quality design standards (80% capture of average annual runoff volume) and infiltration was supported by underlying soils, see Section 2.

For the three subareas and two subarea boundary definitions, methylmercury concentrations are predicted to decrease with future conditions, as methylmercury concentrations in runoff discharged from urban areas are lower than those discharged from open space areas.

### 3.2.2 GSI Treatment Reduction Scenario for Methylmercury

The GSI Implementation Plan scenario was conservative in that only methylmercury entrained within infiltrated runoff was assumed to be removed. No methylmercury load reduction was assumed for runoff filtered and discharged by the stormwater control measures. The GSI Treatment Reduction Scenario assumed that the overall methylmercury loading from treated drainage areas was reduced by 85%. This is consistent with an assumption for methylmercury load reduction through GSI included in the *TMDL Phase 1 Implementation: Final Methylmercury Feasibility Report* completed by the Sacramento Stormwater Quality Partnership (2018), which was based on City of Citrus Heights City Hall green parking lot project (LWA, 2015). This scenario was applied to all three subareas for this scenario. The results of the GSI Treatment Reduction Scenario are summarized in **Table 14** below.

**Table 14: GSI Treatment Reduction Scenario RAA Model Results**

| Subarea within Contra Costa County | CVRWQCB (2010a) Wasteload Allocation (g/year) | 2030 Methylmercury Load (g/year) | 2040 Methylmercury Load (g/year) | 2030 Methylmercury Concentration (ng/L)[1] | 2040 Methylmercury Concentration (ng/L)[1] |
|---|---|---|---|---|---|
| **TMDL Subarea** | | | | | |
| West Delta | 3.2 | 1.01 | 1.00 | 0.15 | 0.15 |
| Central Delta | 0.75 | 0.26 | 0.26 | 0.18 | 0.18 |
| Marsh Creek | 0.3 | 0.48 | 0.47 | 0.16 | 0.14 |
| **Watershed Atlas Subarea** | | | | | |
| West Delta | 3.2 | 1.22 | 1.21 | 0.17 | 0.17 |
| Central Delta | 0.75 | 0.37 | 0.36 | 0.13 | 0.13 |
| Marsh Creek | 0.3 | 0.69 | 0.69 | 0.15 | 0.13 |

1. (Wet Weather Methylmercury Load in RAA Development Scenario / Average Annual Wet Weather Runoff Volume) * unit conversions.

Loads were estimated to decrease slightly for West, Central, and Marsh Creek subareas in future conditions relative to the modeled baseline due to the increased load reduction assumption in treated runoff. As in the baseline condition, future conditions for West Delta and Central Delta are well below the wasteload allocation. However, the estimated methylmercury load in stormwater runoff from the Marsh Creek subarea exceeds the wasteload allocation by 0.18

g/year in 2030 and 0.17 g/year in 2040 for the TMDL subareas, and by 0.39 g/year in both 2030 and 2040 for the Watershed Atlas subareas.

Using the GSI Treatment Reduction Scenario RAA model results, the projected rates for methylmercury load reduction within the Marsh Creek subarea between 2020 and 2040 were extrapolated into the future to estimate when the TMDL wasteload allocation could be achieved. The current projected rate of methylmercury load reduction through GSI implementation within Marsh Creek is approximately 0.003 g/yr per decade. Assuming this increased rate of load reduction into the future, it would take approximately 56 decades to achieve the Marsh Creek wasteload allocation.

## 4. CONCLUSIONS

The East County RAA results predict that with reasonable, foreseeable control measures, mercury concentrations will be below the CTR for mercury for all TMDL subareas by 2030, and methylmercury loads for West and Central Delta are currently below the respective TMDL wasteload allocations. The East County RAA demonstrates that for Marsh Creek, the methylmercury loads are above the TMDL wasteload allocation. Additionally, using the GSI Treatment Reduction Scenario, the East County permittee GI Plans, with predicted development and associated treatment and GSI retrofit, are predicted to reduce loads of methylmercury in wet weather flows within the Marsh Creek subarea from the baseline estimated load of 0.48 g/yr to approximately 0.47 g/yr by 2040, in contrast to the 0.3 g/yr wasteload allocation.

The GSI Treatment Reduction Scenario results are compared to the wasteload allocations in **Table 16**.

**Table 15: Combined East County TMDL Subarea RAA Results**

| Area within Contra Costa County | GSI Treatment Reduction Scenario | | CVRWQCB (2010a) Wasteload Allocation (g/year) |
|---|---|---|---|
| | 2030 Methylmercury Load (g/year) | 2040 Methylmercury Load (g/year) | |
| West Delta | 1.01 | 1.00 | 3.2 |
| Central Delta | 0.26 | 0.26 | 0.75 |
| Marsh Creek | 0.48 | 0.47 | 0.3 |
| Total Contra Costa County Urban Area | 1.75 | 1.73 | 4.25 |

When considering the three East County subareas together, the methylmercury loads discharged to the Delta are predicted to be less than the combined wasteload allocation. As demonstrated by the results of the future scenario modeling, it is infeasible to meet the Marsh Creek wasteload allocation with reasonable, foreseeable control measures.

## 5. LIMITATIONS

The Countywide RAA hydrologic model, GSI performance models, and portions of the water quality model were used for this effort. The Countywide RAA went through a rigorous third-party peer review process and was deemed to meet required standards. The approach described herein does have some limitations, however. These are summarized below.

1. Hydrologic Model – The hydrologic model does not consider hydrologic routing beyond large geospatially defined drainage areas. The model provides output on an average annual basis, consistent with the timescales of the PCBs and mercury TMDLs for the San Francisco Bay and the DMCP. The model was calibrated on the annual scale using available flow gauge data in Alameda and Contra Costa counties for the modeled baseline period of record. See the *Quantitative Relationship Between Green Infrastructure Implementation and Mercury Load Reductions Report* (CCCWP, 2018).
2. Water Quality Model – Land use-based data for methylmercury in stormwater and treated control measure effluent is minimal. Land use-based sediment concentrations are used and multiplied by particle ratios developed through a regression analysis of monitoring data. The particle ratios were calculated by using the methodology in the Methylmercury Control Study (CCCWP, 2020a) and updating the data used to add more recent monitoring data. Due to limitations of land use-based concentrations of SSC, which is the basis for the particle ratio in the Control Study, TSS is modeled and multiplied by the particle ratios. While SSC and TSS both measure suspended sediment, they measure different ranges of the sediment particle distribution.
3. GSI Performance Model – stormwater facility effluent data for methylmercury are limited. In the GSI Implementation scenario, methylmercury is assumed to be reduced by infiltration and no load reduction is assumed through runoff treatment and discharge. In the other future scenarios methylmercury load is reduced in treated runoff by 85%, based on the results of a single monitoring study from Citrus Heights, CA (LWA, 2015), as referenced by the Sacramento Stormwater Quality Partnership (2018).

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# ATTACHMENT A

## TSS Land Use Event Mean Concentration Technical Summary

# 1 TSS EMC DEVELOPMENT

Event Mean Concentration (EMC) is an analytical parameter that refers to a flow-weighted average concentration of a pollutant during a rainfall-runoff event. An EMC is defined as the total event mass load divided by the total event runoff volume. As such, estimates of EMCs can be combined with runoff volume estimates to estimate pollutant loading. EMCs for Total Suspended Solids (TSS) were developed for several land use classifications, using data from the National Stormwater Quality Database (NSQD), a database developed by the University of Alabama and the Center for Watershed Protection under support from the U.S. Environmental Protection Agency (Pitt, 2015). For non-detect data, one-half of the detection limit (a simple substitution method for censored data) is used by the BMP Database Team for purposes of analysis.

The NSQD was queried to obtain all TSS stormwater runoff samples collected within EPA Rain Zone 6 in California, in Spring, Fall, or Winter seasons. This query returned 650 stormwater runoff sample results from 647 rain events at 40 sites. Table 1 below shows the count of data for the listed land use category. Single land use categories are those with greater than 85% of the primary land use in the drainage area tributary to the data sampling point. Mixed land use categories are those with less than 85% of the primary land use in the drainage area tributary to the data sampling point less (i.e., "[Land Use] Mix").

**Table 1: Summary of Selected NSQD TSS Results by Land Use**

| Land Use Category | Count TSS data |
|---|---|
| Commercial | 10 |
| Commercial Mix | 38 |
| Freeway | 105 |
| Freeway Mix | 78 |
| Industrial | 14 |
| Industrial Mix | 95 |
| Institutional | 51 |
| Residential | 114 |
| Residential Mix | 75 |
| Open Space | 70 |
| **Total** | **650** |

As shown in Table 1 above, if data associated with sites that contain less than 85% of the primary land use are removed, the number of data points is greatly decreased in some cases (for example, for Commercial and Industrial) and may not be adequate for developing EMC statistics. Given the data paucity and specifics of the land uses, Geosyntec used the following data analysis groupings to develop representative land use-based TSS EMCs:

- Commercial: Combination of NSQD "commercial" and "commercial mix" data due to the low amount of data.

- Transportation: "Freeway" only data, no mixed freeway land use data.
- Industrial: Combination of "industrial" and "industrial mix" due to the low amount of data.
- Institutional: Summarize "institutional" data and keep separate from Commercial.
- Residential: Use "residential" only data as there is sufficient data.

# 2 STATISTICAL ANALYSIS

Data were first transformed by taking the natural logarithm of each data point, with the hypothesis that environmental data are lognormally distributed. The data for each land use category were then analyzed for outliers prior to developing EMCs. Outliers were defined as any data more than 1.5 interquartile ranges (IQRs) below the first quartile or above the third quartile. Outliers were excluded from future steps in the analysis. The number of outliers removed by land use is shown in Table 2.

**Table 2: Outliers Removed by Land Use**

| Land Use[1] | Outliers Removed |
|---|---|
| Residential | 2 |
| All Commercial | 3 |
| Freeway | 5 |
| All Industrial | 5 |
| Institutional | 0 |
| Open Space | 3 |
| **Grand Total** | **18** |

[1] 'All [ Land Use]' indicate land use types that are the combinations of single land use and mixed land use data.

As shown in Table 2 above, three Open Space data points with concentrations in excess of 3,000 mg/L were removed from the analysis based on engineering judgement. Although these values are within 1.5 IQRs above the third quartile of the log-transformed data, the small data set (n = 70) and large spread of the data (σ = 1185) limit the usefulness of traditional methods for determining outliers. TSS concentrations higher than 3,000 mg/L are likely associated with non-typical conditions, such as unvegetated areas, and are therefore not representative of the conditions this analysis is intended for.

Land uses were then compared to each other to understand if significant differences in the distribution of TSS concentrations exist. The distributions for each land use are shown in Figure 1.

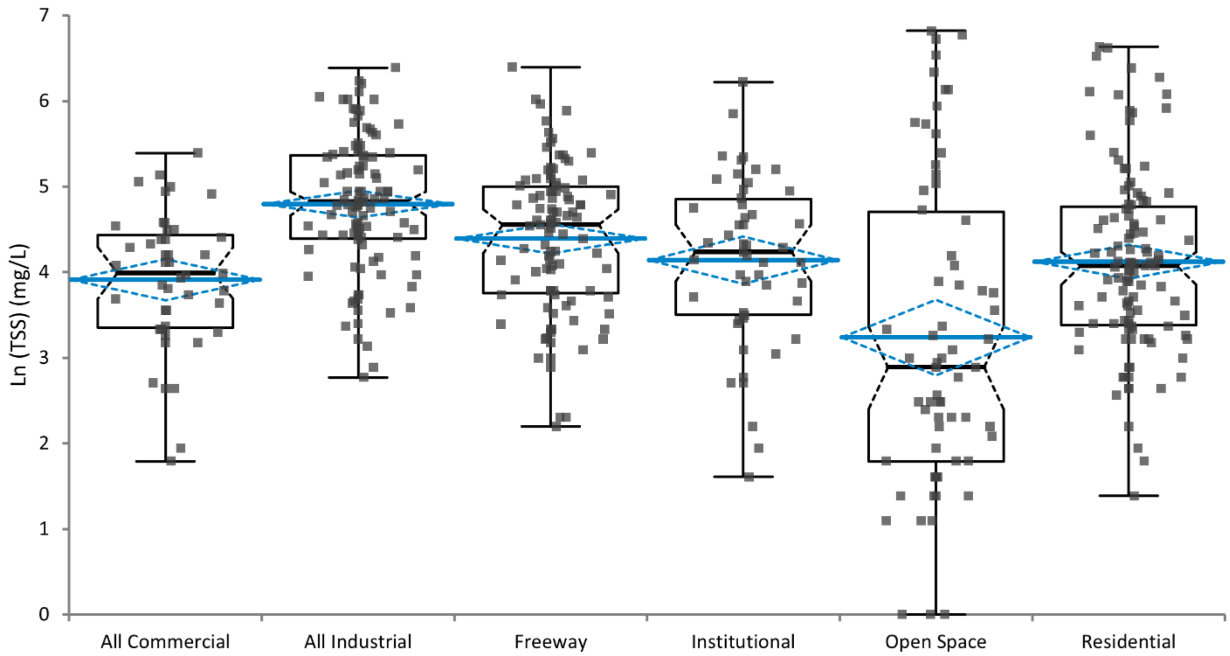


**Figure 1: Distribution of TSS Results by Land Use**

*Throughout this document, medians are shown as bold lines (with a 95% confidence interval shown as a notch on the box), means as blue lines (with 95% confidence interval shown as a dashed diamond), the 1st and 3rd quartiles as the edges of the boxes, and minimums/maximums as end caps.*

Box plot results demonstrate that the data mean, median, 25th, and 75th percentile TSS concentrations for All Industrial and Freeway land use groupings are greater than the rest of the land categories. The overlapping confidence intervals of the medians among All Commercial, Institutional, and Residential land use types suggests they may be derived from the same population (i.e., TSS concentrations are not statistically different between these land uses based on data analyzed). To further investigate, a series of Wilcoxon-Mann-Whitney tests were conducted to compare each land use pair. The results of the tests are shown in Table 3. A p-value below the alpha value of 0.05 (shown in red) indicates the TSS values of the compared land uses are likely not derived from the same population.

**Table 3: Wilcoxon Mann-Whitney Tests Results by Land Use**

| Land Use Comparisons | Wilcoxon-Mann-Whitney Test p-Values |
|---|---|
| All Commercial and Institutional | 0.1554 |
| All Commercial and Residential | 0.0040 |
| Institutional and Residential | 0.0007 |
| Institutional and Freeway | 0.1504 |
| All Industrial and Freeway | 0.0017 |
| All Industrial and Institutional | <0.0001 |
| All Industrial and Residential | <0.0001 |

| Land Use Comparisons | Wilcoxon-Mann-Whitney Test p-Values |
|---|---|
| Residential and Freeway | <0.0001 |
| All Commercial and All Industrial | <0.0001 |
| All Commercial and Freeway | 0.0020 |
| Open Space and All Commercial | 0.0040 |
| Open Space and All Industrial | <0.0001 |
| Open Space and All Freeway | <0.0001 |
| Open Space and Institutional | 0.0007 |
| Open Space and Residential | <0.0001 |

The results shown in Table 3 indicate that the Residential, All Commercial, and Institutional data sets are likely derived from the same population. Since All Commercial, Residential, and Institutional do not have statistically distinct TSS concentrations, the three land use categories are combined for EMC development. In contrast, All Industrial and Open Space data are significantly different than all the other land uses, and Freeway is statistically different than almost all the other land uses.

Given the results of the Wilcoxon-Mann-Whitney tests and review of the data distributions, the following land use groupings were used for TSS EMCs development:

- Residential, All Commercial, and Institutional
- Freeway
- All Industrial
- Open Space

Prior to calculating the EMCs for the land use groups defined above, the log-transformed data were assessed for normality using the Shapiro-Wilk test, the results of which are shown in Table 4. A p-value below the alpha value of 0.05 indicates there is evidence the sample did not come from a normally distributed population. As a result, the log-transformed Open Space land use data was concluded to not come from a normally distributed population, but the remaining three land use groupings were found to come from a normally distributed population.

**Table 4: Shapiro-Wilk Test Results by Land Use for Combined, Log-Transformed Data**

| Land Use | n | W | p | Conclusion |
|---|---|---|---|---|
| Residential, All Commercial, and Institutional | 205 | 0.99 | 0.503 | Normal |
| All Industrial | 104 | 0.99 | 0.335 | Normal |
| Freeway | 100 | 0.98 | 0.271 | Normal |
| Open Space | 67 | 0.95 | 0.009 | Not Normal |

Figure 2 and Figure 3 below show that Open Space data is neither normally (W = 0.59, p < 0.0001), nor lognormally distributed (W = 0.95, p = 0.0088). However, it is clear from Figure 2 and Figure 3 that the data more closely follow a log-normal distribution than a normal distribution. If more data were available, the Shapiro-Wilk test for log-transformed Open Space data may become statistically significant. Taking this into consideration and that most runoff concentrations from most land uses follow a lognormal distribution (Maestre et al., 2005), a lognormal distribution was selected to represent Open Space data as well.

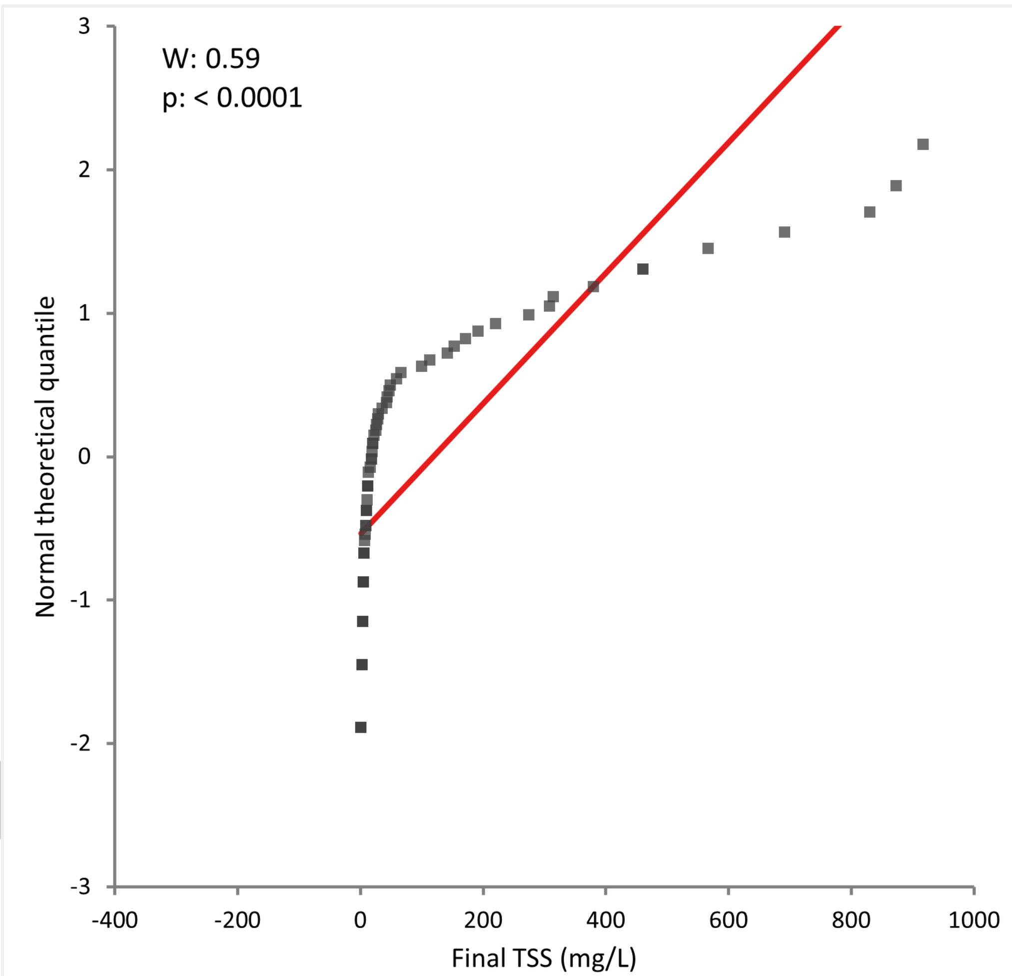


**Figure 2: Normal Distribution Fit for Open Space TSS**

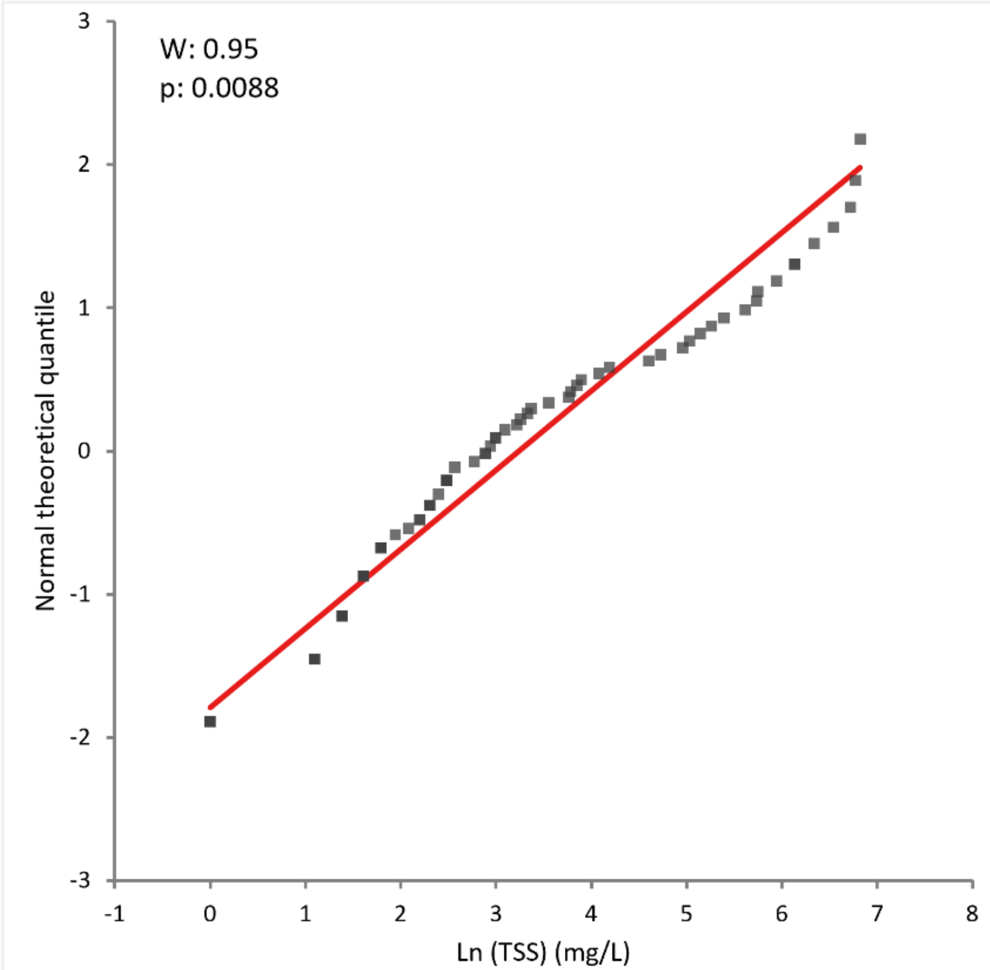


**Figure 3: Log-Normal Distribution Fit for Open Space TSS**

The four land use groups were then compared to understand if significant differences in the distribution of TSS concentrations exist. The distributions for each land use group are shown as box plots in Figure 4, and cumulative distribution functions are shown in Figure 5. The box plots demonstrate that confidence intervals of the median TSS concentration for the four land uses do not overlap, and frequency distributions show the large difference in the values representing each distribution for a given probability.

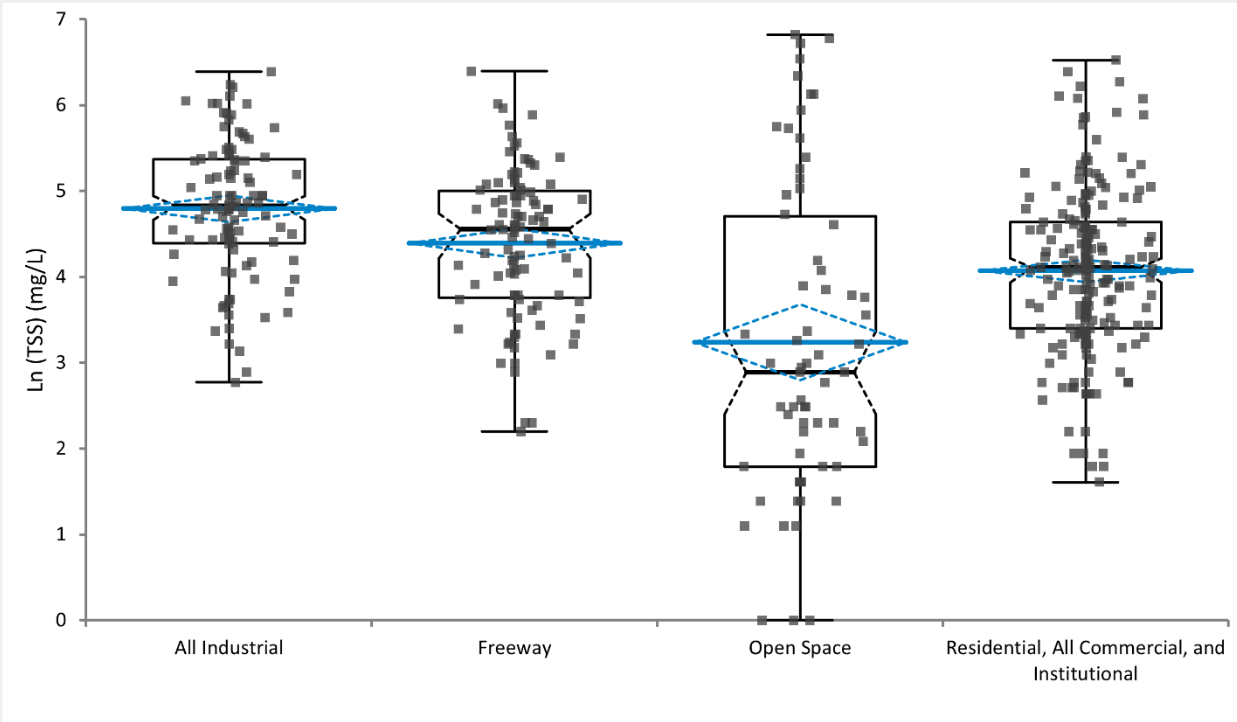


**Figure 4: Distribution of TSS Results by Final Land Use Category**

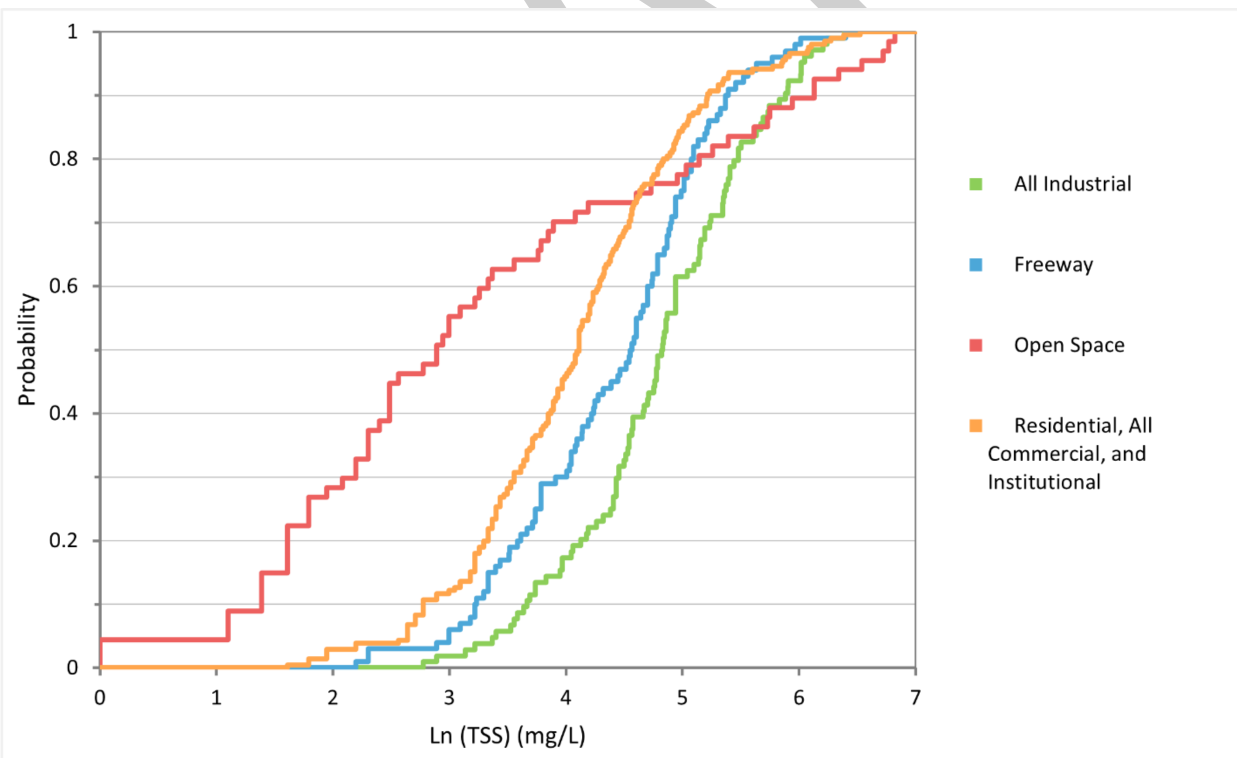


**Figure 5: Cumulative Distribution Functions of TSS Results by Final Land Use Category**

Additional Wilcoxon Mann-Whitney tests were also conducted to confirm that the final land use groups are distinctive from one another as shown in Table 5 below.

**Table 5: Wilcoxon-Mann-Whitney Tests by Land Use**

| Land Use Comparisons | Wilcoxon-Mann-Whitney Test p-Values |
|---|---|
| Residential, All Commercial, and Institutional *and* Open Space | <0.0001 |
| Residential, All Commercial, and Institutional *and* All Industrial | <0.0001 |
| Residential, All Commercial, and Institutional *and* Freeway | 0.0136 |
| Open Space *and* All Industrial | <0.0001 |
| Open Space *and* Freeway | <0.0001 |
| All Industrial *and* Freeway | 0.0075 |

# 3 CONCLUSIONS

TSS EMCs were developed for the four final land use categories (Combined Residential, All Commercial, & Institutional, All Industrial, Freeway, and Open Space) by taking the arithmetic mean of the natural log-transformed distributions, using the natural logs of the mean and the standard deviation as shown in the equation below (from Geosyntec and Wright Water Engineers, 2009):

$$Sample\ Mean = \exp\left(\mu_{ln} + 0.5\sigma_{ln}^2\right)$$

Where:

exp = e to the power of

$\mu_{ln}$ = the mean of the natural log-transformed distribution

$\sigma_{ln}$= the standard deviation of the natural log-transformed distribution

Final TSS EMCs by land use are shown in Table 6.

**Table 6: TSS EMCs by Land Use**

| Land Use | $\mu_{ln}$ | $\sigma_{ln}$ | TSS EMC (mg/L) |
|---|---|---|---|
| Residential, All Commercial, and Institutional | 4.07 | 0.95 | 92 |
| All Industrial | 4.79 | 0.79 | 166 |
| Freeway | 4.39 | 0.86 | 117 |
| Open Space | 3.27 | 1.79 | 130 |

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San Francisco Estuary Institute (SFEI), 2018. Regional Watershed Spreadsheet Model (RWSM) Toolbox v1.0 User Manual and Pollutant Model.

# APPENDIX B

CCCWP Green Infrastructure Cost Estimation Methodology Memo

Geosyntec consultants

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# Memorandum

| | |
|---|---|
| Date: | November 28, 2018 |
| To: | Adele Ho and Courtney Riddle, Contra Costa Clean Water Program |
| Copies to: | Dan Cloak, Dan Cloak Consulting |
| From: | Lisa Austin, Principal; Kelly Havens, Senior Engineer; and Brian Rowley, Senior Engineer |
| Subject: | Green Infrastructure Cost Estimation Methodology<br>Geosyntec Project Number: WW2407 |

## 1. INTRODUCTION

This memorandum provides a simple methodology for estimating green infrastructure capital (design and construction) and operations and maintenance (O&M) costs for use in green infrastructure (GI) planning.

To develop the methodology, GI facility cost data were gathered from several sources within the San Francisco Bay Area and Southern California to develop relationships between project size (tributary shed area) and total capital cost (construction and design). Likewise, O&M cost data were gathered from these sources, as well as through literature review.

## 2. COST ESTIMATE METHODOLOGY OVERVIEW

### 2.1 Projects Reviewed

Geosyntec assessed available cost information for 51 constructed projects, as follows:

- Ten projects constructed as part of the Caltrans BMP Retrofit Pilot Program;
- Fifteen projects constructed in the following California jurisdictions:
  - City of Concord,
  - City of El Cerrito,
  - City of La Mesa,
  - City of Los Angeles,
  - City of Oakley,
  - City of Pittsburg,

    - City of San Diego,
    - Union City, and
    - Unincorporated Contra Costa County;
- Six projects constructed as part of the BASMAA Clean Watersheds for a Clean Bay (CW4CB) Project (BASMAA, 2017); and
- Twenty constructed projects from Enhanced Watershed Management Plans (EWMPs) located in Southern California.

## 2.2 Cost Estimation Project Categories

Construction costs vary by facility type and project location. For example, green street projects often include ancillary construction costs associated with retrofitting the existing right-of-way and therefore are often relatively more expensive than other project types per unit area treated. Regional facilities have greater tributary areas and thus often have reduced costs per acre treated given fixed mobilization costs.

Information on facility type and location was used to group the projects into three cost estimation project categories: Green Street, Distributed Green Infrastructure, and Regional Stormwater Control. The following facility types that were included in each category include:

- Green Street: Projects built within the right-of-way, which include curb cutting and other costs associated with street retrofits. The treatment control measures may include infiltration trenches, bioretention, and infiltration galleries.

- Distributed Green Infrastructure: Biofilters, swales, infiltration strips, and bioretention installed within a parcel to treat runoff generated on that parcel.

- Regional Stormwater Control: Infiltration basins, large storage facilities, and treatment wetlands installed to treat runoff from a larger drainage area.

Projects with significant subsurface components were removed from the analysis for the Green Streets and Distributed Green Infrastructure categories due to large variances in overall trends. Subsurface green infrastructure work often involves shoring, utility relocations, and unforeseen costs associated with unknown subsurface conditions. These cost impacts did not appear to affect trends in the Regional Stormwater Control category, and thus projects with subsurface treatment facilities were included.

## 2.3 Source of Cost Data

Data sources varied for the projects that are summarized. For instance, for EWMP projects, data was collected from various sources, including the Proposition O monthly progress report from

August 2016 (Bureau of Engineering Prop O Clean Water Division, 2016) and publicly available online information, such as the project fact sheets provided by the City of Los Angeles stormwater program (http://www.lastormwater.org/). For CW4CB and Caltrans, cost data was published as part of Project Reports and "BMP Retrofit Pilot Program", respectively. For municipal projects, information was obtained via communication with relevant city staff.

# 3. COST ESTIMATE RESULTS

## 3.1 Design and Construction Cost Estimate

Table 1 below presents unit cost for design and construction, in 2018 dollars, for each project category. When analyzing these cost data, best professional judgment was used to distribute the design and construction costs when the information provided was unclear. If design costs were not available for a project, an estimate for design was inferred from other projects for which such costs were available. From these, the cost of design is approximately 30% of the construction cost.

**Table 1: Statistical Summary of Unit Capital Cost for Each Project Category**

| Project Category | No. of Projects (n) | Unit Capital Cost ($/ac treated) in 2018 Dollars[1] | | | | | |
|---|---|---|---|---|---|---|---|
| | | Minimum | 25th-percentile | Median | 75th-percentile | Maximum | Mean |
| Green Street | 19 | $25,000 | $70,000 | $137,000 | $267,000 | $1,290,000 | $213,000 |
| Distributed Green Infrastructure | 21 | $16,000 | $90,000 | $121,000 | $176,000 | $416,000 | $153,000 |
| Regional Stormwater Control | 11 | $15,000 | $25,000 | $61,000 | $127,000 | $427,000 | $101,000 |

[1] Units have been rounded to the nearest $1,000.

## 3.2 Annual O&M Cost Estimate

Annual O&M costs are intended to account for activities necessary to maintain the effectiveness of a project that recur on a regular basis, such as routine maintenance on an annual basis or repairs following a large storm event. For this cost analysis, annual O&M costs do not include replacement (of portions) or rehabilitation of green infrastructure facilities, which occurs approximately every 20 to 30 years.

Data was compiled from the cost estimation sources listed in Section 2.1., when available, as well as from a literature review of reports and studies. Additionally, interviews were conducted in May and June of 2017 [City of Tacoma, Washington (J. Knickerbocker, personal communication, June 1, 2017, and the City of Portland, Oregon (M. Juon, personal communication, May 30, 2017)]. Sources of O&M data are summarized in Table 2.

For planning purposes, annual O&M costs are often assumed to be a percentage of the capital (design and construction) costs. As shown in Table 2 below, annual O&M costs range from approximately 1% to 6% of the capital costs, with an average of 4% of capital cost for the data sources reviewed.

**Table 2: Comparison of O&M Cost Estimates**

| Source | Cost Estimation Category | O&M Annual Cost Factor (Percent of Capital Costs) |
|---|---|---|
| EWMP | Green Street | 3.6 % |
| EWMP | Distributed GI | 1.3 % |
| EWMP | Regional | 1.3 % |
| City of Tacoma, Interview, 2017 | Green Street | 1.0 % - 4.6 % |
| City of Tacoma, Interview, 2017 | Regional | 5 % |
| City of Portland, Interview, 2017 | Regional | 1.5 % - 4.7 % |
| City of Portland, Interview, 2017 | Green street | 1.0 % - 3.1 % |
| Los Angeles Alliance for a New Economy (LAANE) Liquid Assets Report, 2018 (LAANE, 2018) | Not Specified | 4.3 % |
| Comparison of Maintenance Cost, Labor Demands, and System Performance for LID and Conventional Stormwater Management, 2013 (Houle et al., 2013) | Not specified | 4.1 % - 6.3 % |
| Caltrans BMP Retrofit Pilot Program Final Report, 2004 (Caltrans, 2004) | Not specified | 3.2 % |
| EPA Green Streets Municipal Handbook, 2008 (EPA, 2008) | Not specified | 5.6 % |

## 3.3 Total Project Cost Estimation

The total cost of a project includes the capital costs and the annual O&M costs over the design life of the project.

$$Total\ Cost = Capital\ Cost + Present\ Value\ O\&M\ Cost$$

The capital cost, which includes both the design cost and the construction cost, is estimated for a new project based upon its cost estimation category and treatment area using the equations provided in Table 2. The annual O&M cost is calculated by multiplying the capital cost by the applicable fixed O&M cost factor of 4%, derived from the sources listed in Table 3. For the purposes of this analysis, a 20-year design life and a 3% inflation rate were used to calculate the total present value of the annualized O&M costs.

## 4. REFERENCES

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* * * * *

# APPENDIX C

## CCCWP RAA Modeling Report & Peer Review

# REASONABLE ASSURANCE ANALYSIS PEER REVIEW PACKAGE

# Alameda Countywide Clean Water Program and Contra Costa Clean Water Program

## Municipal Regional Stormwater Permit
## NPDES Permit No. CAS612008
## Order No. R2-2015-0049


*Prepared by*

Geosyntec Consultants, Inc.

1111 Broadway, 6th Floor

Oakland, California 94607


Project Numbers: LA0542 and LA0540

December 11, 2019

Geosyntec consultants

# Table of Contents

**Peer Review Matrix:** Attached File:
*RAA_PeerReviewMatrix_ACCWP_CCCWP_120419_RTC.xlsx*

# PR-1: Peer Review Component Descriptions

## 0. INTRODUCTION

This Peer Review package is intended to provide descriptions and back-up references associated with each model component identified for review in the Peer Review for SF Bay PCBs and Mercury Reasonable Assurance Analyses (RAAs) for Green (Stormwater) Infrastructure Instructions/Guidance to Peer Reviewers (Peer Review Instructions) and "FINAL_RAA_PeerReviewMatrix_Template_8_1_19.xlsx" (Peer Review Matrix), provided by BASMAA (2019). The descriptions herein are repeated or expanded from those included in the Peer Review Matrix, which includes fields that are requested to be populated by the peer reviewer. The descriptions provide summary information regarding the model inputs and/or reference other reports and documentation attached to this Peer Review Package that provide more extensive detail.

The Alameda Countywide Clean Water Program Quantitative Relationship Between Green Infrastructure Implementation and PCBs/Mercury Load Reductions Report (ACCWP, 2018) [PR-2] and the Contra Costa Clean Water Program Quantitative Relationship Between Green Infrastructure Implementation and PCBs/Mercury Load Reductions Report (CCCWP, 2018) [PR-3] (i.e., GI Quantitative Relationship Reports) are frequently referenced throughout this Peer Review package. Note that both GI Quantitative Relationship Reports are very similar, as the same RAA modeling methodology was used for both Counties; often reading one of the two reports will provide the referenced information.

## 1. BASELINE CONDITION MODELING

### 1.A Model Selection

Refer to Section 2.1 and 2.2 of the GI Quantitative Relationship Reports [PR-2; PR-3] for an overview of the model selected for the CCCWP and ACCWP RAA baseline condition models.

*Rationale:* The approach used for modeling hydrology is to use a hydrologic response unit (HRU) approach. An HRU is a unique combination of land surface features (imperviousness, underlying soil characteristics, slope, etc.) which is expected to give a consistent runoff response to rainfall, no matter where that unique combination is found. The HRU approach involves modeling thousands of combinations of land surface features present within the area of analysis, for a generic unit area drainage catchment, and then storing these results in a database. These HRU results can been be scaled geospatially across the entire area of analysis without developing a detailed hydrologic model and this method is appropriate for estimating average annual runoff and pollutant loading. This method is consistent with the *Bay Area RAA Guidance Document* (BASMAA, 2017).

*Spatial/Temporal Resolution:* Generic HRUs, characterized by varying the values of specific identified parameters within a defined range, are modeled using USEPA's Stormwater Management Model (SWMM). Continuous simulation HRU models are run on an hourly timestep for the identified baseline period of record (water year [WY] 2000 – 2009). An average annual runoff volume per acre is obtained for each HRU. The average annual runoff volume per acre associated with a specific HRU can then be multiplied by the area represented by that HRU within the entire area for analysis. The resulting volumes associated with each represented HRU within the area of analysis can then be added together to estimate the total average annual runoff volume.

*Alignment with Information/Needs/Data Available:* The HRU approach is consistent with the *Bay Area RAA Guidance Document* and the precision of the methods used to develop the TMDLs. As the TMDL WLA and MRP requirements are in terms of annual load reduction, event-specific modeling results are not needed. Additionally, long-term continuous simulation modeling allows for effects such as those relating to antecedent conditions (e.g., soil saturation resulting from back-to-back storms) to be incorporated into the results. Finally, detailed storm drain information is not currently available for all areas within the area of analysis, so it is not possible to develop a detailed routing model at this time.

A flow chart representing the Baseline Loading Model is provided:

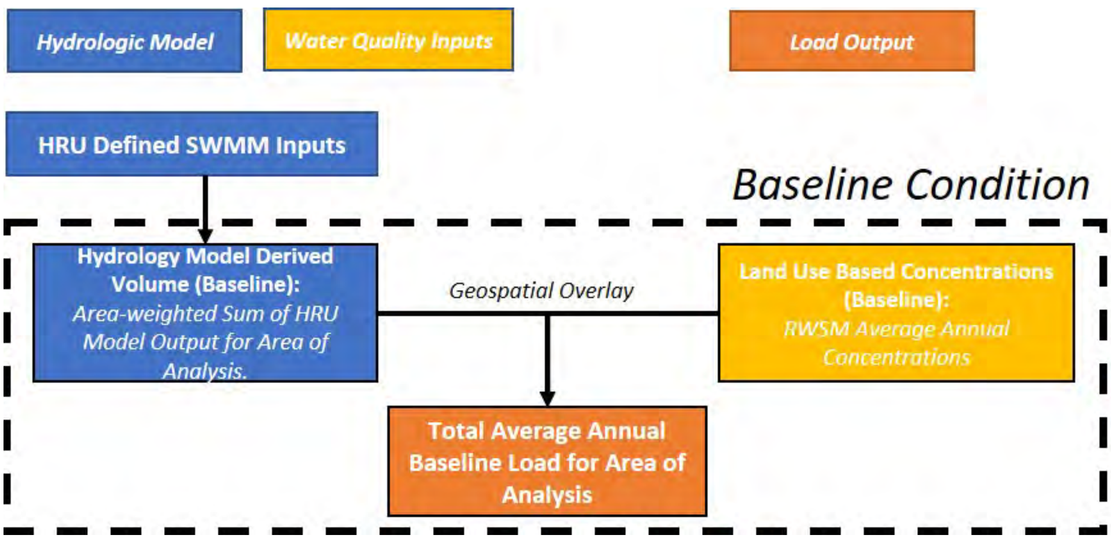


**Figure 1-1: Baseline Condition Model Flow Chart**

## 1.B Geographic Area of Analysis

The geographic area of analysis includes the entire area within Contra Costa and Alameda Counties, as shown in Exhibits 1 through 6 of the GI Quantitative Relationship Reports [PR-2; PR-3]. Note that the Counties are not labeled in PR-2 and PR-3; Contra Costa County is north of Alameda County. While the entire area is modeled, baseline results are ultimately subdivided based on regulatory (i.e., MRP covered areas vs. Phase II and Industrial General Permit covered areas) and jurisdictional boundaries. Modeled areas and jurisdictional boundaries are shown in Figure PR-1A and Figure PR-1B for Alameda and Contra Costa Counties, respectively.

## 1.C Period of Time

Baseline period of record is WY 2000 – 2009 (i.e., October 1, 1999 through September 30, 2009), as documented in the GI Quantitative Relationship Reports [PR-2; PR-3], see section 3.1.1. As included in the RAA Guidance Document (BASMAA, 2017), "For the purposes of RAA analyses, the baseline period for both PCBs and mercury analyses is recommended to be water years 2000

– 2009 (for long-term continuous simulation), or water year 2002 (for representative year simulation). These baseline period options are generally representative of the period during which much of the data were collected for mercury and PCBs." Also see additional detail in item 1.I "Meteorology".

## 1.D Flows and Pollutant Load Simulation

Section 2.2 of the GI Quantitative Relationship Reports [PR-2; PR-3] describes flow and pollutant load simulation. Refer to Section 2.2.2. of the GI Quantitative Relationship Reports [PR-2; PR-3] specifically for information regarding the water quality model.

## 1.E Rainfall/Runoff Processes

Rainfall/runoff processes are modeled using USEPA SWMM Version 5.1. A summary of the computational methods employed within SWMM to simulate runoff is provided in Section 3.4 of the USEPA SWMM Manual (USEPA, 2015) [PR-4].

## 1.F Pollutant Loading Variability

Land use variability is accounted for using SFEI's Regional Watershed Spreadsheet Model (RWSM) output, as described in the "Regional Watershed Spreadsheet Model Version 1.0 Results Summary" memo (Geosyntec, 2019a), provided by BASMAA. The results were developed using Wu et al (2017). Also refer to Section 2.2.2. of the GI Quantitative Relationship Reports [PR-2; PR-3] specifically for information regarding the water quality model.

## 1.G Watershed Characteristics

See Section 3.1.1 and Table 3 of the GI Quantitative Relationship Reports [PR-2; PR-3] for the watershed characteristics that were varied and the ranges of inputs; also see Table 1.H-1 below, which summarizes SWMM parameter input values.

## 1.H Watershed Hydrology Parameterization

The output of each uniquely parameterized HRU is matched to those geospatial areas with the unique combination of parameter values, as identified with geospatial data. The geospatial data used to develop the ranges of parameters and match geospatial area to the unique HRUs are shown in Exhibits 1 through 6 of the GI Quantitative Relationship Reports [PR-2; PR-3]. Geospatial data sources associated with each parameter are provided within the text of Section 3.1.1 of the reports (also refer to footnotes). Table 1.H-1 below provides SWMM input values not summarized in Table 3 of the GI Quantitative Relationship Reports [PR-2; PR-3].

### Table 1.H-1: SWMM Parameter Input Values

| Parameter | Description & Source[1] | Unit | Value |
|---|---|---|---|
| Infiltration Model | Controls how infiltration of rainfall into the upper soil zone of subcatchments is modeled in SWMM. | -- | Green Ampt, see parameters in Table 1.H-2 |
| Routing Method | Determines the method used to route flows through the system in SWMM. | -- | Kinematic Wave |
| Reporting Time Step | *Model time step input.* | Minutes | 5 |
| Dry Weather Time Step | *Model time step input.* | Minutes | 240 |
| Wet Weather Time Step | *Model time step input.* | Minutes | 5 |
| Routing Time Step | *Model time step input.* | Seconds | 30 |
| Flow Path Length | Overland flow path length assumed for sheet flow runoff. Selected default inputs represent typical overland sheet flow path lengths for undeveloped/open space areas and developed/urban areas, respectively. | Feet | 500 (Existing non-developed condition; development footprint) |
| | | | 250 (Proposed developed condition; development footprint) |
| N-Imperv | Manning's roughness for impervious or pervious surfaces. | -- | 0.012 (corresponds to smooth concrete) |
| N-Perv | | -- | 0.25 (corresponds to dense grass) |
| Dstore-Imperv | Depth of depression storage (i.e., the maximum surface storage provided by ponding, surface wetting, and interception) for impervious and pervious surfaces. | Inches | 0.1, 0.075, and 0.05 for slopes of 3%, 7.5%, and 15%, respectively |
| Dstore-Perv | | Inches | 0.2, 0.15, and 0.1 for slopes of 3%, 7.5%, and 15%, respectively |
| %Zero-Imperv | Percent of the impervious area with no depression storage. | % | 25 |
| Groundwater | -- | - | Not simulated |
| Snowmelt | -- | - | Not simulated |

[1] Source of description and selected model input values obtained from USEPA, 2015 unless otherwise indicated.

Soil parameter model input values are provided in Table 1.H-2.

**Table 1.H-2: Green-Ampt Soil Parameters**

| Hydrologic Soil Group | Prevalent Soil Texture Class | Saturated Soil Conductivity (in/hr) | | Suction Head[1] (in) | IMD[1] (in/in) |
|---|---|---|---|---|---|
| | | Existing Condition[1] | Developed Condition[2] | | |
| A | Sand, Loamy Sand | 2.5 | 1.88 | 2.61 | 0.34 |
| B | Sandy Loam | 0.3 | 0.23 | 6.02 | 0.22 |
| C | Loam | 0.15 | 0.11 | 10.4 | 0.13 |
| D | Clay | 0.1 | 0.08 | 7.4 | 0.17 |

[1] HSG A and B estimated based on texture class from Rawls, et al., (1983); HSG C and D estimated through calibration, see the "Alameda Countywide Clean Water Program and Contra Costa Clean Water Program Reasonable Assurance Analysis Model Calibration and Validation" Memo [PR-5].

[2] Determined based on an assumption of 25% reduction of conductivity due to compaction.

The varied input characteristics resulted in a total of 586 unique pervious HRU models, which are defined by the combinations of rainfall zone, ET zone, HSG, and slope. Additionally, a total of 74 impervious HRU types were modeled, defined by the combinations of rainfall zone, ET zone, and slope. The top 15 most dominant pervious HRU's account for about 50% of the study area. The two most dominant pervious HRU types represent 14% of the total study area, and are both <1% developed (developed includes urbanized and agricultural areas).

## 1.I Meteorology

Rainfall files used for hydrologic model are documented in Table 1 and Evaporation data inputs are documented in Table 2 of the GI Quantitative Relationship Reports [PR-2; PR-3].

## 1.J Drainage System Representation

Storm drain system routing was not modeled, as an HRU approach was used, as described above. However, large-scale drainage routing was accounted for when conducting model calibration and validation. Model calibration and validation is further described in the "Alameda Countywide Clean Water Program and Contra Costa Clean Water Program Reasonable Assurance Analysis Model Calibration and Validation Memo" (Geosyntec, 2019b) [PR-5].

## 1.K Model Calibration

Refer to the "Alameda Countywide Clean Water Program and Contra Costa Clean Water Program Reasonable Assurance Analysis Model Calibration and Validation Memo" (Geosyntec, 2019b) [PR-5].

## 1.L Model Validation

Refer to the "Alameda Countywide Clean Water Program and Contra Costa Clean Water Program Reasonable Assurance Analysis Model Calibration and Validation Memo" (Geosyntec, 2019b) [PR-5].

## 2. GREEN INFRASTRUCTURE LOAD REDUCTION MODELING

A flow chart showing the development and components of the future condition model is provided.

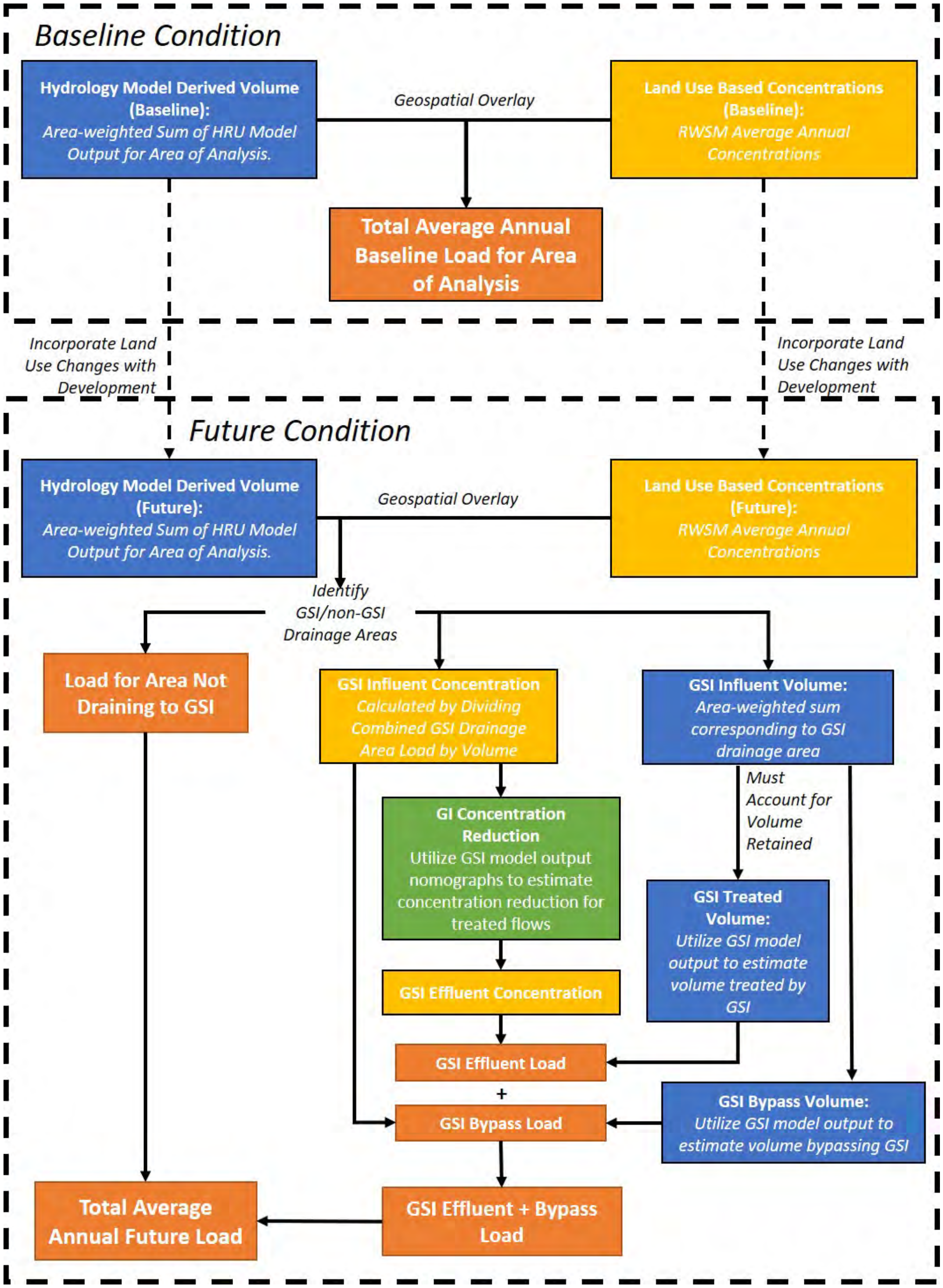


**Figure 2-1: Future Condition Model Flow Chart**

## 2.A Load Reduction Goal

The mercury load reduction required to be achieved through GI by 2040 per the MRP is 10 kg/yr MRP area-wide, or 3.1 kg/yr for Alameda County, and 1.7 kg/yr for Contra Costa County.

Calculations were conducted to develop the PCBs load reduction goals as described in the *Bay Area RAA Guidance Document* (BASMAA, 2017). The calculation methodology is summarized below.

### 2.A.1 TMDL Attainment Load Reduction (2030)

$LR_{goal}$ = Baseline – WLA (kg/yr)

Where:

$LR_{goal}$ = The load reduction goal (kg/yr)

Baseline = The baseline pollutant loading as calculated through the RAA

WLA = The population-based wasteload allocation

The TMDL population-based wasteload allocations for Alameda County and Contra Costa County are provided Table 2.A-1.

**Table 2.A-1:TMDL Population-Based Wasteload Allocations for Alameda County and Contra Costa County**

| Stormwater Improvement Goal | PCBs (kg/yr) |
|---|---|
| Alameda County | 0.5 |
| Contra Costa County | 0.3 |

### 2.A.2 RAA Calculated Baseline Load - PCBs

The results of the RAA baseline modeling are presented for Alameda County and for Contra Costa County in Table 2.A-2, below. The baseline countywide load used to establish the PCBs load reduction goal for the Permittee area is shown in bold. Refer to the RAA Guidance Document Section 2 and Section 3.5 (BASMAA, 2017) for details on the calculation methodology.

**Table 2.A-2: RAA Model Baseline Loading Estimates – PCBs**

| RWQCB Region | Above/Below Dam | Permit | Baseline Load Alameda County (kg/yr) | Baseline Load Contra Costa County (kg/yr) |
|---|---|---|---|---|
| **Region 2** | **Below Dam** | **MRP** | **3.6** | **1.6** |
| | | NPDES | 0.2 | 0.8 |
| | | Phase 2 | 0.5 | <0.1 |
| | Above Dam | MRP | <0.1 | <0.1 |
| | | NPDES | 0.0 | <0.1 |
| | | Phase 2 | 0.0 | 0.0 |
| Region 5 | Below Dam | MRP | <0.1 | 0.1 |
| | | NPDES | 0.0 | <0.1 |
| | | Phase 2 | 0.0 | <0.1 |
| | Above Dam | MRP | 0.0 | <0.1 |
| | | NPDES | 0.0 | 0.0 |
| | | Phase 2 | 0.0 | 0.0 |
| | | Total | 4.3 | 2.6 |

Using the preliminary RAA-calculated baseline load[1] of PCBs for each County, the load reduction goal is estimated to be 3.1 kg/yr for Alameda County and 1.3 kg/yr for Contra Costa County.

### 2.A.3 MRP Load Reduction through GI by 2040

The PCBs load reduction required to be achieved through GI by 2040 (i.e., 3 kg/yr MRP area-wide or 0.9 kg/yr for Alameda County and 0.5 kg/yr for Contra Costa County) must be adjusted to reflect the RAA-calculated baseline load (i.e., 3.6 kg/yr and 1.6 kg/yr for Alameda and Contra Costa Counties, respectively). The MRP load reduction requirement for GI for all permittees (3 kg/yr) represents 20.8% of the overall required TMDL load reduction. Therefore, the adjusted countywide load reduction through GI can be calculated as:

$$LR_{MRP,\ GI,\ 2040} = LR_{goal} * 20.8\%$$

The adjusted countywide PCBs load reduction goal through GI by 2040 are calculated as summarized in Table 2.A-3.

**Table 2.A-3: Adjusted Countywide PCBs Load Reduction Goals through GI by 2040**

| County | PCBs Load Reduction Goal through GI (kg/yr) |
|---|---|
| Alameda County | 0.6 |
| Contra Costa County | 0.3 |

## 2.B Overall Methodology to Account for GI Load Reductions

Refer to Sections 2.3, 3.2, and 3.3 of the GI Quantitative Relationship Reports [PR-2; PR-3].

[1] As of the May 2019 draft model run; the final baseline load is subject to change per peer review comments

## 2.C Load Reduction Calculation Method

The load reduction is calculated based on the difference between the baseline PCBs and mercury load and the PCBs and mercury load accounting for GI. The baseline model produces a PCBs and mercury load for each County, along with a "load production" GIS layer that estimates the load corresponding with each parcel and ROW segment within each County (note that individual parcel loadings should be considered representative of the 'average tendency' of loading for similar parcels). This "load production" layer is revised for the future condition based on land use changes, then combined in GIS with planned green infrastructure projects to estimate the resulting parcel load, assuming standard bioretention treatment. The estimated load reduced per acre using this approach is calculated and presented in Sections 4 and 5 of the GI Quantitative Relationship Reports [PR-2; PR-3].

The sum of the revised and treated parcel loads, across each County, provides the load under the future estimated condition. This future estimated load is then subtracted from the baseline estimated load to estimate loads reduced.

# 3. REFERENCES

ACCWP, 2018. Quantitative Relationship Between Green Infrastructure Implementation and PCBs/Mercury Load Reductions. September 28.

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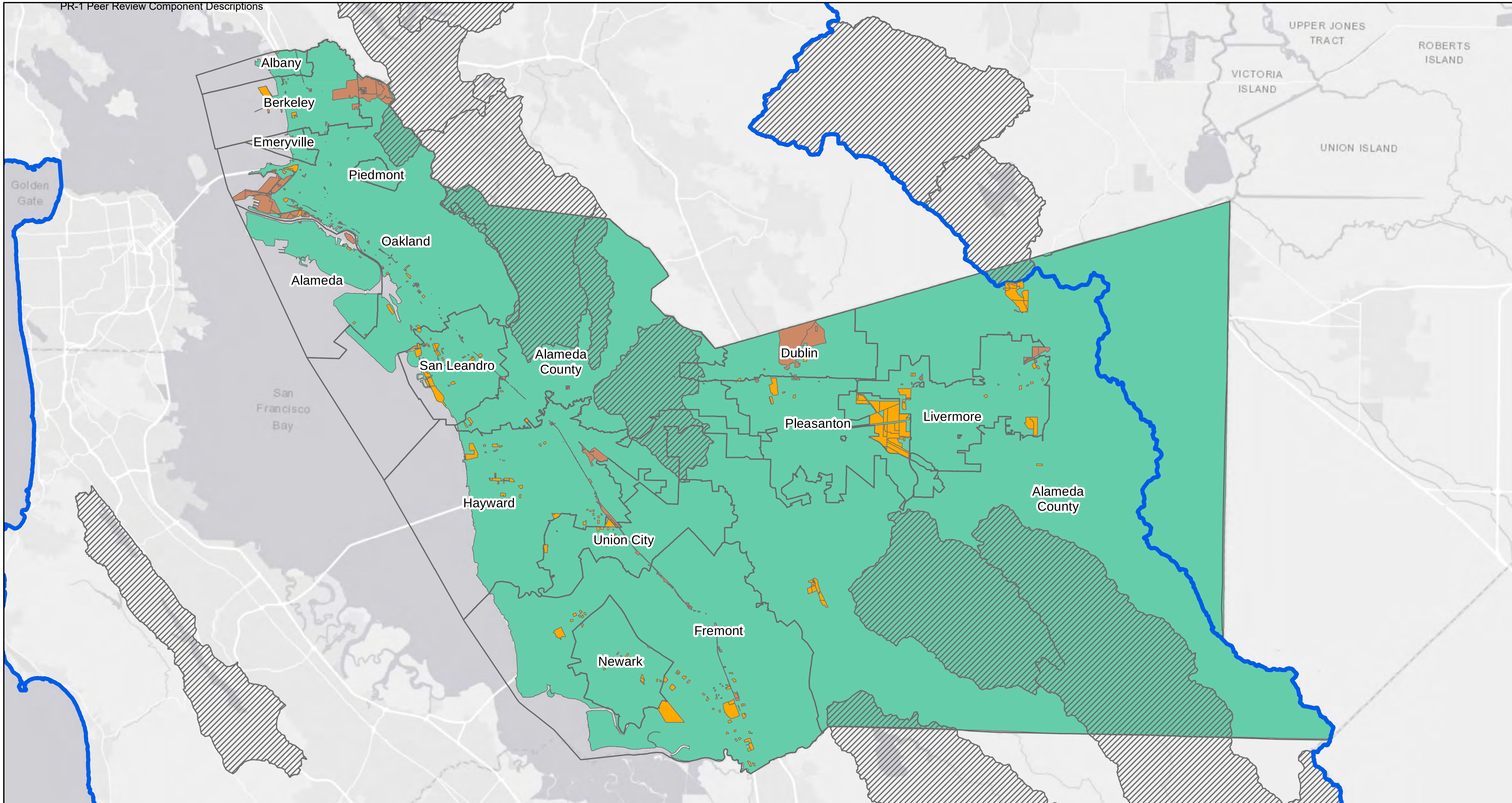
USEPA, 2015. Storm Water Management Model User's Manual Version 5.1. September.

Wu, J., Gilbreath, A.N., McKee, L.J., 2017. Regional Watershed Spreadsheet Model (RWSM): Year 6 Progress Report. A technical report prepared for the Regional Monitoring Program for Water Quality in San Francisco Bay (RMP), Sources, Pathways and Loadings Workgroup (SPLWG), Small Tributaries Loading Strategy (STLS). Contribution No. 811. San Francisco Estuary Institute, Richmond, California.




**Legend**

- Municipalities
- Area Above Dams[1]
- RWQCB Region 2 Boundary
- RWQCB Region 5

**Stormwater Permit Coverage**

- Individual Stormwater NPDES Permit
- Phase II General Stormwater Permit Water Quality Order 2013-0001-DWQ
- MS4

Notes:
1. Areas above Dams are not included in baseline load estimated for Municipal Regional Stormwater Permittees. Areas covered under different stormwater permits (i.e., individual NPDES permits, Phase II permit) are not included in baseline load estimates for Municipal Regional Stormwater Permittees.

N

0 20,000 Feet

**Alameda County RAA**
**Baseline Loading Analysis Area**

Alameda County
California

Geosyntec consultants

Oakland | October 2019

**Figure 1A**



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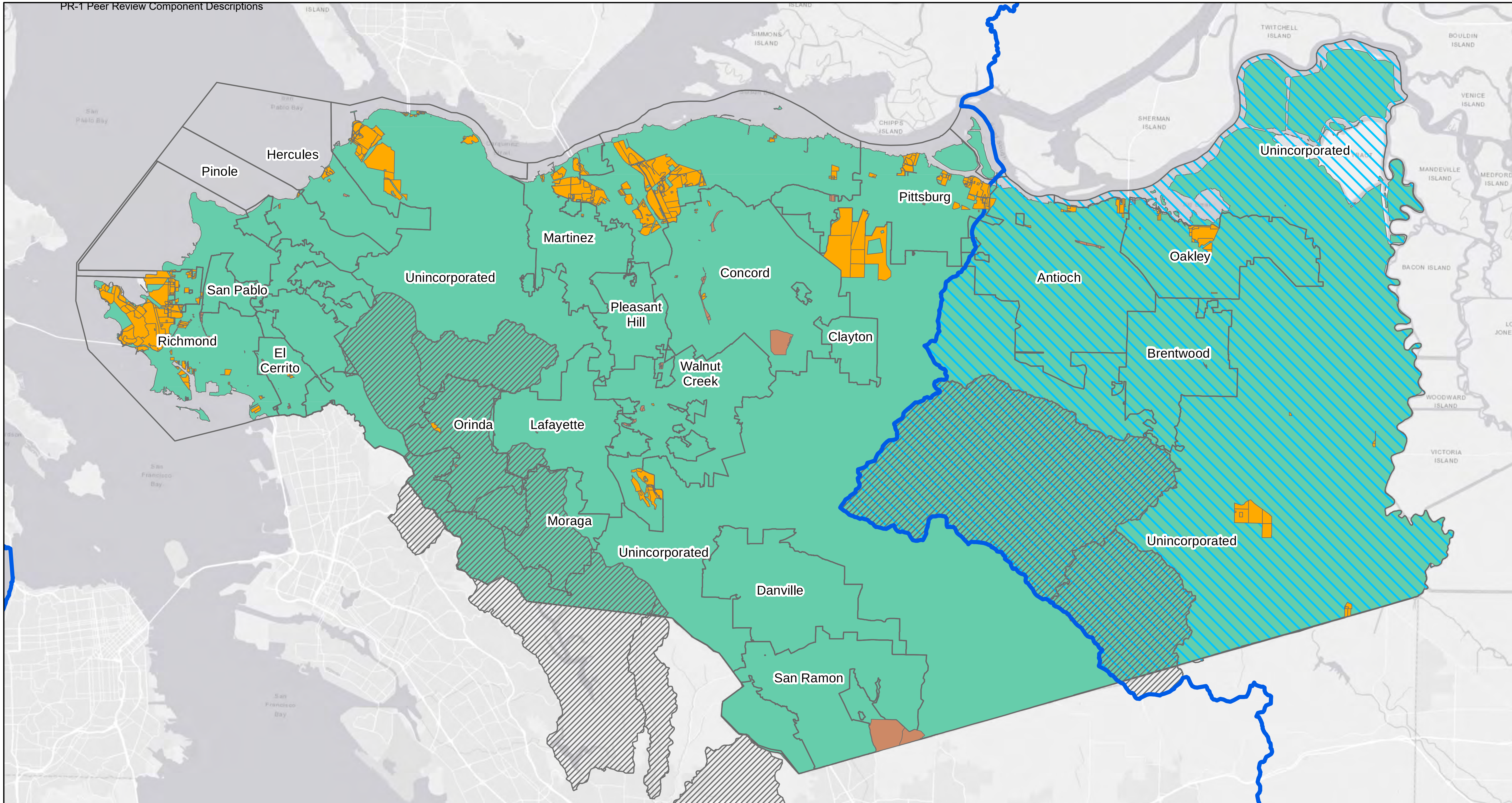



**Legend**

- Municipalities
- Area Above Dams[1]
- RWQCB Region 2 Boundary
- RWQCB Region 5

**Stormwater Permit Coverage**

- Individual Stormwater NPDES Permit
- Phase II General Stormwater Permit Water Quality Order 2013-0001-DWQ
- MS4

Notes:
1. Areas above Dams are not included in baseline load estimated for Municipal Regional Stormwater Permittees. Areas covered under different stormwater permits (i.e., individual NPDES permits, Phase II permit) are not included in baseline load estimates for Municipal Regional Stormwater Permittees.

**Contra Costa County RAA Baseline Loading Analysis Area**

Contra Costa County
California

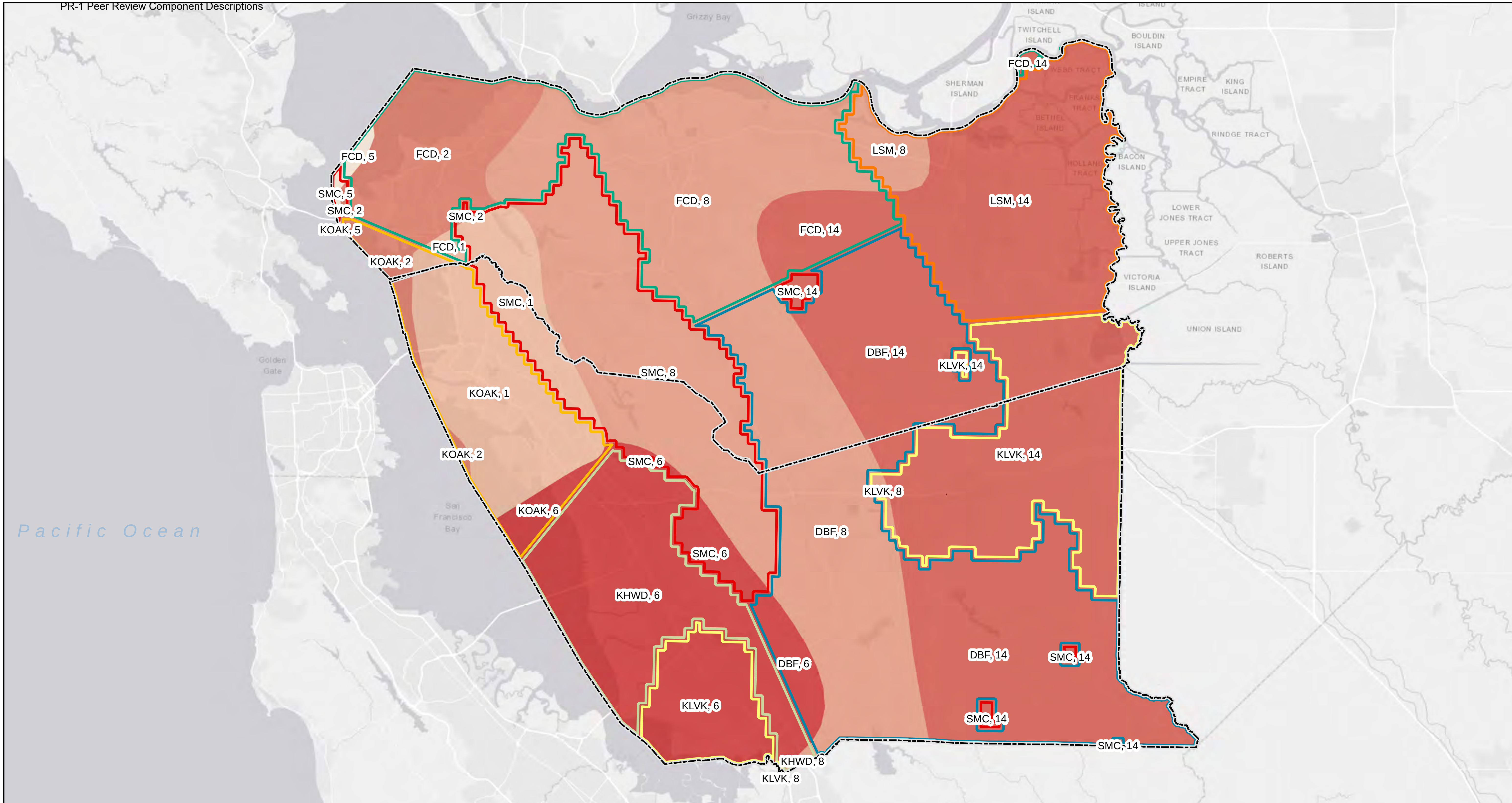
Geosyntec consultants

Oakland | October 2019

**Figure 1B**



P:\GIS\Bay_Area_RAA\Project\Peer_Review_Documentation\PR_Figure_1B_Baseline_Loading_Map_ContraCosta.mxd 10/1/2019 2:49:36 PM




County Boundary

| Rain Gauge Zones | CIMIS ET Zone |
|---|---|
| DBF | 1 |
| FCD | 2 |
| KHWD | 5 |
| KLVK | 6 |
| KOAK | 8 |
| LSM | 14 |
| SMC | |

Climate Zones are created by overlapping precipitation zones and ET zones. In Contra Costa County and Alameda County, unique climate zones are labeled as "Gauge ID, ET Zone".

N

0 6 12 Miles

**RAA Climate Zones**

Alameda County and Contra Costa County
California

Geosyntec consultants

Oakland | November 2019

**Figure PR-1C**

# PR-2 Alameda Countywide Clean Water Program GI Quantitative Relationship Report

# ALAMEDA COUNTYWIDE CLEAN WATER PROGRAM

# QUANTITATIVE RELATIONSHIP BETWEEN GREEN INFRASTRUCTURE IMPLEMENTATION AND PCBS/MERCURY LOAD REDUCTIONS

Report prepared by:

Alameda Countywide Clean Water Program
399 Elmhurst Street
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Submitted to:

California Regional Water Quality Control Board, San Francisco Bay Region

September 28, 2018

MEMBER AGENCIES:

Alameda
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Berkeley
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Hayward
Livermore
Newark
Oakland
Piedmont
Pleasanton
San Leandro
Union City
County of Alameda
Alameda County Flood Control and Water Conservation District
Zone 7 Water Agency

# Acknowledgements

This report was prepared in cooperation with the Contra Costa County Clean Water Program. Geosyntec Consultants contributed substantially to the writing and preparation of this report.

# Preface

This *Quantitative Relationship Between Green Infrastructure Implementation and PCBs/Mercury Load Reductions* was prepared by the Alameda Countywide Clean Water Program (ACCWP) per the Municipal Regional Permit (MRP; NPDES Permit No. CAS612008; Order No. R2-2015-0049) for urban stormwater issued by the San Francisco Bay Regional Water Quality Control Board. This report fulfills the requirements of MRP Provisions C.11.b.iii.(3), C.11.c.iii.(1), C.12.b.iii.(3), and C.12.c.iii.(1) to submit refinements to the measurement and estimation methodologies for assessing mercury and PCBs load reductions in the next permit term and the quantitative relationship between green infrastructure implementation and mercury and PCBs load reductions that will be used for the reasonable assurance analyses.

This report is submitted by ACCWP on behalf of the following Permittees:

- The cities of Alameda, Albany, Berkeley, Dublin, Emeryville, Fremont, Hayward, Livermore, Newark, Oakland, Piedmont, Pleasanton, San Leandro, and Union City;
- Alameda County;
- Alameda County Flood Control and Water Conservation District; and
- Zone 7 of the Alameda County Flood Control and Water Conservation District (Zone 7 Water Agency).

# LIST OF ACRONYMS

| | |
|---|---|
| ASOS | Automated Surface Observation System |
| BASMAA | Bay Area Stormwater Management Agencies Association |
| BMP | Best Management Practices |
| CCCWP | Contra Costa Clean Water Program |
| CIMIS | California Irrigation Management Information System |
| GI | Green Infrastructure |
| GIS | Geographic Information System |
| HRU | Hydrologic Response Unit |
| KTRL | Kendall-Theil Robust Line |
| MAD | Median Absolute Deviation |
| MRP | Municipal Regional Permit |
| MS4 | Municipal Separate Storm Sewer System |
| ng/kg | nanogram per kilogram |
| NPDES | National Pollutant Discharge Elimination System |
| PCBs | Polychlorinated Biphenyls |
| RAA | Reasonable Assurance Analysis |
| RMSE | Root Mean Square Error |
| ROW | Right-of-Way |
| RWSM | Regional Watershed Spreadsheet Model |
| SFBRWQCB | San Francisco Bay Regional Water Quality Control Board |
| SFEI | San Francisco Estuary Institute |
| SWMM | Stormwater Management Model |
| TMDL | Total Maximum Daily Load |
| USEPA | United States Environmental Protection Agency |
| USGS | United States Geologic Survey |
| WY | Water Year |

# Table of Contents

Appendix A: Modeling Inputs and Data Exhibits

# List of Tables

# List of Figures

# 1. INTRODUCTION

## 1.1 Purpose

This *Quantitative Relationship between Green Infrastructure Implementation and PCBs/Mercury Load Reductions* report was prepared by the Alameda Countywide Clean Water Program (ACCWP) per the Municipal Regional Permit (MRP) for urban stormwater issued by the San Francisco Bay Regional Water Quality Control Board (SFBRWQCB; Order No. R2-2015-0049). This report fulfills the requirements of MRP Provisions C.11.b.iii.(3), C.11.c.iii.(1), C.12.b.iii.(3), and C.12.c.iii.(1) for submitting the quantitative relationship between green infrastructure (GI) implementation and PCBs load reductions that will be used for the Reasonable Assurance Analysis (RAA) required by MRP Provisions C.11.c.ii.(2), C.11.d.ii, C.12.c.ii.(2), and C.12.d.ii.

This report was prepared in cooperation with the Contra Costa Clean Water Program. The RAA modeling described herein will be conducted for both countywide programs and will use data inputs from both Alameda County and Contra Costa County.

## 1.2 Background

### 1.1.1 PCBs and Mercury Total Maximum Daily Loads

Fish tissue monitoring in San Francisco Bay has revealed bioaccumulation of PCBs, mercury, and other pollutants. The levels found are thought to pose a health risk to people consuming fish caught in the Bay. As a result of these findings, California has issued an interim advisory on the consumption of fish from the Bay. The advisory led to the Bay being designated as an impaired water body on the Clean Water Act "Section 303(d) list" due to PCBs and mercury. In response, the SFBRWQCB has developed Total Maximum Daily Load (TMDL) water quality restoration programs targeting PCBs and mercury in the Bay. The general goals of the TMDLs are to identify sources of PCBs and mercury to the Bay and implement actions to control the sources and restore water quality.

Municipal separate storm sewer systems (MS4s) are one of the PCBs and mercury source/pathways identified in the TMDL plans. Local public agencies (i.e., Permittees) subject to requirements via National Pollutant Discharge Elimination System (NPDES) permits are required to implement control measures in an attempt to reduce PCBs and mercury from entering stormwater runoff and the Bay. These control measures, also referred to as Best Management Practices (BMPs), are the tools that Permittees can use to assist in restoring water quality in the Bay.

### 1.1.2 Municipal Regional Permit

NPDES permit requirements associated with Phase I municipal stormwater programs and Permittees in the Bay area are included in the MRP, which was issued to 76 cities, counties and flood control districts in 2009 and revised in 2015. The MRP includes provisions to reduce loads of mercury and PCBs consistent with the TMDL implementation timeframe (Provisions C.11 and C.12, respectively) through implementation of GI projects (Provisions C.3.j, C.11.c, and C.12.c) and source controls (Provisions C.11.d and C.12.d).

The Permittees are reporting load reductions achieved before and during the current MRP term (2014 – 2020) using the approved Interim Accounting Methodology (BASMAA, 2017). MRP Provisions C.11.b.iii.(3) and C.12.b.iii.(3) requires the Permittees to report in the 2018 and subsequent Annual Reports any refinements to the Interim Accounting Methodology to be used in subsequent Permit terms. As part of this reporting requirement, Provision C.11.c.iii.(3) and C.12.c.iii.(1) requires the Permittees to report on the quantitative relationship between GI implementation and PCBs and mercury load reductions, including all data used and a full description of models and model inputs relied on to establish this relationship.

*Green Infrastructure Planning and RAA*

MRP Provision C.3.j requires the Permittees to develop a Green Infrastructure Plan for inclusion in the 2019 Annual Report. The Green Infrastructure Plan must be developed using a mechanism to prioritize and map areas for potential and planned GI projects, both public and private, on a drainage-area-specific basis, for implementation by 2020, 2030, and 2040.

MRP Provisions C.11.c and C.12.c require the Permittees to prepare an RAA for inclusion in the 2020 Annual Report that quantitatively demonstrates that specified mercury and PCBs load reductions will be achieved by 2040 through implementation of GI.

This RAA should do the following:

1. Quantify the relationship between the areal extent of GI implementation (e.g., acres treated) and mercury and PCBs load reductions. This quantification should take into consideration the scale of contamination of the treated area as well as the pollutant removal effectiveness of GI strategies likely to be implemented.
2. Estimate the amount and characteristics of land area that will be treated by GI by 2020, 2030, and 2040.
3. Estimate the amount of mercury and PCBs load reductions that will result from GI implementation by 2020, 2030, and 2040.

4. Ensure that the calculation methods, models, model inputs, and modeling assumptions used have been validated through a peer review process.

Additionally, MRP Provisions C.11.d. and C.12.d. require the Permittees to prepare plans and implementation schedules for mercury and PCBs control measures and an RAA demonstrating that sufficient control measures will be implemented to attain the mercury TMDL wasteload allocations by 2028 and the PCBs TMDL wasteload allocations by 2030. The implementation plans, which will also be included in the 2020 Annual Report, along with the GI-based RAA outlined above, must:

1. Identify all technically and economically feasible mercury or PCBs control measures (including GI projects, but also other control measures such as source property identification and abatement, managing PCBs in building materials during demolition, enhanced operations and maintenance, and other source controls) to be implemented;
2. Include a schedule according to which technically and economically feasible control measures will be fully implemented; and
3. Provide an evaluation and quantification of the mercury and PCBs load reduction of such measures as well as an evaluation of costs, control measure efficiency, and significant environmental impacts resulting from their implementation.

This report presents the quantitative relationship between GI implementation and PCBs and mercury load reductions, including the data used and a full description of models and model inputs relied on to establish this relationship. This relationship will be used to predict loads reduced through GI implementation for the RAAs described above and to report loads reduced through GI implementation in the subsequent Permit term.

## 2. DESCRIPTION OF RAA MODEL

This section provides an overview of the RAA modeling framework and describes the output of each component.

### 2.1 RAA Model Overview

The approach used to estimate the load reductions resulting from implementation of GI includes the model components listed below, which are described in further detail in the following sections:

- Baseline Pollutant Loading Model – the baseline pollutant loading model is a continuous simulation[1] hydrology model combined with pollutant loading inputs to obtain the average annual loading of mercury and PCBs across the county during the TMDL baseline period (i.e., 2003 – 2005).
    - Hydrology – this model component produces average annual runoff across each county for the period of record using a hydrologic response unit (HRU) approach. The HRU approach involves modeling various combinations of land surface features (i.e., imperviousness, underlying soil characteristics, slope, etc.) present within each county for a unit area drainage catchment. See Section 2.2.1.
    - Water Quality – the hydrology output is combined with average annual concentrations estimated by the Regional Monitoring Program's Regional Watershed Spreadsheet Model (RWSM; Wu et al, 2017) developed by the San Francisco Estuary Institute (SFEI) to produce average annual PCBs and mercury loading for the period of record. See Section 2.2.2.
- GI Performance Models – the GI performance models are developed to represent load reductions resulting from implementation of GI. See Section 2.3.
- Future Condition (RAA Scenario) Models – the RAA scenario models are conducted to represent future land use changes and control measure implementation that could result in pollutant load reduction. Both GI and source controls are considered, depending on the time frame of interest. See Section 2.4 for a description of load reduction calculations.

## 2.2 Baseline Loading Model

### 2.2.1 Hydrologic Model

As introduced above, the proposed approach for modeling hydrology is to use a hydrologic response unit (HRU) approach. An HRU is a unique combination of land surface features (imperviousness, underlying soil characteristics, slope, etc.) which is expected to give a consistent runoff response to rainfall, no matter where that unique combination is found. The HRU approach involves modeling all possible combinations of land surface features present within each county for a unit area drainage catchment and then storing these results in a database. These HRU results can been be scaled geospatially across the entire county without developing

[1] Continuous simulation models calculate outputs (e.g., runoff) "continuously", i.e., for many time steps over a long-term period of record (e.g., every 10 minutes for 10 years). Long-term "continuous" input data (e.g., hourly rainfall) is required. This is contrasted with design-event simulations which model a single rainfall event, e.g., a 24-hour storm with a 10-year recurrence frequency.

a detailed hydrologic model. This method is consistent with the *Bay Area RAA Guidance Document* (BASMAA, 2017b).

The generic HRUs are modeled using USEPA's Stormwater Management Model (SWMM) to obtain an average annual runoff volume per acre for the identified baseline period of record (water year [WY] 2000 – 2009) for each HRU. Certain HRU inputs (imperviousness, soil parameters) are adjusted as needed to calibrate the HRUs on an average annual basis to identified flow gauges in the counties.

The average annual runoff volume per acre associated with a specific HRU can then be multiplied by the area represented by that HRU across each county (or a selected smaller planning area, such as a watershed or jurisdictional boundary). The resulting volumes associated with each represented HRU within the specified geospatial area can then be summed for the identified area to obtain the estimated total average annual runoff volume.

### 2.2.2 Water Quality Model

Identified HRUs across each county are combined with the RWSM land use classifications layer to determine pollutant loading rates. The RWSM provides average annual concentrations of PCBs and mercury that wash off from various land use categories. On an average annual basis, this approach approximates the total load.

Average annual runoff volume associated with the geospatial HRUs is multiplied by the PCBs and mercury average annual concentration (based on the RWSM land use categories for the identified area) to obtain average annual pollutant load using the following equation:

$$Load_{Baseline} = \sum\left(\sum Unit\ Runoff_{HRU} \times Area_{LU,HRU}\right) \times Concentration_{LU} \times 0.00123 \qquad \text{Eqn. 1}$$

Where:

$Load_{Baseline}$ = The total average annual baseline pollutant load for the identified area for calculation [grams/year]

$Unit\ Runoff_{HRU}$ = The average annual runoff per acre for a given HRU within the identified area for calculation [ac-ft/acre/yr]

$Area_{LU,HRU}$ = The total area of the HRU within the RWSM land use category within the identified area for calculation [acres]

$Concentration_{LU}$ = The average annual pollutant concentration associated with the RWSM land use category [ng/L]

0.00123 = Conversion factor [(L/ac-ft)*(g/ng)]

## 2.3 Green Infrastructure Performance Model

Volume reduction (via retention in the green infrastructure facility) and pollutant load reduction (via filtration through media and discharge through an underdrain) are modeled utilizing a combination of hydraulic modeling in SWMM and currently available empirical GI performance data.

### 2.3.1 Hydraulic GI Models

GI control measure hydraulic performance is modeled in SWMM with a 100% impervious tributary area for three GI facility types: (1) bioretention[2] with a raised underdrain, (2) bioretention with no underdrain, and (3) lined bioretention. The model is run with varying footprint sizes and varying underlying infiltration rates (i.e., the rate at which treated runoff infiltrates into native soils underlying the BMP facility). Average annual volume retained, volume treated, and volume bypassed by the GI measure are recorded for each GI model run.

Volume-based performance[3] corresponding to the generic 100% impervious tributary area can be applied to the effective area in GI drainage areas made up of identified HRUs. The effective area is also known as the “runoff generating area” and is calculated as the tributary area multiplied by the long-term or average annual runoff coefficient.

### 2.3.2 Green Infrastructure Pollutant Reduction Calculations

To calculate pollutant load reduction associated with GI implementation, the hydraulic model results are combined with water quality performance data. The annual estimate of pollutant load reduction from the modeled drainage area is equivalent to the difference between the influent load and the sum of the pollutant load that bypasses the GI measure and the effluent load (Eqn. 2). Equations corresponding to the pollutant reduction calculation are provided below and the water balance is illustrated in Figure 1. In summary, influent load is calculated as the pollutant load produced by the 100% impervious tributary area for each RWSM land use category using Eqn. 3. The pollutant load that bypasses the facility is calculated as the proportion of runoff that bypasses the facility per the hydraulic GI model output, multiplied by the influent concentration

[2] The bioretention is assumed to include: 6-inch or 12-inch ponding depth, 1.5 ft of filter media with a 5 in/hr flow through rate, and 1 ft of gravel beneath the media.

[3] Volume-based performance refers to how much runoff volume the GI facility captures and retains or treats and discharges through the underdrain, typically represented as a percentage of the average annual runoff volume.

(Eqn. 4). The effluent load is calculated as the proportion of runoff that is captured by the facility per the hydraulic GI model output, combined with an effluent concentration (Eqn. 5 and Eqn. 6).

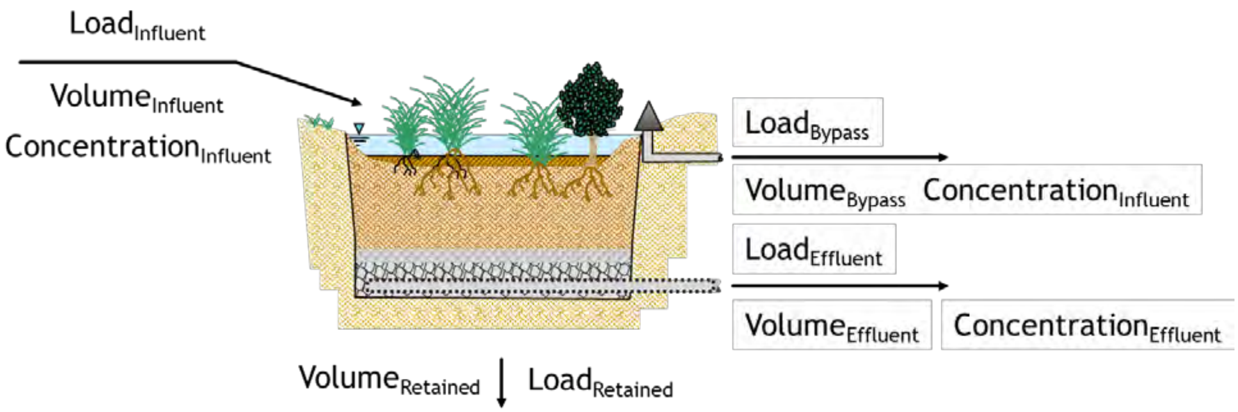


**Figure 1: Illustration of GI Facility Pollutant Load Reduction Calculations**

$$Load_{Reduced} = Load_{Influent} - Load_{Bypass} - Load_{Effluent} \quad \text{Eqn. 2}$$

$$Load_{Influent} = Volume_{Influent} \times Concentration_{Influent} \times C \quad \text{Eqn. 3}$$

$$Load_{Bypass} = Volume_{Bypass} \times Concentration_{Influent} \times C \quad \text{Eqn. 4}$$

$$Load_{Effluent} = (Volume_{Captured} - Volume_{Retained}) \times Concentration_{Effluent} \times C \quad \text{Eqn. 5}$$

$$Volume_{Captured} = Volume_{Influent} - Volume_{Bypass} \quad \text{Eqn. 6}$$

Where:

Load$_{Reduced}$ = The total average annual pollutant load reduced by the GI facility [g/year]

Load$_{Influent}$ = The total average annual pollutant load produced by the facility drainage area [g/year]

Load$_{Bypass}$ = The pollutant load that bypasses the facility [g/year]

Load$_{Effluent}$ = The pollutant load discharged from the facility after treatment [g/year]

Volume$_{Influent}$ = The runoff produced by the drainage area to the GI facility [ac-ft/year]

Volume$_{Bypass}$ = The proportion of influent runoff that bypasses the facility [ac-ft/year]

| | | |
|---|---|---|
| $Volume_{Captured}$ | = | The proportion of influent runoff that is captured by the facility [ac-ft/year] |
| $Volume_{Retained}$ | = | The proportion of captured runoff that is retained by the facility through infiltration and/or evapotranspiration [ac-ft/year] |
| $Concentration_{Influent}$ | = | The pollutant concentration associated with the GI drainage area [ng/L] |
| $Concentration_{Effluent}$ | = | The concentration discharged from the facility after treatment [ng/L] |
| C | = | Conversion factor constant = 0.00123 [(L/ac-ft)*(g/ng)] |

### 2.4 RAA Scenario Loading Model

The loading corresponding with RAA future condition scenarios (2020, 2030, 2040) will be developed using the same volume and concentration combination approach used for the baseline condition. HRU outputs developed for the baseline model will scaled across the county corresponding to anticipated land use and development changes for each of the future conditions. Similarly, the RWSM land use classifications layer will be updated corresponding to each future condition scenario.

The outputs of the future hydrology scaling combined with the concentrations corresponding with future RWSM land use classification provides the land use-based loading estimated for each of the future conditions. To obtain the discharged load corresponding to each future GI scenario, load reductions associated with anticipated GI (developed as described above) will be subtracted from the land use-based load.

## 3. MODEL INPUTS AND DATA USED

This section describes the inputs to each component of the model and the data used.

### 3.1 Baseline Loading Model

#### 3.1.1 Hydrologic Model

Generic HRU models are developed in SWMM to estimate average annual runoff volume per acre values that can be applied to all land surfaces within each county. The land surface feature inputs that will be varied to model the generic HRUs are described in the sections below and summarized in Table 3.

*Climate Inputs*

HRU climate inputs provide the total amount of precipitation that falls on the land surface and the amount of precipitation that is lost to the atmosphere via evapotranspiration before running off the land surface. Multiple gauges from across Alameda and Contra Costa counties that had continuous hourly precipitation data were chosen to represent distinct rainfall regions within both counties. For precipitation, these regions are based on 30-year annual rainfall regimes as identified by PRISM[4]. For evapotranspiration rates, the California Irrigation Management Information System (CIMIS) evapotranspiration zones were used within each county. The combination of the identified precipitation regions and evapotranspiration regions were combined to yield "climate zones" used for generic HRU models. Precipitation zones, evapotranspiration zones, and climate zones are shown in Exhibit 1 through Exhibit 3 (see Appendix A). Table 1 provides a summary of precipitation gauges used and average annual rainfall corresponding to the entire period of record and WY 2000 - 2009. Table 2 provides a summary of the CIMIS data used for the daily reference evapotranspiration rate for each evapotranspiration zone.

**Table 1: HRU Precipitation Gauges WY2000-2009**

| Gauge ID | Gauge Name | Average Annual Precipitation (inches) WY 2000 - 2009 | Gauge Source |
|---|---|---|---|
| KHWD | Hayward Air Terminal (ASOS) | 16.3 | ASOS[1] |
| KLVK | Livermore Municipal Airport (ASOS) | 14.6 | ASOS |
| KOAK | Oakland Airport (ASOS) | 19.0 | ASOS |
| DBF | Dublin Fire Station, San Ramon | 17.3 | CCCFCD[2] |
| FCD | Flood Control District, Martinez | 16.2 | CCCFCD |
| LSM | Los Medanos, Pittsburg | 11.8 | CCCFCD |
| SMC | Saint Mary's College, Moraga | 28.9 | CCCFCD |

1. Automated Surface Observation System (ASOS) data were used for Alameda County gauge sites for the period of WY2000-2009 since NCDC gauge data was not available for the baseline period. ASOS sites sometimes co-occur with NCDC gauge sites (e.g., airports), but are maintained and delivered by separate government entities.
2. Contra Costa County gauge data is collected by the Flood Control District but was provided to Geosyntec by Dubin Engineering.

[4] Parameter-elevation Relationships on Independent Slopes Model (PRISM), developed and managed by the PRISM Climate Group, Oregon State University http://prism.oregonstate.edu/.

**Table 2: CIMIS Reference Evapotranspiration**

| ET Zone | Monthly Evapotranspiration (in/day)[1] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| 1 | 0.03 | 0.05 | 0.08 | 0.11 | 0.13 | 0.15 | 0.15 | 0.13 | 0.11 | 0.08 | 0.04 | 0.02 |
| 2 | 0.04 | 0.06 | 0.1 | 0.13 | 0.15 | 0.17 | 0.16 | 0.15 | 0.13 | 0.09 | 0.06 | 0.04 |
| 3 | 0.06 | 0.08 | 0.12 | 0.16 | 0.17 | 0.19 | 0.18 | 0.17 | 0.14 | 0.11 | 0.08 | 0.06 |
| 6 | 0.06 | 0.08 | 0.11 | 0.16 | 0.18 | 0.21 | 0.21 | 0.2 | 0.16 | 0.12 | 0.08 | 0.06 |
| 8 | 0.04 | 0.06 | 0.11 | 0.16 | 0.2 | 0.23 | 0.24 | 0.21 | 0.17 | 0.11 | 0.06 | 0.03 |
| 14 | 0.05 | 0.08 | 0.12 | 0.17 | 0.22 | 0.26 | 0.28 | 0.25 | 0.19 | 0.13 | 0.07 | 0.05 |

1. CIMIS reference evapotranspiration, which is based on irrigated turf grass, was scaled by 0.6 to represent the local mix of vegetated cover including urban vegetation, native xeric adapted plants, and unirrigated vegetated open space areas.

*Slope*

Slope affects how quickly rainfall will run off a modeled land surface and therefore how much is able to be infiltrated into the subsurface. The available digital elevation model (DEM)[5] for the counties was analyzed to obtain percent slope values for each ~30m by ~30m square of land surface. These percent slope values were classified into three distinct slope zones as summarized in Table 3 and shown in Exhibit 4 (see Appendix A).

*Underlying Soil Inputs*

Physical characteristics of the soil underlying the land surface affect the amount of rainfall that may be infiltrated into the subsurface. Infiltration was simulated in SWMM using the Green-Ampt infiltration model option. The physical soil input parameters for the Green-Ampt infiltration model were varied based on hydrologic soil group (HSG) as identified by the National Resource Conservation Service (NRCS[6]) soil survey and were modified as described below for developed areas. Soil parameters used as model inputs include suction head, hydraulic conductivity, and initial moisture deficit. Developed areas that are assumed to have been compacted and therefore result in less infiltration to the subsurface are modeled using 75 percent of the HSG hydraulic conductivity value. Soil parameters are not reported here, as this input is adjusted as part of baseline model calibration. Details about soil inputs are provided in Table 3. A map of hydrologic soil group is provided as Exhibit 5 (see Appendix A).

[5] U.S. Geological Survey. National Elevation Dataset (NED) 1/3 arc-second. 2013

[6] Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. link: https://websoilsurvey.sc.egov.usda.gov/

Areas of development were identified based on the land use of the surface. Soils within urban and agricultural use areas were considered to have been compacted by the site preparation and activities.

*Imperviousness*

Imperviousness (i.e., the percentage of impervious area) affects area on the land surface where rainfall may be infiltrated and therefore the quantity of runoff produced. The runoff from a range of land use imperviousness values is modeled by area-weighting the results of a pervious surface runoff result (i.e., pervious HRU output) with a corresponding impervious surface runoff result (i.e., impervious HRU output) (see Table 3 and Exhibit 6 (see Appendix A)).

The baseline model HRU imperviousness is developed by geospatially combining the land uses identified by the Association of Bay Area Governments (ABAG, 2005) with the National Land Cover Dataset (NLCD, 2006) data. Each feature of the ABAG dataset is assigned a single imperviousness value that is used to determine the average hydrologic response of that land surface. A lookup-table containing NLCD-based imperviousness for each ABAG land use code was used as a starting value for HRU calibration. Imperviousness may be adjusted within an appropriate range as part of baseline model calibration.

### 3.1.2 <u>Developing HRUs across each County</u>

Each identified combination of land surface features is modeled for a generic unit-acre drainage area in SWMM for the baseline period of record (i.e., WY 2000 – 2009), utilizing a batch-processing method (which allows for inputs to be altered, model files run, and results extracted for many models automatically). The average annual runoff volume per acre is then extracted for each generic HRU modeled.

**Table 3: Land Surface Feature Inputs for Generic HRU Hydrologic Models**

| Variables | Description | Number of Varying Features | Feature Representations | Source |
|---|---|---|---|---|
| Hourly Annual Precipitation | Rainfall Gauge and Rainfall Zone | 7 | Contra Costa County Gauges: DBF, FCD, LSM, SMC<br>Alameda County ASOS Gauges: KHWD, KLVK, KOAK | PRISM[1], NCDC/ County-maintained rainfall gauges |
| Daily Evapotranspiration Rate | Evapotranspiration Zone | 5 | Zones 1, 2, 3, 6, 8, 14 | CIMIS[2] |
| Slope Zone | Representation of Slope | 3 | <5%, 5-15%, 15%+ | USGS[3] |
| Developed/ Undeveloped Areas | Representation of Compaction of Underlying Soils (Pervious Areas Only) | 2 | Undeveloped (Ksat * 1)<br>Developed (Ksat * 0.75) | ABAG Land Use 2005[4] |
| Hydrologic Soil Group | Representation of Underlying Soil Type (pervious areas only) | 6 | HSG A, B, C, D[5], Rock, Water | NRCS[6] |
| Imperviousness | Representation of Imperviousness | 2 | 0% and 100% | NLCD and ABAG 2005 |

1. PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, 30-year normal mean annual precipitation
2. California Irrigation Management Information System (CIMIS) Reference Evapotranspiration; digitized from http://www.cimis.water.ca.gov/App_Themes/images/etozonemap.jpg
3. U.S. Geological Survey. National Elevation Dataset (NED) 1/3 arc-second. 2013
4. ABAG land use features are proposed to be used for identifying developed and undeveloped condition and will have an imperviousness value assigned based on a geospatial analysis of the NLCD Imperviousness layer. The impervious value for each ABAG land use feature will then be carried into the HRU model calibration and adjusted accordingly.
5. "Urban" representation will be re-classified based on the dominant adjacent HSG.
6. U.S. Department of Agriculture, Natural Resources Conservation Service. Soil Survey Geographic (SSURGO) database. 2016

HRUs are determined geospatially based on the climate zone, slope zone, developed/undeveloped areas, and HSG, along with land use-based imperviousness. Exhibits 1 through 5 (see Appendix A) display the data used to develop climate zones, county slope zones, and the HSG distribution across each county. Imperviousness designations will occur based on land use at the parcel, by combining the geospatial ABAG land use layer[7] with the other hydrologic input regions. This results in a "patchwork" of HRUs across the counties[8].

The resulting patchwork of HRUs can be combined at the scale of choice to provide total runoff volumes for a specific area, such as a watershed or jurisdictional boundary. To estimate the total runoff for the identified area, the total acreage of each designated HRU present within a watershed or jurisdiction will be multiplied by the average annual runoff per acre associated with each HRU and then summed (i.e., area-weighting the average annual runoff volume per acre for all HRUs present).

### 3.1.3 HRU Input Calibration

Calibration of hydrologic models is required by the *Bay Area RAA Guidance Document*. Calibration of the generic HRU models will be conducted utilizing available stream flow records and based solely upon the annual discharge volume between WY 2000-2009. This annual calibration means that the HRU runoff estimates are representative of the approximate annual runoff volume but will not be used to estimate or compare discharge rates at smaller timesteps, such as the hourly or daily runoff hydrograph.

The list of candidate gauge sites within the counties was developed based on an assessment of the representativeness of the gauged watersheds and the mitigation of confounding factors that interfere with calibration such as missing data and upstream impoundments. For the purposes of calibration, the candidate gauge sites that were selected included stream depth rating curves and at least daily mean records for the historical period of interest. The USGS flow gauges considered for calibration are provided in Table 4 and shown in Exhibit 8 (see Appendix A).

**Table 4: Flow Gauge Considered for RAA Model Calibration**

| Gauge ID | Gauge Name | Location | County | Data Frequency |
|---|---|---|---|---|
| 11337600 | Marsh Creek | Brentwood | Contra Costa | Daily |
| 11182500 | San Ramon Creek | San Ramon | Contra Costa | Daily |
| 11181390 | Wildcat Creek | Richmond / San Pablo | Contra Costa | Daily |
| 11181040 | Lan Lorenzo Creek | San Lorenzo | Alameda | Daily |
| 11181008 | Castro Valley Creek | Hayward | Alameda | Daily |

[7] ABAG land use features will be used to aggregate the imperviousness for the land surface. The relationship between ABAG feature and its imperviousness will be developed based upon other local sources (SMCWPPP, 2017) and analysis of national public data sets such as the National Land Cover Dataset (NLCD).

[8] This will be done once all the HRU input files are finalized, including the imperviousness layers.

| Gauge ID | Gauge Name | Location | County | Data Frequency |
|---|---|---|---|---|
| 11181000 | San Lorenzo Creek | Hayward | Alameda | Daily |
| 11180700 | Alameda Creek Flood Channel | Union City | Alameda | Daily |
| 11179000 | Alameda Creek | Fremont | Alameda | Daily |
| 11176900 | Arroyo de la Laguna | Verona | Alameda | Daily |
| 11173575 | Alameda Creek Below Welch Creek | Sunol | Alameda | Daily |
| 11173510 | Alameda Creek Below Calaveras Creek | Sunol | Alameda | Daily |

The effective area tributary to each flow gauge is used to calibrate the HRUs to the stream gauge records. Annual flow predicted by area-weighting HRU runoff output for the watersheds draining to the stream gauges was compared to annual flow in the stream records for the identified period of record.

Calibration of land surface runoff hydrology to stream gauge records requires that baseflow be computed and accounted for throughout the period of record. A variety of methods exist for separating baseflow from runoff, including the fixed-interval method and the local-minimum method (Sloto and Crouse, 1996). The most appropriate method for separating baseflow is determined on a gauge by gauge basis depending on the variability in the flow record, and the occurrence of confounding factors that affect baseflow such as dam releases and other dry weather inflows.

The average percent difference between the area-weighted HRU total average annual runoff volume for the watershed and the average annual flow (converted to volume) measured for the WY 2000 – 2009 period will be calculated. The acceptable ranges included in the RAA Guidance document are provided in Table 5 below.

**Table 5: Allowable Difference between Simulated and Observed Annual Volumes**

| Model parameters | Average % difference between simulated annual results and observed data | | |
|---|---|---|---|
| | Very Good | Good | Fair (lower bound, upper bound) |
| Hydrology/Flow | <10 | 10-15 | 15-25 |

If the average percent difference between simulated and measured annual storm flow volumes is greater than 25%, HRU model parameters are adjusted until the percent difference is within the acceptable range. The primary model parameters adjusted include underlying soil hydraulic conductivity and land use imperviousness, but other hydrologic model parameters, such as depression storage, may be adjusted as appropriate.

Once average percent differences in all identified watersheds are within the acceptable range, the HRU model parameters are finalized and the HRU results database will be regenerated. HRUs and resulting average annual baseline volume will be applied across each county to obtain the baseline volume discharged by each county.

#### 3.1.4 Water Quality Model

RWSM values used to develop pollutant loading estimates across each county are:

**Table 6: Regional Watershed Spreadsheet Model PCBs and Mercury Concentrations in Runoff**

| Land Use Category | Total PCBs (ng/L) | Total mercury (ng/L) |
|---|---|---|
| Ag, Open | 0.2 | 80 |
| New Urban | 0.2 | 3 |
| Old Residential | 4 | 63 |
| Old Commercial/ Transportation | 40 | 63 |
| Old Industrial and Source Areas | 204 | 40 |

Water quality calculations are also used to perform baseline pollutant loading validation. The calculated pollutant load draining to Regional Monitoring Program stations will be validated by calculating the volume-weighted watershed pollutant concentration using the modeling results and comparing it to the observed concentrations in the Regional Monitoring Program data. The equation used to calculate concentration (in ng/L) at an end-of-watershed location is as follows:

$$Concentration_{Baseline} = \frac{\sum Runoff_{HRU} \times Area_{HRU} \times Concentration_{LU,HRU}}{\sum Runoff_{HRU} \times Area_{HRU}} \quad \text{Eqn. 7}$$

Pollutant concentration and loading data from the Regional Monitoring Program will be compared to the result of Equation 7 for several watersheds for validation purposes.

### 3.2 Green Infrastructure Performance Model

#### 3.2.1 Long-Term Green Infrastructure Simulations

Long term performance was assessed for each BMP configuration using continuous historical rainfall records. In Contra Costa County historical data was available at the same gauges that were used for the HRU runoff modeling between WY2000-2009, but for Alameda County other gauge sites with longer histories were used for long term BMP performance modeling. The rainfall gauges used to model BMP performance are shown in Table 7.

**Table 7: Long Term GI Performance Precipitation Gauges**

| Gauge ID | Gauge Name | Period of Record | Average Annual Precipitation (inches) | Gauge Source[1] |
|---|---|---|---|---|
| 040693 | Berkeley (NCDC) | 1948-1990 | 19.8 | NCDC |
| 041060 | Brentwood (NCDC) | 1950-1985 | 14.9 | NCDC |
| 043863 | Hayward (NCDC) | 1948-1988 | 24.3 | NCDC |
| 046335 | Oakland Airport (NCDC) | 1948-1985 | 16.4 | NCDC |
| 047821 | San Jose Airport (NCDC) | 1948-2010 | 13.6 | NCDC |
| DBF | Dublin Fire Station, San Ramon | 1973-2016 | 15.0 | CCCFCD |
| FCD | Flood Control District, Martinez | 1971-2016 | 16.5 | CCCFCD |
| LSM | Los Medanos, Pittsburg | 1974-2016 | 10.6 | CCCFCD |
| SMC | Saint Mary's College, Moraga | 1972-2016 | 26.8 | CCCFCD |

1. NCDC data was used for Alameda County and San Jose gauge sites. Contra Costa County gauge data is collected by the Flood Control District and was provided to Geosyntec by Dubin Engineering.

### 3.2.2 Hydraulic Green Infrastructure Model

Hydraulic GI models were developed in SWMM to estimate hydraulic performance for a 100% impervious tributary area. Hydraulic model inputs that were varied to model the GI facility performance for the counties are described below and summarized in Table 8.

1. BMP Configuration – three GI facility types were assumed: (1) bioretention with a raised underdrain, (2) bioretention with no underdrain, and (3) lined bioretention with an underdrain.
2. BMP Footprint Size – the BMP footprint size was varied as a percent of impervious area to model different levels of hydraulic capture performance depending on facility sizing.
3. BMP Underlying Infiltration Rate – the infiltration rate of the soils underneath the bioretention facility was varied for the bioretention with a raised underdrain and bioretention with no underdrain configurations (I.e., the unlined facility types).

**Table 8: Land Surface Feature Inputs for Generic GI Performance Hydraulic Models**

| Variables | Description | Number of Varying Features | Feature Representations |
|---|---|---|---|
| Hourly Precipitation | Rainfall Gauge | 9 | NCDC:<br>040693 (Berkeley)<br>046335 (Oakland Airport)<br>043863 (Hayward)<br>047821 (San Jose)<br>041060 (Brentwood)<br>Contra Costa County:<br>DBF, FCD, LSM, SMC |
| Daily Evapotranspiration Rate | Evapotranspiration Zone | 4 | CIMIS Zones:<br>1, 6, 8, 14 |
| BMP Configurations | BMP profiles and underdrain | 3 | Lined Bioretention with underdrain<br>Unlined Bioretention with elevated underdrain<br>Infiltration Basin without underdrain |
| BMP Surface Ponding Depth | Depth (feet) | 2 | 0.5, 1 |
| BMP Footprint Sizes | % of Impervious Area | 12 | 0.25, 0.5, 0.75, 1, 1.5, 2, 2.5, 3, 3.5, 4, 5, 6 |
| BMP Infiltration Rates | Ksat of underlying soil (in/hr) | 7<br><br>3 | Unlined Bioretention:<br>0.024, 0.05, 0.1, 0.2, 0.24, 0.3, 0.4, 0.5<br>Infiltration Basin:<br>0.5, 1, 2 |

The BMP cross-sections that were modeled each include:

- 6-inches or 12-inches ponding depth (both were modeled),
- 1.5 ft of filter media with 25% porosity with a 5 in/hr flow through rate, and
- 1 ft of gravel beneath the media with 40% porosity.

Two of the modeled BMP configurations include underdrains. In the lined bioretention facility, the underdrain is located at the bottom of the gravel layer. In the unlined bioretention facility, the underdrain was modeled at the top of the gravel layer. BMP configurations are shown in Exhibits 9 through 11 (see Appendix A).

### 3.2.3 Green Infrastructure Pollutant Reduction Calculations

As described in Section 2.3.2, pollutant load reduction associated with GI is calculated by combining the hydraulic model results with water quality performance data. The annual estimate of pollutant load reduction from the modeled drainage area is equivalent to the difference between the influent load and the sum of the pollutant load that bypasses the GI measure and the effluent load. The effluent load is calculated as the proportion of runoff that is treated by the GI measure multiplied by an effluent concentration.

Water quality performance data from selected, representative studies were used to determine a method to predict effluent concentrations in stormwater following treatment through a biofiltration (bioretention or tree well filters) GI measure. The data used to develop the relationship came from three studies: a) 2011 monitoring study of the El Cerrito Rain Gardens (Gilbreath, Pearce, and McKee, 2012), b) Clean Watersheds for a Clean Bay (CW4CB)[9] (Geosyntec and EOA, 2017), and c) a study at Echo Lake in King County, WA (King County, 2017). A summary of the paired influent-effluent data associated with each study is provided in table:

**Table 9: Data used to Develop Effluent Concentrations**

| Project Name | Project Sponsor | Facility ID | Influent-Effluent Data Pairs (n pairs) | |
|---|---|---|---|---|
| | | | PCBs | Mercury |
| El Cerrito Green Streets – CW4CB | El Cerrito | ELC-B1 | 3 | 3 |
| El Cerrito Green Streets – SFEI | SFEI | ELC-B1 | 4 | 4 |
| PG&E Substation 1st and Cutting Bioretention Cells – CW4CB | Richmond | LAU-3 | 8 | 8 |
| Monitoring Stormwater Retrofits in the Echo Lake Drainage Basin Bioretention Planter Boxes – SAM Effectiveness Study | King County, Dept. of Natural Resources and Parks | BPB-1<br>BPB-2<br>BPB-3<br>BPB-4 | 4<br>4<br>4<br>2 | 0<br>0<br>0<br>0 |
| West Oakland Industrial Area Tree Wells – CW4CB | Oakland | ETT-TW2<br>ETT-TW6 | 4<br>4 | 4<br>4 |
| Monitoring Stormwater Retrofits in the Echo Lake Drainage Basin Tree Well – SAM Effectiveness Study | King County, Dept. of Natural Resources and Parks | FLT-1 | 4 | 0 |
| | | Total Data Pairs | 41 | 23 |

[9] The CW4CB study included additional monitoring of the El Cerrito rain gardens.

These data were statistically evaluated to identify an appropriate method for predicting effluent concentrations of PCBs and total mercury. The data analysis first evaluated whether available influent and effluent concentration data were significantly different and, if so, whether a monotonic relationship existed (i.e., effluent generally increased when influent increased).

A Wilcoxon non-parametric hypothesis test was run on the PCBs and total mercury paired influent-effluent data to determine if influent and effluent concentrations were statistically different at a 5% significance level. This difference was found to be significant for PCBs, and significant for total mercury when corresponding influent suspended solids concentration was greater than 20 mg/L.

Spearman’s rho and Kendall’s tau, which are non-parametric rank correlation coefficients, were used to identify the direction and strength of correlation between influent and effluent concentrations. As shown in Table 10, both correlation coefficients suggest that effluent concentrations are positively correlated with influent concentrations for both PCBs and mercury.

**Table 10: Influent/Effluent Correlation Coefficients**

| Correlation Coefficient | Total PCBs | Total Mercury |
|---|---|---|
| Spearman’s rho | 0.725 | 0.547 |
| Kendall’s tau | 0.527 | 0.396 |

The Kendall-Theil Robust Line (KTRL) method (Granato, 2006) was used to determine the best fit line between influent and effluent data. This non-parametric method uses the median of all possible pairwise slopes between points, which is more robust to outliers than a simple linear regression. Because stormwater data tend to be lognormal, the analysis was focused on linear and log-linear relationships. After the KTRL was generated, the lower portion of the curve was adjusted to assume that neither PCBs nor total mercury can be exported from biofilters under normal circumstances, i.e., that the maximum effluent concentration of PCBs or total mercury is equal to the influent concentration. The resulting KTRL for PCBs is shown Figure 2. The resulting KTRL for total mercury is shown in Figure 3. Each figure also includes a constant average effluent concentration line with data fit statistics: root mean square error (RMSE) and median absolute deviation (MAD). As indicated, the KTRL provide a better fit of the data. However, the resulting effluent concentrations are not much different between the two lines except when influent PCBs are low (<10 ng/L) and total mercury concentration are high (>50 ng/L). For total mercury, concentration reductions are only predicted to occur when influent concentrations are greater than about 30 ng/L. Due to observed export of total mercury for several events, particularly for the 1$^{st}$ and Cutting bioretention cell (LAU-3), the moderate concentration reductions assumed by the KTRL at higher influent concentrations is reasonably conservative.

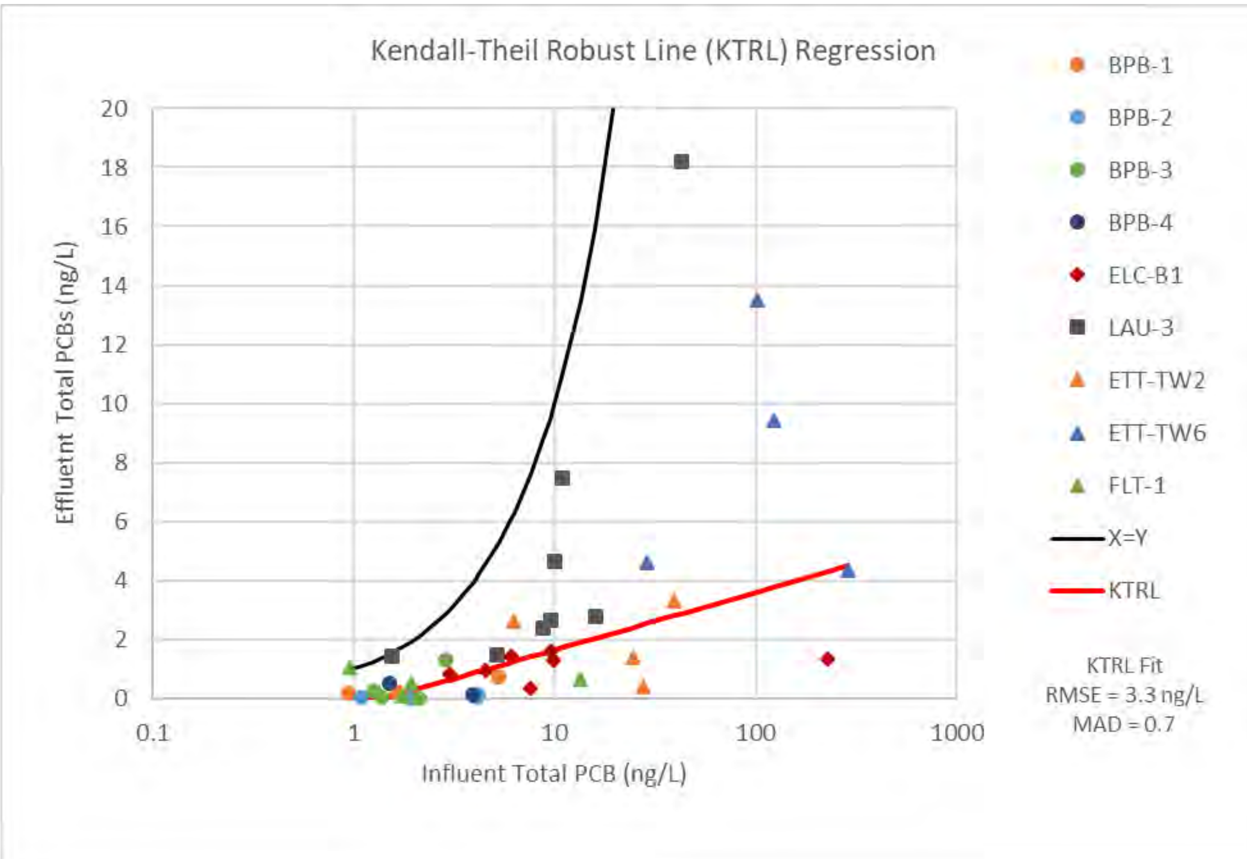


**Figure 2: PCBs Influent vs Effluent Concentration Relationship Determined by KTRL Regression**

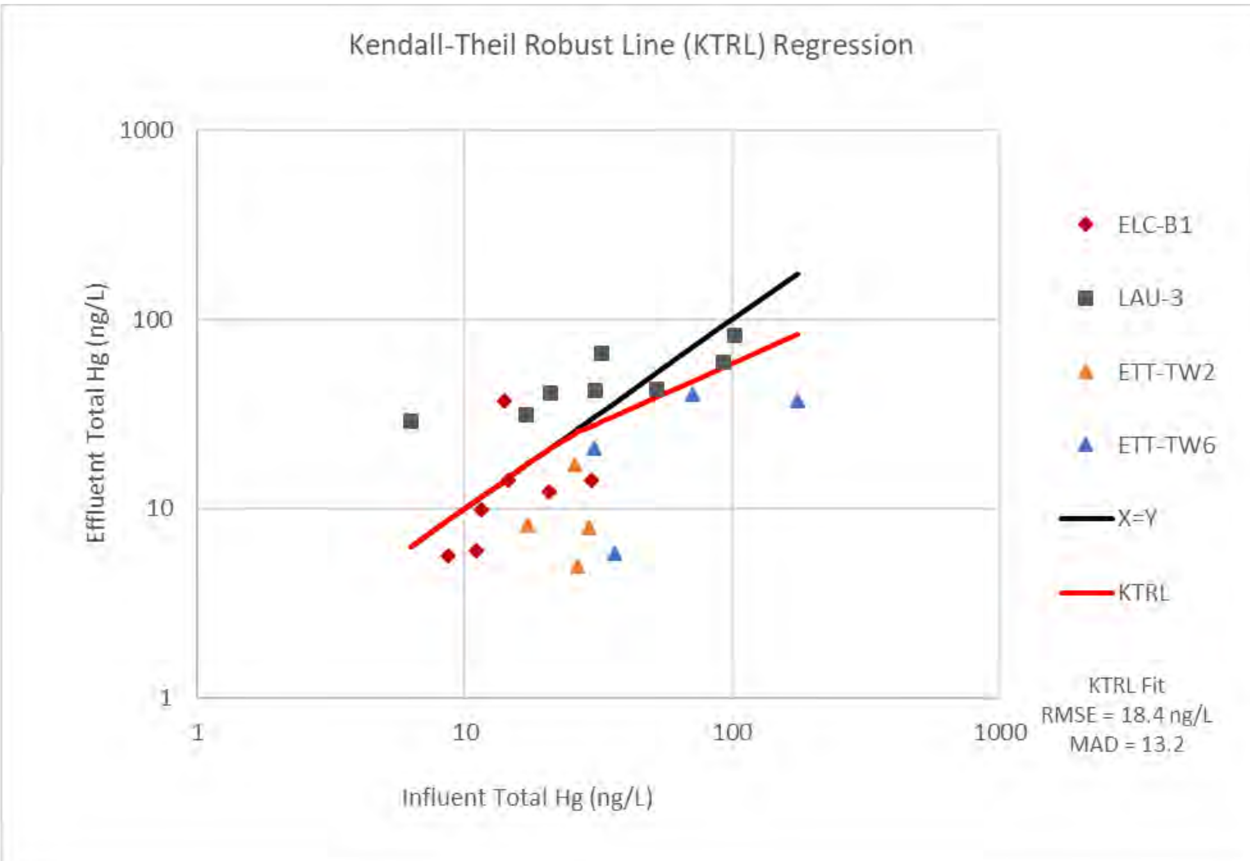


**Figure 3: Mercury Influent vs Effluent Concentration Relationship Determined by KTRL Regression**

### 3.3 RAA Scenario Loading Model

To model RAA future scenarios, future condition land use is needed. Future condition land use will be estimated using predictions of private parcel new development and redevelopment in combination with GI implementation on public parcels and rights-of-way.

Load reductions estimated for implementation of GI will be applied to future condition RAA scenario models based on estimated locations of GI and the tributary drainage areas to those GI. Effective area will be used to relate the HRUs, which can have a variety of imperviousness values, to the GI performance which will be based on a unit of effective area with 100% imperviousness. The GI performance curves can thus be applied to many different HRU types and/or combinations of HRUs that make up the tributary drainage areas for future GI measures.

# 4. QUANTITATIVE RELATIONSHIP BETWEEN GI IMPLEMENTATION AND PCBS LOADS REDUCED

The results of the hydraulic and pollutant reduction modeling of GI measures were used to develop a quantitative relationship between GI implementation and PCBs that can be applied to RAA future scenario models. An example quantitative relationship is provided for GI models run for the Berkeley gauge (040693). Utilizing output from hydraulic modeling, GI measure volumetric percent capture was calculated on an average annual basis. Volumetric model results for runs with GI measures sized to achieve 80%, 85%, 90%, and 95% capture were combined with water quality inputs to obtain pollutant load reduction for varying PCBs influent concentration.

The results of this analysis are shown in nomographs[10] provided in Figure 4, Figure 5, and Figure 6, which correspond to infiltrating bioretention (i.e., with no underdrain), bioretention with a raised underdrain, and lined bioretention, respectively. All facilities shown in the figures below have a 6-inch ponding depth. For bioretention with a raised underdrain, the facility configuration with an underlying infiltration rate of 0.24 in/hr only is shown (see Table 8 for all modeled infiltration rates). Facilities sized to achieve 80%, 85%, 90%, and 95% capture from the 100% impervious tributary catchment are shown in series, with pollutant load reduction in grams per effective acre[11] displayed as a function of influent concentration. Constant influent lines corresponding with RWSM land use-based influent concentrations are shown.

[10] A nomograph is a graphical relationship between two variables that can be used to quickly estimate one value from another.

[11] Effective area is calculated as the area multiplied by the runoff coefficient.

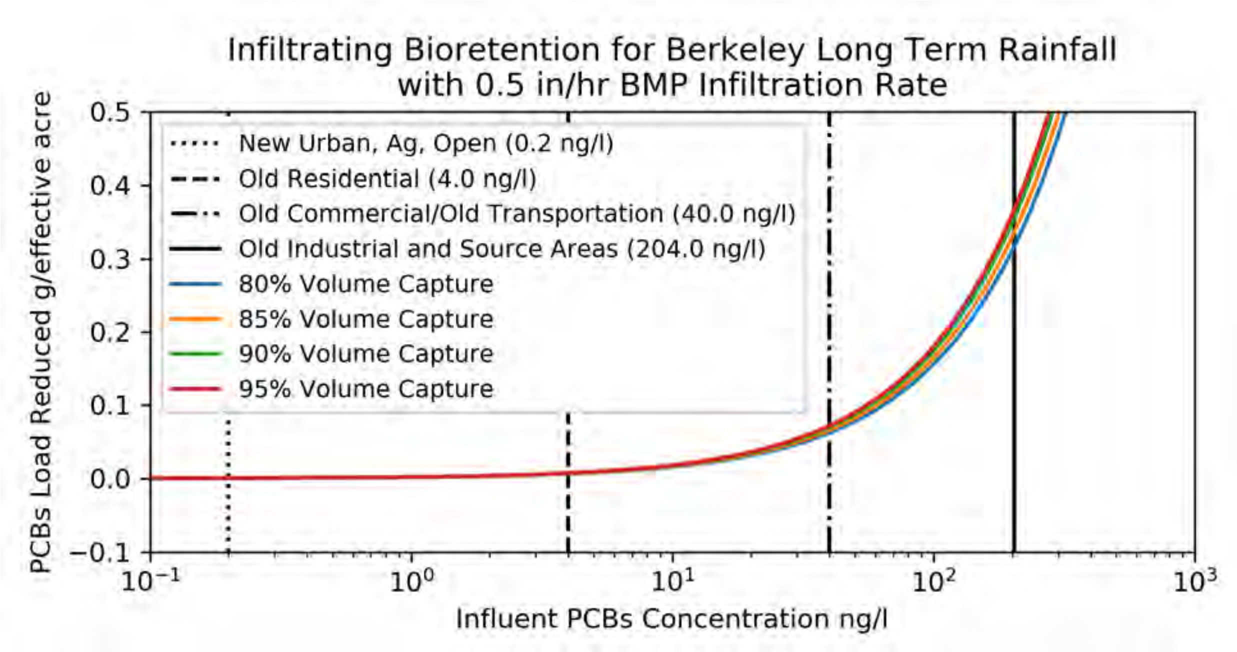


**Figure 4: Modeled PCBs Load Removal Performance for Infiltrating Bioretention Basin**

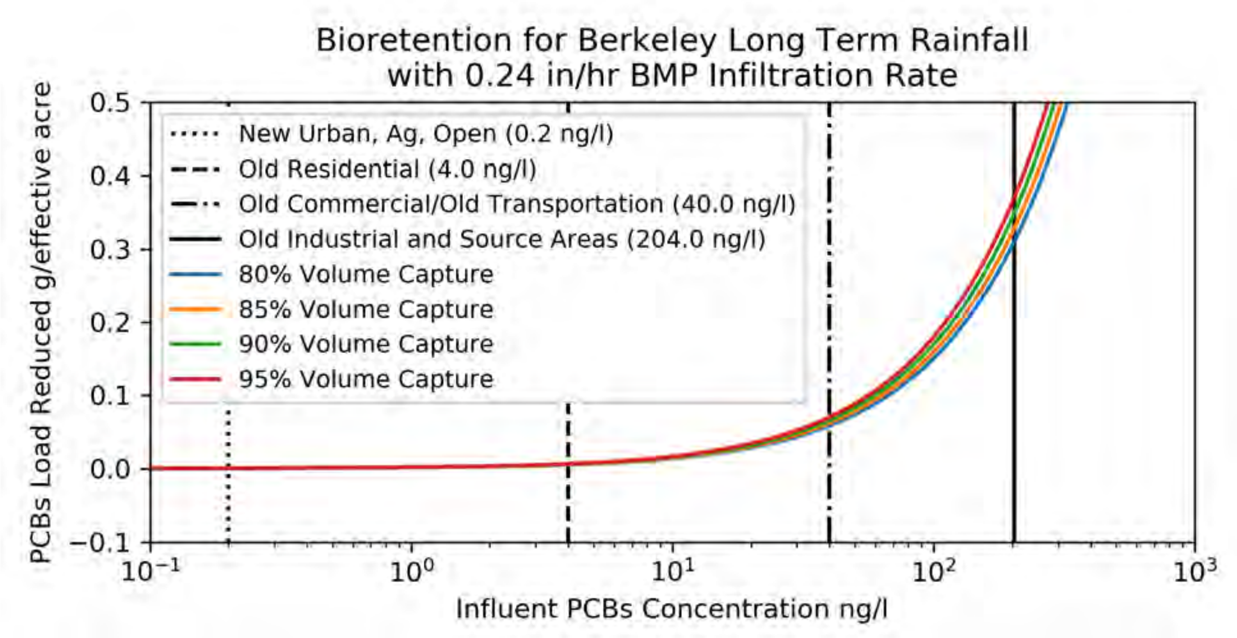


**Figure 5: Modeled PCBs Load Removal Performance for Bioretention Basin with Elevated Underdrain**

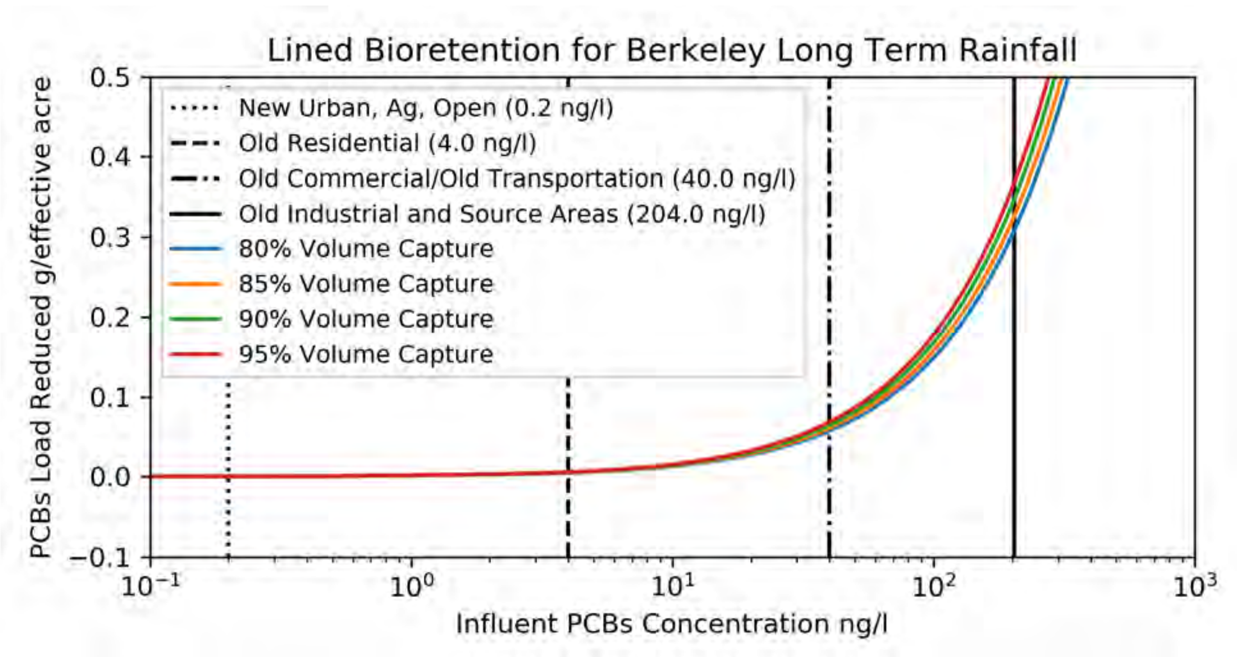


**Figure 6: Modeled PCBs Load Removal Performance for Lined Bioretention Basin with Underdrain**

The intersection points between the load reduction series and the constant influent lines represent the load reduced in grams per acre for each specific RWSM land use category. These intersection points are listed in Table 11.

**Table 11: PCBs Load Reduction for RWSM Land Use Categories for Berkeley Gauge for Different BMP Percent Capture Values**

| Facility Configuration | Land Use Category | PCBs Load Reduced (g/effective ac) | | | |
|---|---|---|---|---|---|
| | | 80% Capture[1] | 85% Capture[1] | 90% Capture[1] | 95% Capture[1] |
| Infiltrating Bioretention (0.5 underlying infiltration rate) | New Urban, Ag, Open | 3.12E-04 | 3.30E-04 | 3.49E-04 | 3.61E-04 |
| | Old Residential | 0.00623 | 0.0066 | 0.00698 | 0.00722 |
| | Old Commercial / Old Transportation | 0.0623 | 0.066 | 0.0698 | 0.0722 |
| | Old Industrial and Source Areas | 0.318 | 0.337 | 0.356 | 0.368 |
| Bioretention with Raised Underdrain (0.24 underlying infiltration rate) | New Urban, Ag, Open | 3.08E-04 | 3.26E-04 | 3.47E-04 | 3.67E-04 |
| | Old Residential | 0.00518 | 0.0055 | 0.00589 | 0.00633 |
| | Old Commercial / Old Transportation | 0.0586 | 0.0621 | 0.0661 | 0.0703 |
| | Old Industrial and Source Areas | 0.311 | 0.329 | 0.350 | 0.371 |
| Lined Bioretention | New Urban, Ag, Open | 3.08E-04 | 3.26E-04 | 3.46E-04 | 3.67E-04 |
| | Old Residential | 0.00484 | 0.00513 | 0.00545 | 0.00577 |
| | Old Commercial / Old Transportation | 0.0574 | 0.0608 | 0.0647 | 0.0685 |
| | Old Industrial and Source Areas | 0.309 | 0.327 | 0.348 | 0.368 |

1. Average Annual Facility Volumetric Runoff Capture

## 5. QUANTITATIVE RELATIONSHIP BETWEEN GI IMPLEMENTATION AND MERCURY LOADS REDUCED

Mercury load reduction results for the Berkeley Gauge are shown in nomographs[12] in Figure 7, Figure 8, and Figure 9, which correspond to infiltrating bioretention (i.e., with no underdrain), bioretention with a raised underdrain, and lined bioretention, respectively. All facilities shown in the figures below have a 6-inch ponding depth. For bioretention with a raised underdrain, the facility configuration with an underlying infiltration rate of 0.24 in/hr only is shown (see Table 9 for all modeled infiltration rates). Facilities sized to achieve 80%, 85%, 90%, and 95% capture from the 100% impervious tributary catchment are shown in series, with pollutant load reduction in grams per acre displayed as a function of influent concentration. Constant influent lines corresponding with RWSM land use-based influent concentrations are shown.

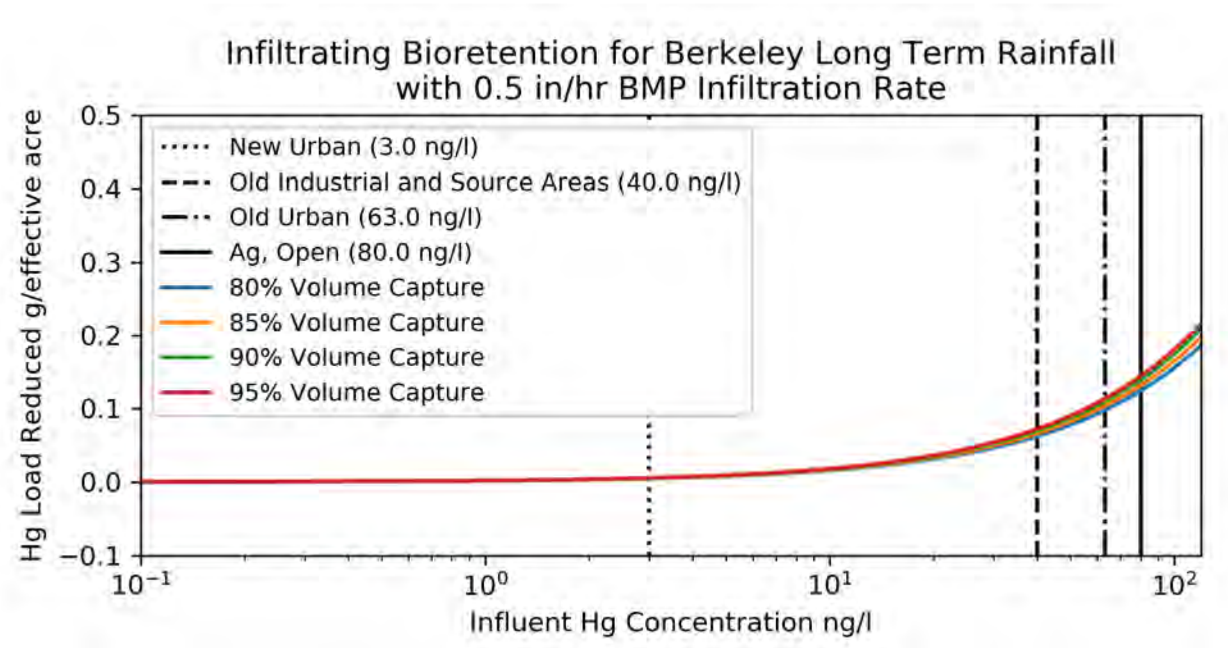


**Figure 7: Modeled Mercury Load Removal Performance for Infiltrating Bioretention Basin**

[12] A nomograph is a graphical relationship between two variables that can be used to quickly estimate one value from another.

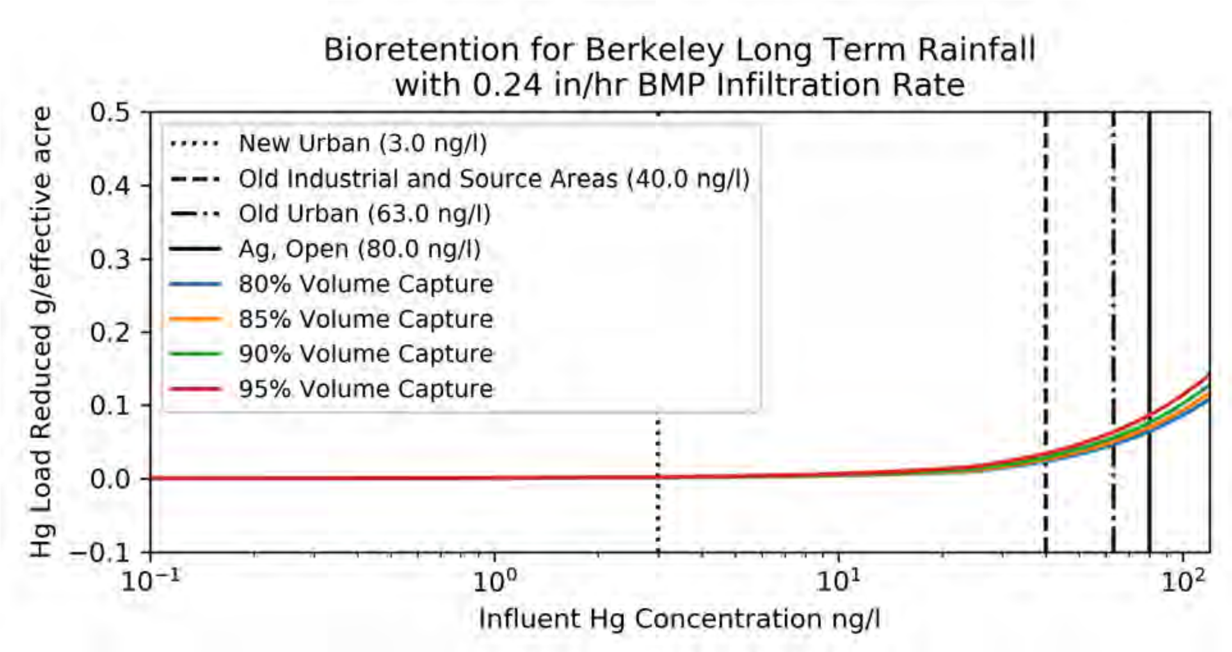


**Figure 8: Modeled Mercury Load Removal Performance for Bioretention Basin with Elevated Underdrain**

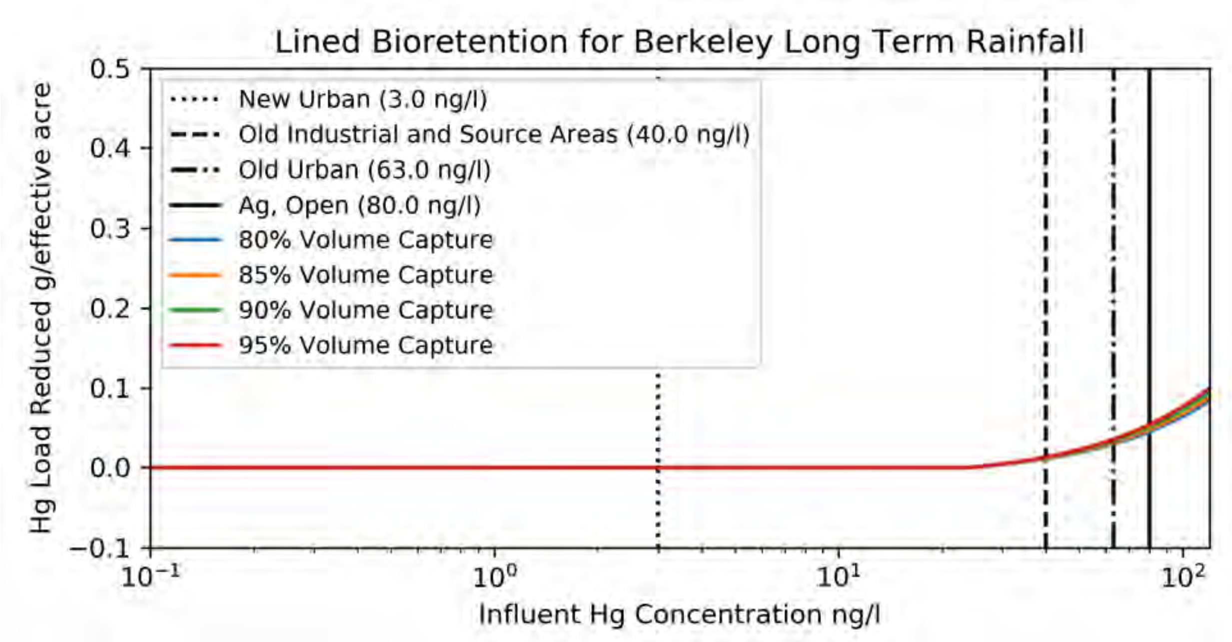


**Figure 9: Modeled Mercury Load Removal Performance for Lined Bioretention Basin with Underdrain**

The intersection points between the load reduction series and the constant influent lines represent the load reduced in grams per acre for each specific RWSM land use category. These intersection points are summarized in Table 12.

**Table 12: Mercury Load Reduction for RWSM Land Use Categories for Berkeley Gauge for Different BMP Percent Capture Values**

| Facility Configuration | Land Use Category | Mercury Load Reduced (g/effective acre) 80% Capture[1] | 85% Capture[1] | 90% Capture[1] | 95% Capture[1] |
|---|---|---|---|---|---|
| Infiltrating Bioretention (0.5 underlying infiltration rate) | New Urban | 0.00467 | 0.00495 | 0.00524 | 0.00541 |
| | Old Industrial and Source Areas | 0.0623 | 0.066 | 0.0698 | 0.0722 |
| | Old Urban | 0.0981 | 0.104 | 0.110 | 0.114 |
| | Ag, Open | 0.125 | 0.132 | 0.140 | 0.144 |
| Bioretention with Raised Underdrain (0.24 underlying infiltration rate) | New Urban | 0.00113 | 0.0013 | 0.00153 | 0.00192 |
| | Old Industrial and Source Areas | 0.0234 | 0.0258 | 0.029 | 0.0341 |
| | Old Urban | 0.0462 | 0.0503 | 0.0556 | 0.0634 |
| | Ag, Open | 0.0643 | 0.0696 | 0.0765 | 0.0862 |
| Lined Bioretention | New Urban | 0 | 0 | 0 | 0 |
| | Old Industrial and Source Areas | 0.0108 | 0.0115 | 0.0123 | 0.0130 |
| | Old Urban | 0.0296 | 0.0314 | 0.0335 | 0.0353 |
| | Ag, Open | 0.0449 | 0.0476 | 0.0507 | 0.0536 |

[1] Average Annual Facility Volumetric Runoff Capture

## 6. REFERENCES

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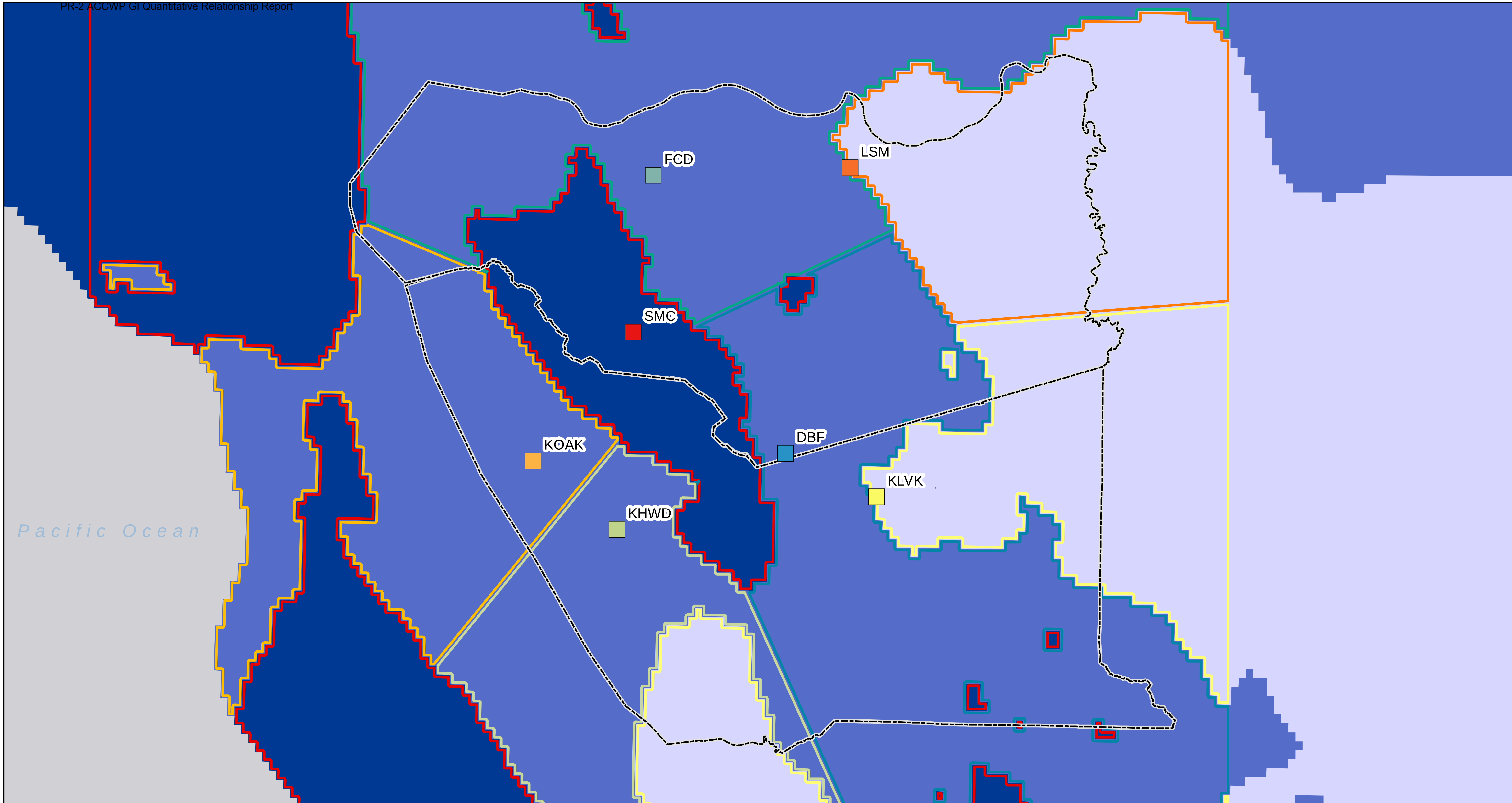
# APPENDIX A

# Modeling Inputs and Data Exhibits




**Rain Gauge ID**

- Rain Gauge ID
- County Boundary

**Mean Annual Precipitation (in)**

- < 16
- 16 - 25
- > 25

**Rain Gauge Zones**

- DBF
- FCD
- KHWD
- KLVK
- KOAK
- LSM
- SMC

N

0 6 12 Miles

**Precipitation Zones for Baseline Runoff Period (WY 2000-2009)**

Alameda County and Contra Costa County
California

Geosyntec consultants

| Oakland | July 2018 | **Exhibit** **1** |
| --- | --- | --- |



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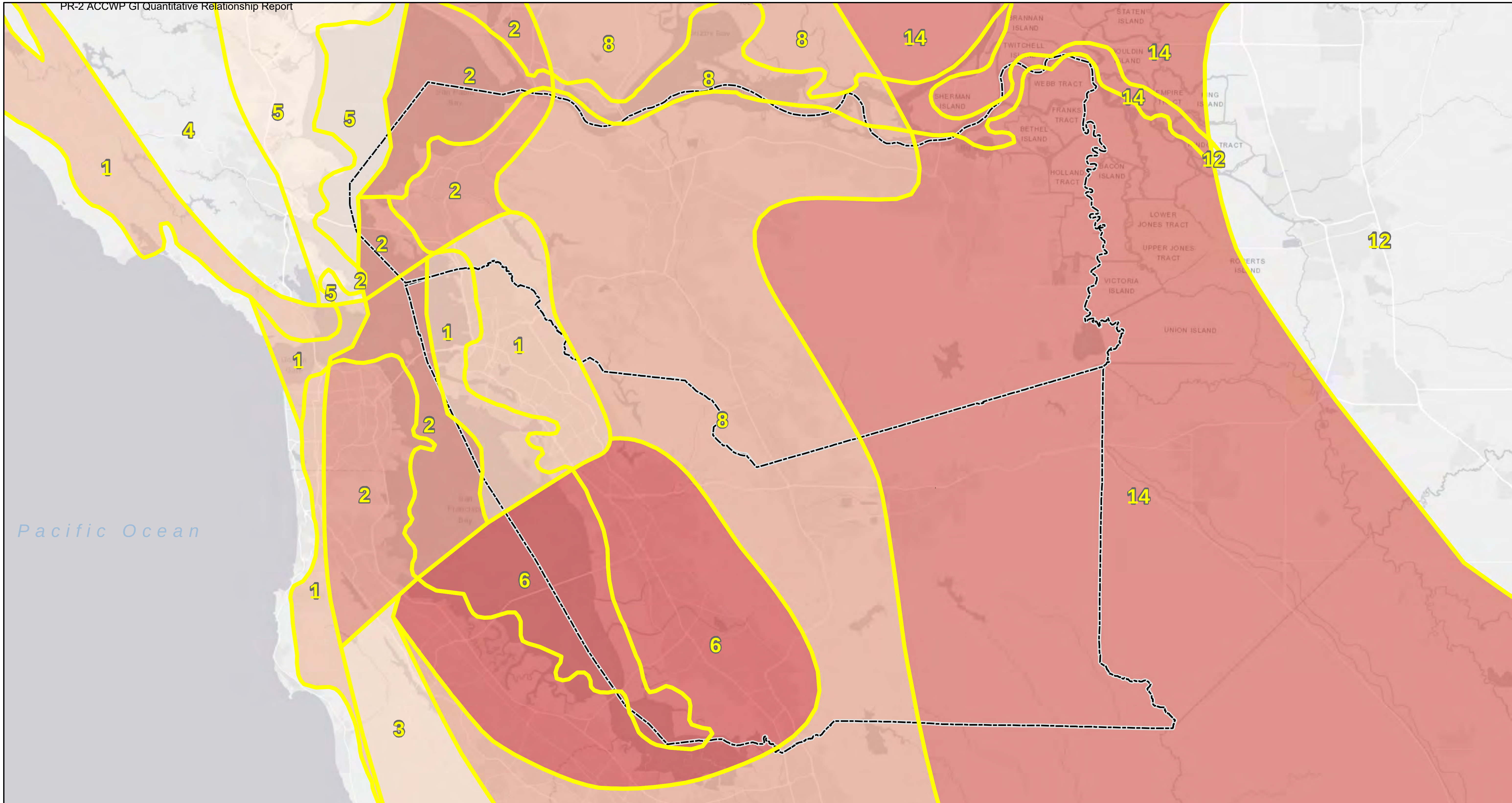



County Boundary
CIMIS ET Zone Boundary

**CIMIS ET Zone**

- 1
- 2
- 3
- 5
- 6
- 8
- 14

N

0 6 12 Miles

**CIMIS Evapotranspiration Zones**

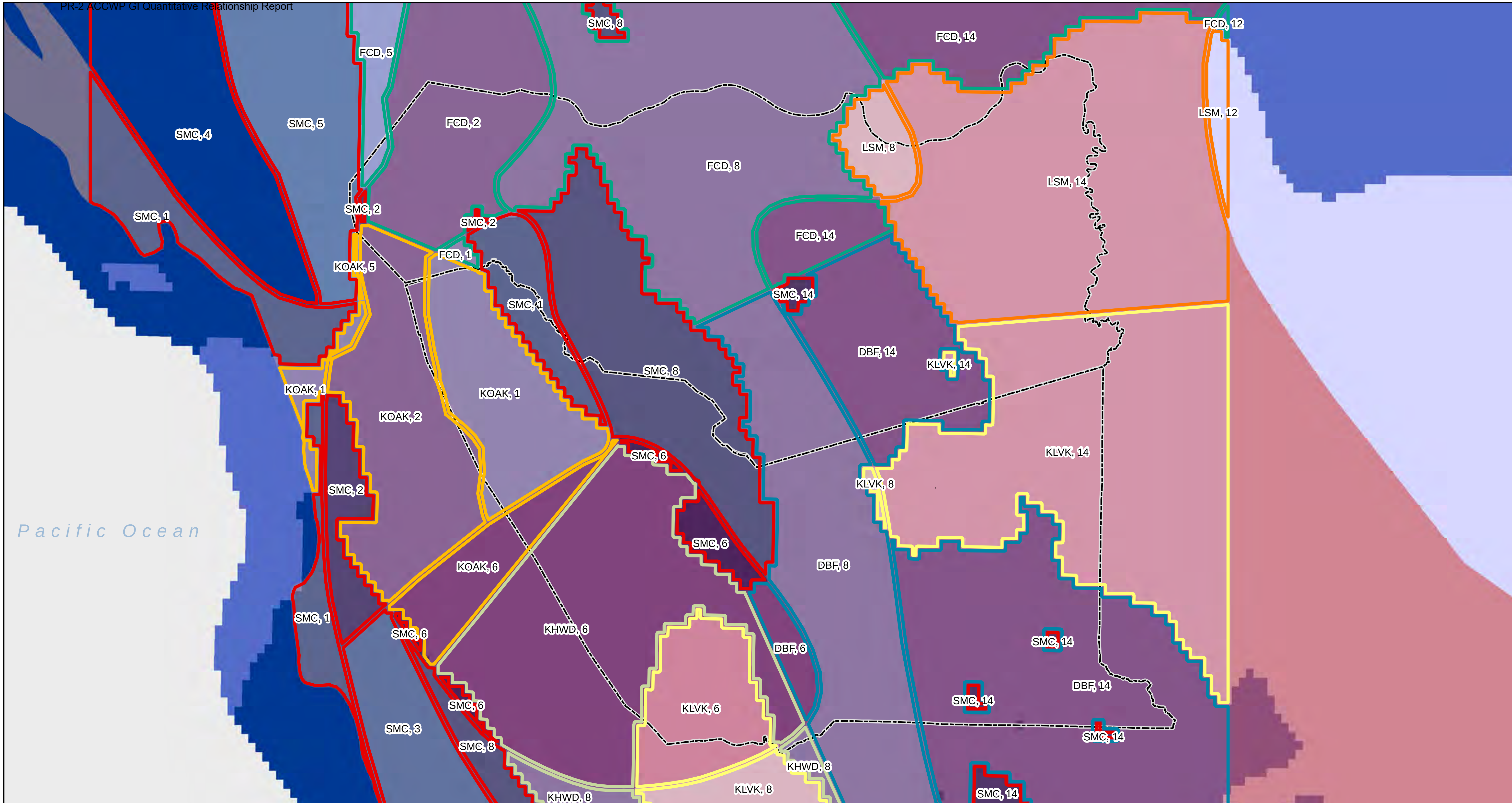
Alameda County and Contra Costa County
California

Geosyntec consultants

Oakland | July 2018

**Exhibit**

**2**




County Boundary

**Mean Annual Precipitation (in)**
- < 16
- 16 - 25
- > 25

**CIMIS ET Zone**
- 1
- 2
- 3
- 5
- 6
- 8
- 14

Climate Zones are created by overlapping precipitation zones and ET zones.The unique climate zones that occur in Contra Costa and Alameda County are labeled as "Gauge ID, ET Zone".

N

0 6 12 Miles

**Climate Zones for Baseline Runoff Period (WY 2000-2009)**

Alameda County and Contra Costa County
California

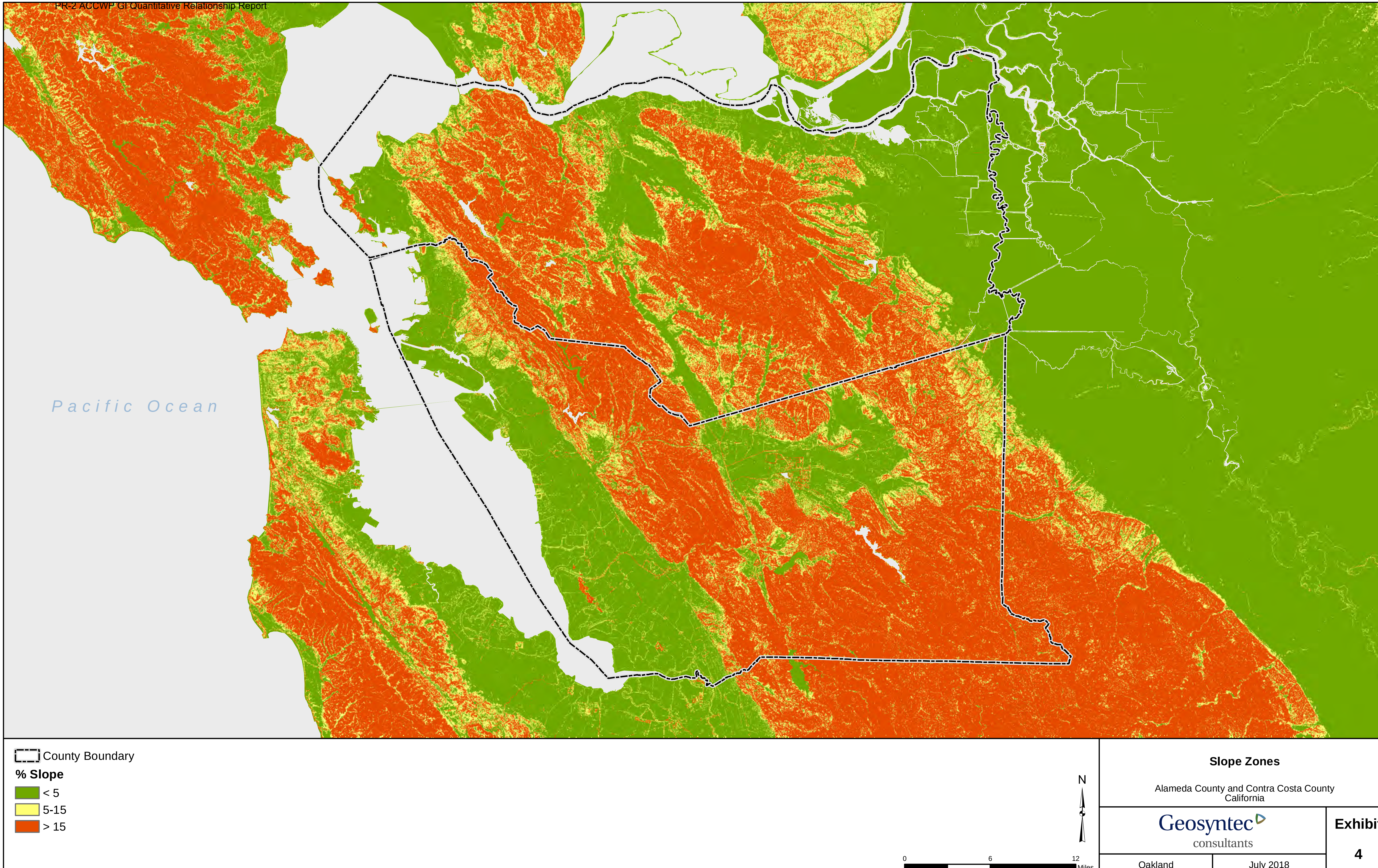
Geosyntec consultants

Oakland | July 2018

**Exhibit 3**



P:\GIS\Bay_Area_RAA\Project\GI_Load_Reduced_Report_Exhibits\Figure_4_Climate_Zones.mxd 7/5/2018 6:00:27 PM




**Slope Zones**

Alameda County and Contra Costa County
California

Geosyntec consultants

Exhibit 4

| Oakland | July 2018 |
|---|---|



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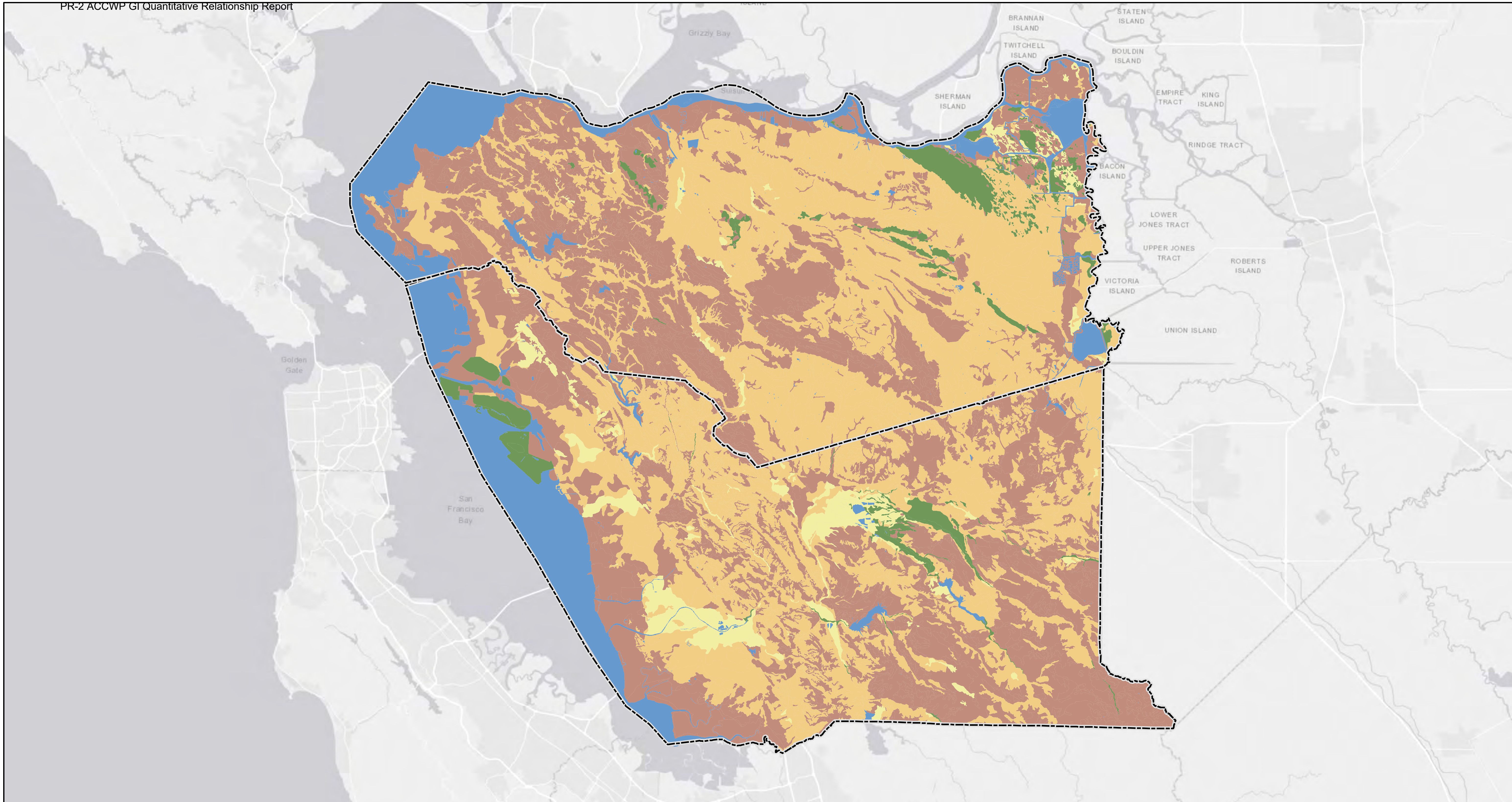



County Boundary

**HSG**

- A
- B
- C
- D
- W

Note: Area within the county with no HSG assignment was assigned the HSG of the most prominant adjacent soil group.

N

0 6 12 Miles

**Hydrologic Soil Group**

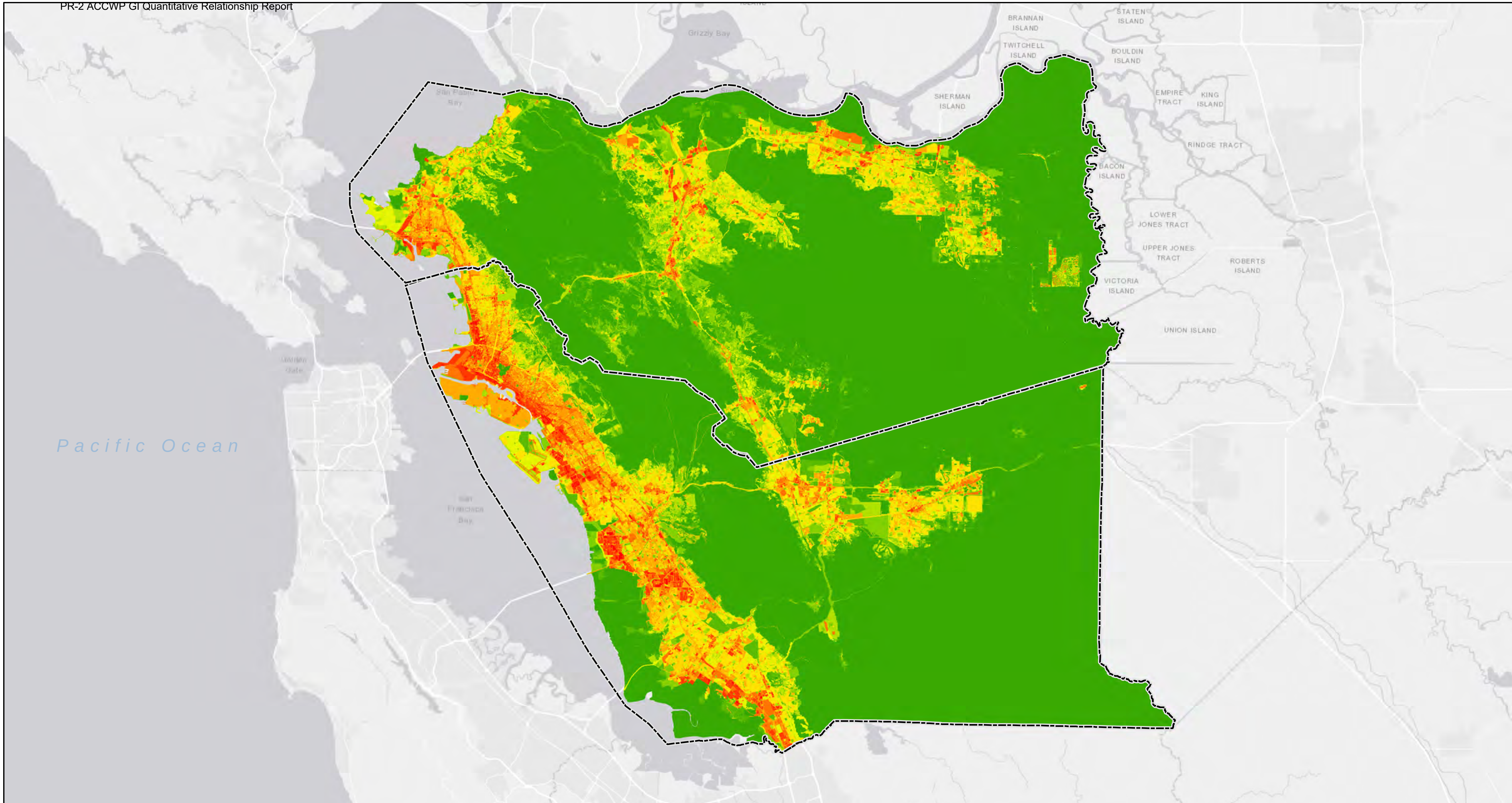
Alameda County and Contra Costa County
California

Geosyntec consultants

Oakland | July 2018

**Exhibit**

**5**




County Boundary

**ABAG 2005 Imperviousness**

- 0 - 10
- 11 - 20
- 21 - 30
- 31 - 40
- 41 - 50
- 51 - 60
- 61 - 70
- 71 - 80
- 81 - 90
- 91 - 100

Note:
Imperviousness is assigned to ABAG 2005 landuse based on the NLCD 2006 Impervious Cover layer. These values may be adjusted during calibration for certain categories of ABAG landuse.

For purposes of calculating runoff from areas with compacted soil, developed areas and agricultural uses were assumed to be compacted to 0.75 times the underlying saturated soil conductivity (ksat). These areas generally have percent imperviousness > 20%.

N

0 6 12 Miles

**Regional Imperviousness**

Alameda County and Contra Costa County
California

Geosyntec consultants

Oakland | July 2018

**Exhibit 6**



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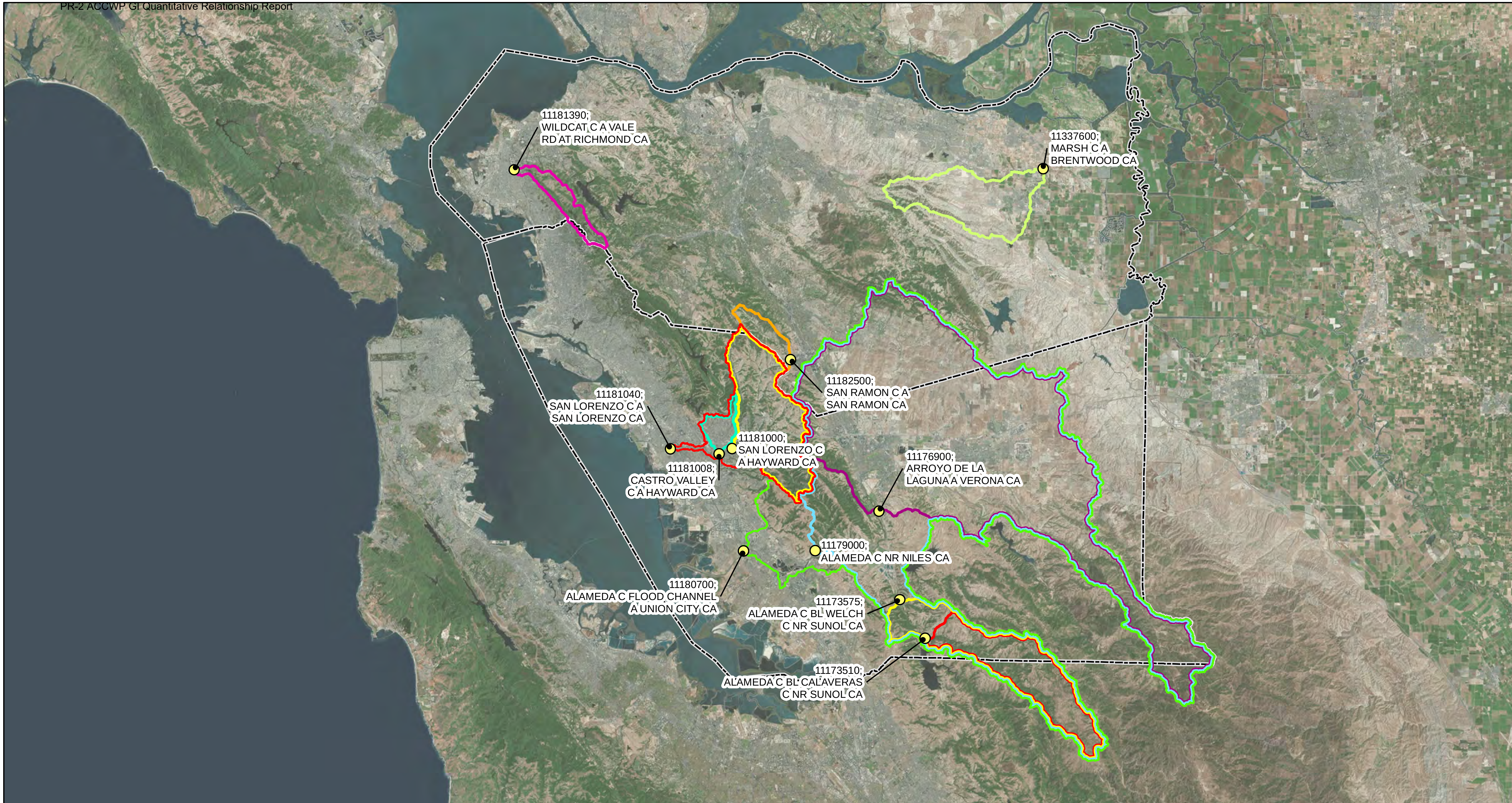



| | Group 1 | Group 2 | Group 3 | Group 4 | Group 4 |
|---|---|---|---|---|---|
| County Boundary | 11181040 | 11180700 | 11182500 | 11337600 | 11181390 |
| Gauge Location | 11181000 | 11179000 | | | |
| | 11181008 | 11173575 | | | |
| | | 11176900 | | | |
| | | 11173510 | | | |

N

0 6 12 Miles

**Candidate Calibration Watersheds**

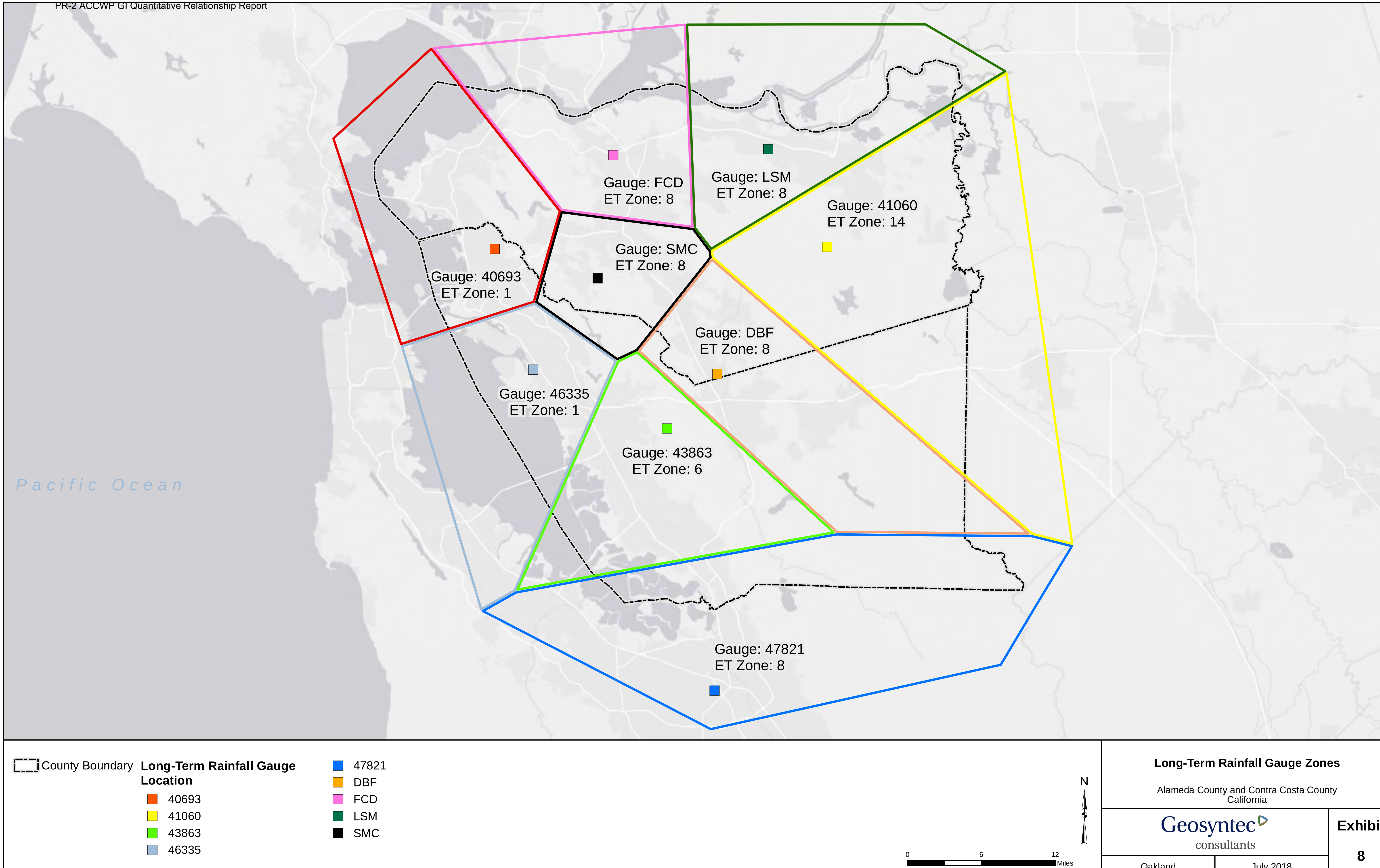
Alameda County and Contra Costa County
California

Geosyntec
consultants

Oakland | July 2018

**Exhibit**

**7**




**Long-Term Rainfall Gauge Zones**

Alameda County and Contra Costa County
California

Geosyntec consultants

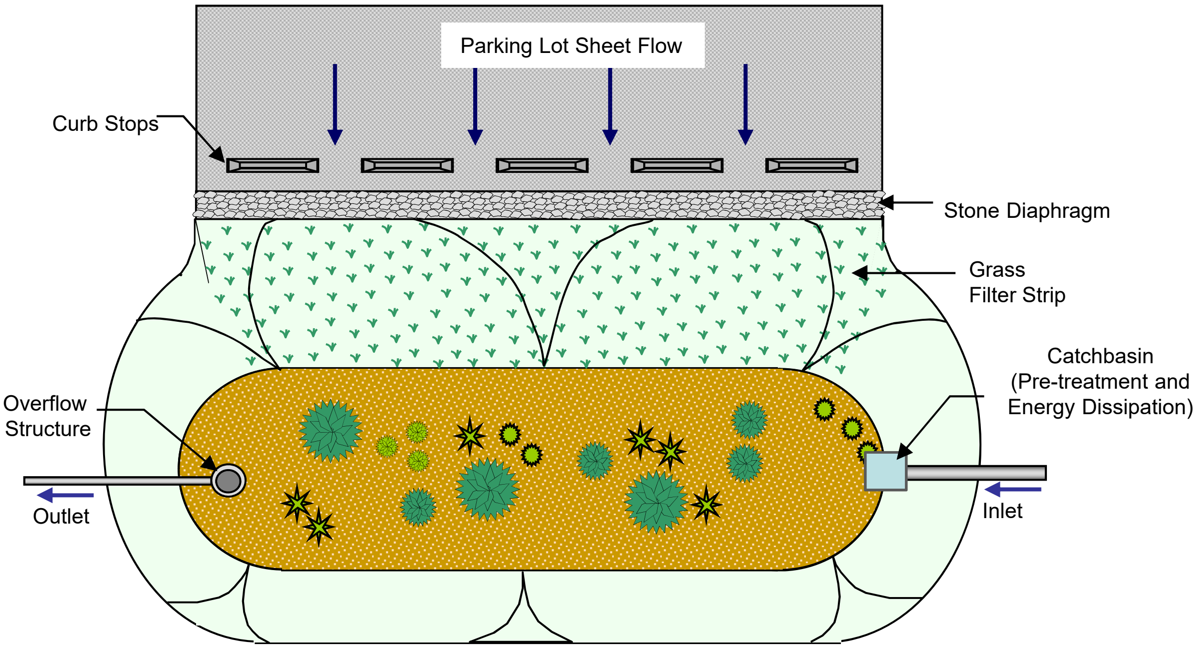
Oakland | July 2018

Exhibit 8

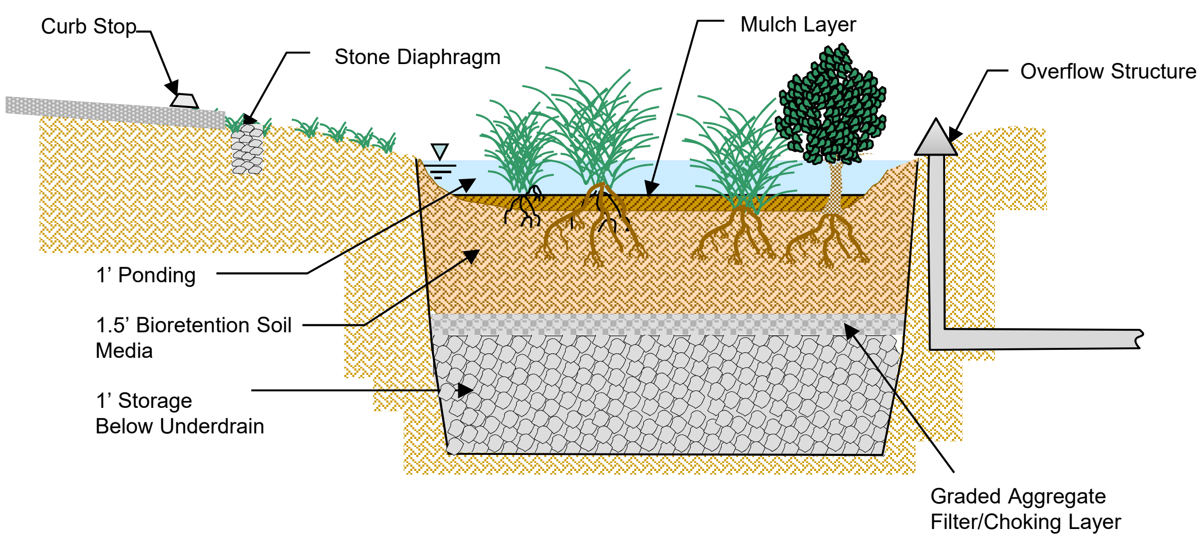


P:\GIS\Bay_Area_RAA\Project\GI_Load_Reduced_Report_Exhibits\Figure_8_GI_Long_Term_Rainfall_Precipitation_Zones.mxd 7/5/2018 6:01:01 PM

# Plan View



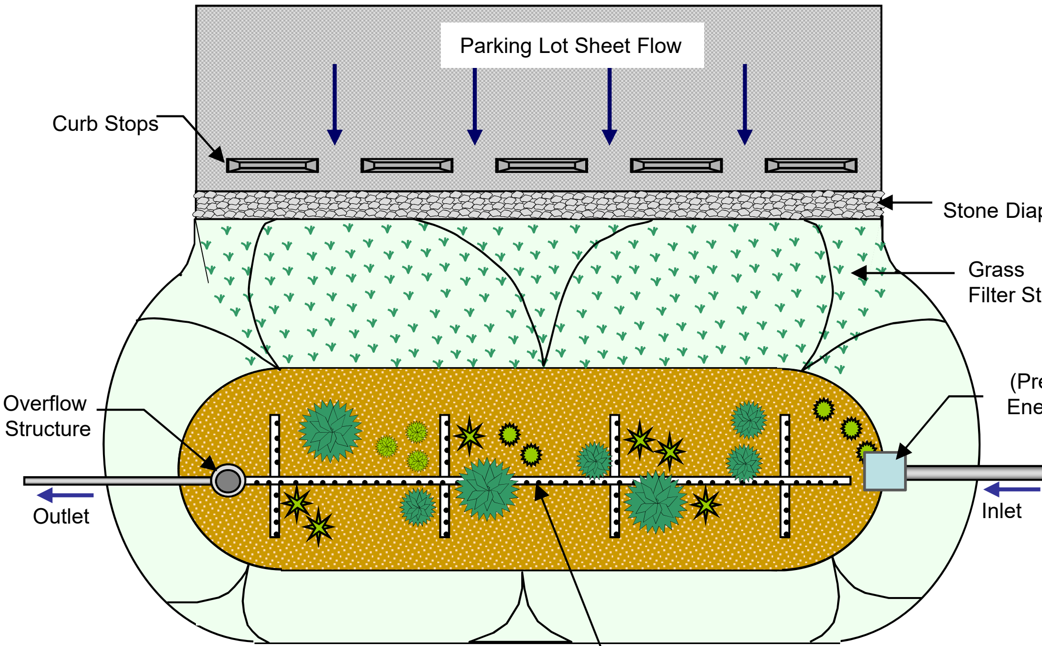

# Profile




**Note: Plan and Profile views are not to scale**

| **Conceptual Illustration of an Infiltration Facility** | | |
|---|---|---|
| Geosyntec consultants | | Exhibit 9 |
| Oakland | July 2018 | |

# Plan View

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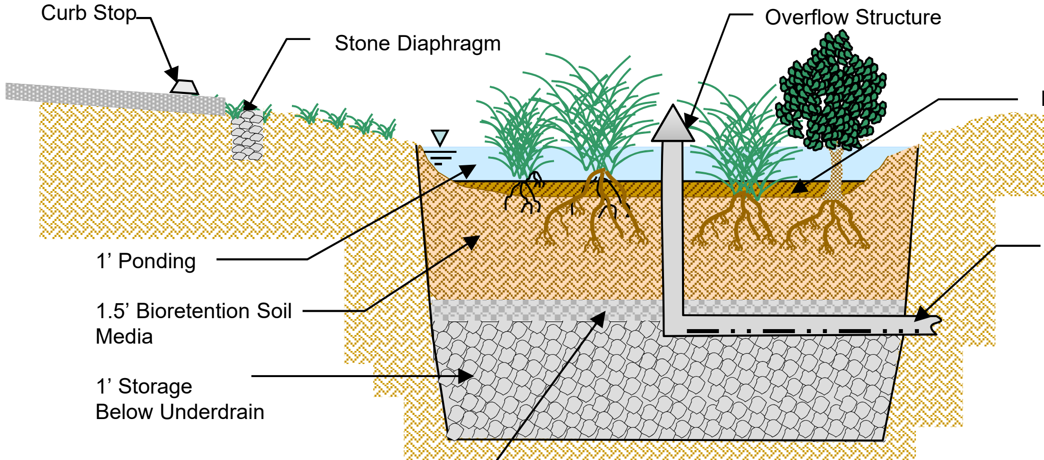
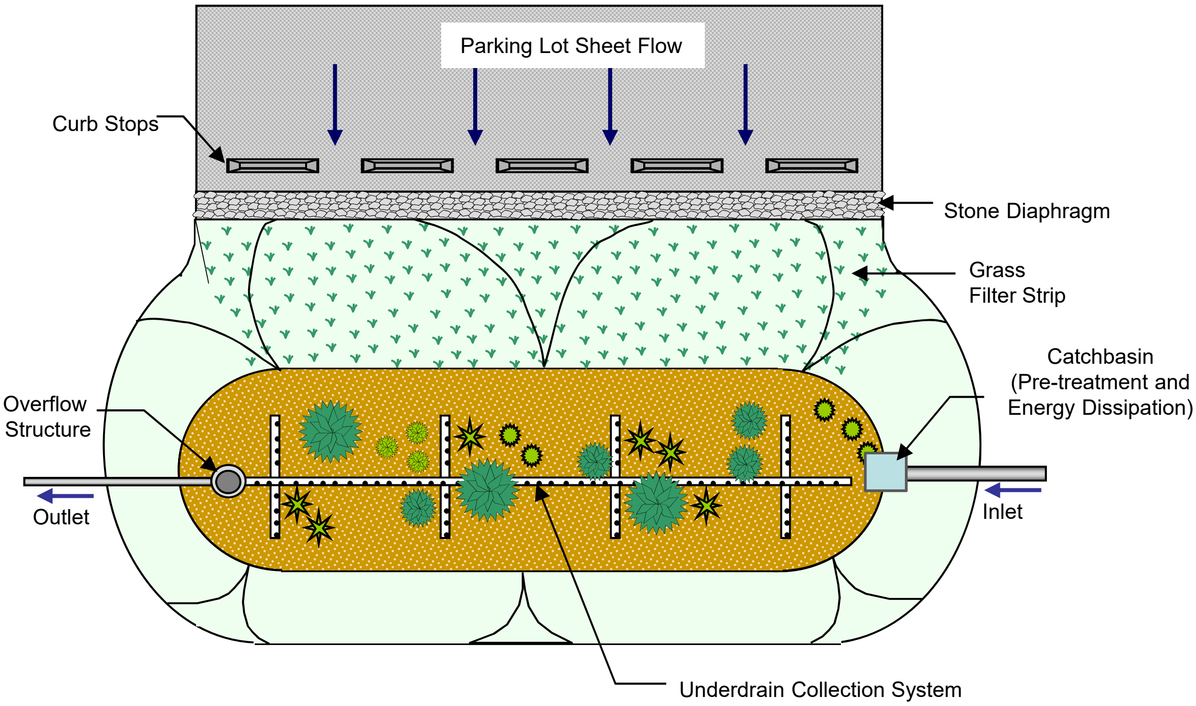


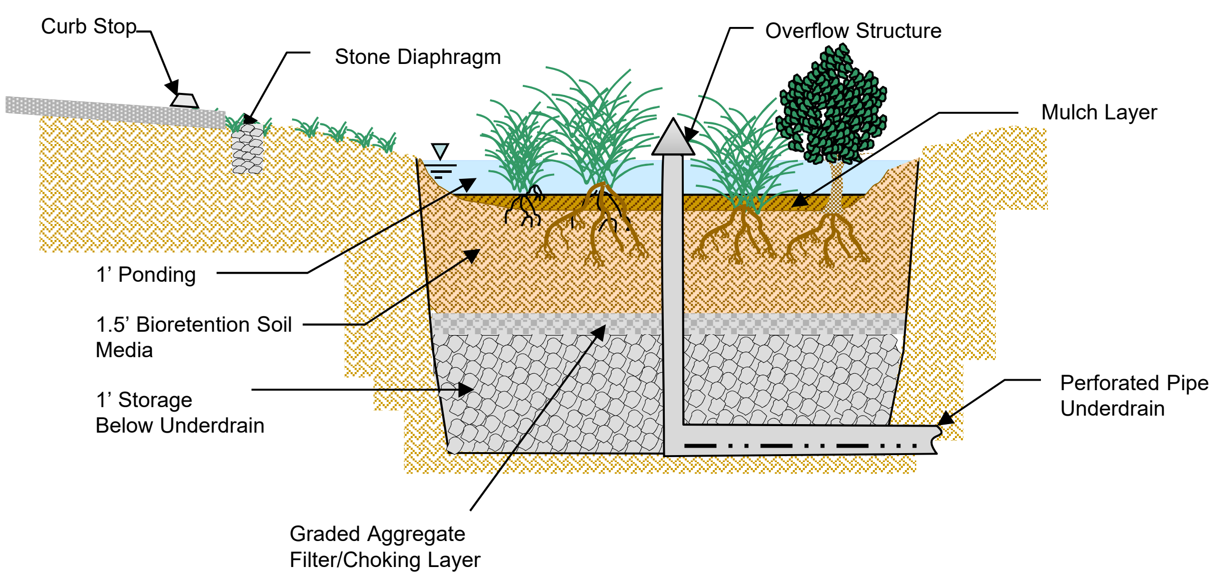

**Note: Plan and Profile views are not to scale**

| **Conceptual Illustration of a Bioretention/Bioinfiltration Facility** | | |
|---|---|---|
| Geosyntec consultants | | Exhibit 10 |
| Oakland | July 2018 | |

# Plan View




# Profile




**Note: Plan and Profile views are not to scale**

**Conceptual Illustration of a Biofiltration Facility**

Geosyntec consultants

Oakland | July 2018

Exhibit 11

# PR-3 Contra Costa Clean Water Program GI Quantitative Relationship Report

# *QUANTITATIVE RELATIONSHIP BETWEEN GREEN INFRASTRUCTURE IMPLEMENTATION AND PCBs/MERCURY LOAD REDUCTIONS*

***Submitted in Compliance with Provisions C.11.b.iii.(3), C.11.c.iii.(3), C.12.b.iii.(3), and C.12.c.iii.(1)***

***Municipal Regional Stormwater Permit***
***NPDES Permit No. CAS612008***
***Order No. R2-2015-0049***

***August 22, 2018***

***The Contra Costa Clean Water Program – A Municipal Stormwater Program consisting of Contra Costa County, its 19 Incorporated Cities/Towns, and the Contra Costa County Flood Control & Water Conservation District***

This report is submitted by the agencies of the

**Program Participants:**

- Cities of: Antioch, Brentwood, Clayton, Concord, Danville (Town), El Cerrito, Hercules, Lafayette, Martinez, Moraga (Town), Oakley, Orinda, Pinole, Pittsburg, Pleasant Hill, Richmond, San Pablo, San Ramon and Walnut Creek
- Contra Costa County
- Contra Costa County Flood Control & Water Conservation District

**Contra Costa Clean Water Program**
**255 Glacier Drive**
**Martinez, CA 94553-482**
**Tel (925) 313-2360**
**Fax (925) 313-2301**
**Website: www.cccleanwater.org**

**Report Prepared By:**

**Geosyntec Consultants**

on behalf of the
Contra Costa Clean Water Program

## LIST OF ACRONYMS

| | |
|---|---|
| ASOS | Automated Surface Observation System |
| BASMAA | Bay Area Stormwater Management Agencies Association |
| BMP | Best Management Practices |
| CCCWP | Contra Costa Clean Water Program |
| CIMIS | California Irrigation Management Information System |
| GI | Green Infrastructure |
| GIS | Geographic Information System |
| HRU | Hydrologic Response Unit |
| KTRL | Kendall-Theil Robust Line |
| MAD | Median Absolute Deviation |
| MRP | Municipal Regional Permit |
| MS4 | Municipal Separate Storm Sewer System |
| ng/kg | nanogram per kilogram |
| NPDES | National Pollutant Discharge Elimination System |
| PCBs | Polychlorinated Biphenyls |
| RAA | Reasonable Assurance Analysis |
| RMSE | Root Mean Square Error |
| ROW | Right-of-Way |
| RWSM | Regional Watershed Spreadsheet Model |
| SFBRWQCB | San Francisco Bay Regional Water Quality Control Board |
| SFEI | San Francisco Estuary Institute |
| SWMM | Stormwater Management Model |
| TMDL | Total Maximum Daily Load |
| USEPA | United States Environmental Protection Agency |
| USGS | United States Geologic Survey |
| WY | Water Year |

# Table of Contents

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# 1. INTRODUCTION

## 1.1 Purpose

This *Quantitative Relationship between Green Infrastructure Implementation and PCBs/Mercury Load Reductions* report was prepared by the Contra Costa Clean Water Program (CCCWP) per the Municipal Regional Permit (MRP) for urban stormwater issued by the San Francisco Bay Regional Water Quality Control Board (SFBRWQCB; Order No. R2-2015-0049). This report fulfills the requirements of MRP Provisions C.11.b.iii.(3), C.11.c.iii.(3), C.12.b.iii.(3), and C.12.c.iii.(1) for submitting the quantitative relationship between green infrastructure (GI) implementation and PCBs load reductions that will be used for the Reasonable Assurance Analysis (RAA) required by MRP Provisions C.11.c.ii.(2), C.11.d.ii, C.12.c.ii.(2), and C.12.d.ii.

This report was prepared in cooperation with the Alameda Countywide Clean Water Program. The RAA modeling described herein will be conducted for both countywide programs and will use data inputs from both Contra Costa County and Alameda County.

## 1.2 Background

### 1.1.1 <u>PCBs and Mercury Total Maximum Daily Loads</u>

Fish tissue monitoring in San Francisco Bay has revealed bioaccumulation of PCBs, mercury, and other pollutants. The levels found are thought to pose a health risk to people consuming fish caught in the Bay. As a result of these findings, California has issued an interim advisory on the consumption of fish from the Bay. The advisory led to the Bay being designated as an impaired water body on the Clean Water Act "Section 303(d) list" due to PCBs and mercury. In response, the SFBRWQCB has developed Total Maximum Daily Load (TMDL) water quality restoration programs targeting PCBs and mercury in the Bay. The general goals of the TMDLs are to identify sources of PCBs and mercury to the Bay and implement actions to control the sources and restore water quality.

Municipal separate storm sewer systems (MS4s) are one of the PCBs and mercury source/pathways identified in the TMDL plans. Local public agencies (i.e., Permittees) subject to requirements via National Pollutant Discharge Elimination System (NPDES) permits are required to implement control measures in an attempt to reduce PCBs and mercury from entering stormwater runoff and the Bay. These control measures, also referred to as Best Management Practices (BMPs), are the tools that Permittees can use to assist in restoring water quality in the Bay.

### 1.1.2 Municipal Regional Permit

NPDES permit requirements associated with Phase I municipal stormwater programs and Permittees in the Bay area are included in the MRP, which was issued to 76 cities, counties and flood control districts in 2009 and revised in 2015[1]. The MRP includes provisions to reduce loads of mercury and PCBs consistent with the TMDL implementation timeframe (Provisions C.11 and C.12, respectively) through implementation of GI projects (Provisions C.3.j, C.11.c, and C.12.c) and source controls (Provisions C.11.d and C.12.d).

The Permittees are reporting load reductions achieved before and during the current MRP term (2014 – 2020) using the approved Interim Accounting Methodology (BASMAA, 2017). MRP Provisions C.11.b.iii.(3) and C.12.b.iii.(3) requires the Permittees to report in the 2018 and subsequent Annual Reports any refinements to the Interim Accounting Methodology to be used in subsequent Permit terms. As part of this reporting requirement, Provision C.11.c.iii.(3) and C.12.c.iii.(1) requires the Permittees to report on the quantitative relationship between GI implementation and PCBs and mercury load reductions, including all data used and a full description of models and model inputs relied on to establish this relationship.

*Green Infrastructure Planning and RAA*

MRP Provision C.3.j requires the Permittees to develop a Green Infrastructure Plan for inclusion in the 2019 Annual Report. The Green Infrastructure Plan must be developed using a mechanism

[1] The cities of Antioch, Brentwood, and Oakley, and the eastern portions of unincorporated Contra Costa County and the Contra Costa County Flood Control & Water Conservation District (the East County Permittees) are located within the jurisdiction of the Central Valley Water Board and are covered under a separate Joint Municipal NPDES Permit titled "East Contra Costa County Municipal NPDES Permit" (East County Permit), which was last reissued in September 2010 (NPDES Permit No. CAS083313, Order No. R5-2010-0102). The East County Permit expired on September 1, 2015; however, it remains in force and effect until a new permit is reissued. In October 2016, the East County Permittees requested that the Central Valley Water Board designate the San Francisco Bay Water Board as the permitting authority for MS4 discharges in eastern Contra Costa County. In response to this request, the Central Valley Water Board provided a letter, dated January 6, 2017, that documents written agreement by both Water Boards to designate the San Francisco Bay Water Board to regulate MS4 discharges from the East County Permittees under MRP 2.0 and any successor orders. This East County Permittees are implementing PCBs and mercury control measures and this document reports those implementation efforts and the associated load reductions.

to prioritize and map areas for potential and planned GI projects, both public and private, on a drainage-area-specific basis, for implementation by 2020, 2030, and 2040.

MRP Provisions C.11.c and C.12.c require the Permittees to prepare an RAA for inclusion in the 2020 Annual Report that quantitatively demonstrates that specified mercury and PCBs load reductions will be achieved by 2040 through implementation of GI.

This RAA should do the following:

1. Quantify the relationship between the areal extent of GI implementation (e.g., acres treated) and mercury and PCBs load reductions. This quantification should take into consideration the scale of contamination of the treated area as well as the pollutant removal effectiveness of GI strategies likely to be implemented.
2. Estimate the amount and characteristics of land area that will be treated by GI by 2020, 2030, and 2040.
3. Estimate the amount of mercury and PCBs load reductions that will result from GI implementation by 2020, 2030, and 2040.
4. Ensure that the calculation methods, models, model inputs, and modeling assumptions used have been validated through a peer review process.

Additionally, MRP Provisions C.11.d. and C.12.d. require the Permittees to prepare plans and implementation schedules for mercury and PCBs control measures and an RAA demonstrating that sufficient control measures will be implemented to attain the mercury TMDL wasteload allocations by 2028 and the PCBs TMDL wasteload allocations by 2030. The implementation plans, which will also be included in the 2020 Annual Report, along with the GI-based RAA outlined above, must:

1. Identify all technically and economically feasible mercury or PCBs control measures (including GI projects, but also other control measures such as source property identification and abatement, managing PCBs in building materials during demolition, enhanced operations and maintenance, and other source controls) to be implemented;
2. Include a schedule according to which technically and economically feasible control measures will be fully implemented; and
3. Provide an evaluation and quantification of the mercury and PCBs load reduction of such measures as well as an evaluation of costs, control measure efficiency, and significant environmental impacts resulting from their implementation.

This report presents the quantitative relationship between GI implementation and PCBs and mercury load reductions, including the data used and a full description of models and model inputs relied on to establish this relationship. This relationship will be used to predict loads reduced through GI implementation for the RAAs described above and to report loads reduced through GI implementation in the subsequent Permit term.

## 2. DESCRIPTION OF RAA MODEL

This section provides an overview of the RAA modeling framework and describes the output of each component.

### 2.1 RAA Model Overview

The approach used to estimate the load reductions resulting from implementation of GI includes the model components listed below, which are described in further detail in the following sections:

- Baseline Pollutant Loading Model – the baseline pollutant loading model is a continuous simulation[2] hydrology model combined with pollutant loading inputs to obtain the average annual loading of mercury and PCBs across the county during the TMDL baseline period (i.e., 2003 – 2005).
    - Hydrology – this model component produces average annual runoff across each county for the period of record using a hydrologic response unit (HRU) approach. The HRU approach involves modeling various combinations of land surface features (i.e., imperviousness, underlying soil characteristics, slope, etc.) present within each county for a unit area drainage catchment. See Section 2.2.1.
    - Water Quality – the hydrology output is combined with average annual concentrations estimated by the Regional Monitoring Program's Regional Watershed Spreadsheet Model (RWSM; Wu et al, 2017) developed by the San Francisco Estuary Institute (SFEI) to produce average annual PCBs and mercury loading for the period of record. See Section 2.2.2.

[2] Continuous simulation models calculate outputs (e.g., runoff) "continuously", i.e., for many time steps over a long-term period of record (e.g., every 10 minutes for 10 years). Long-term "continuous" input data (e.g., hourly rainfall) is required. This is contrasted with design-event simulations which model a single rainfall event, e.g., a 24-hour storm with a 10-year recurrence frequency.

- GI Performance Models – the GI performance models are developed to represent load reductions resulting from implementation of GI. See Section 2.3.
- Future Condition (RAA Scenario) Models – the RAA scenario models are conducted to represent future land use changes and control measure implementation that could result in pollutant load reduction. Both GI and source controls are considered, depending on the time frame of interest. See Section 2.4 for a description of load reduction calculations.

## 2.2 Baseline Loading Model

### 2.2.1 Hydrologic Model

As introduced above, the proposed approach for modeling hydrology is to use a hydrologic response unit (HRU) approach. An HRU is a unique combination of land surface features (imperviousness, underlying soil characteristics, slope, etc.) which is expected to give a consistent runoff response to rainfall, no matter where that unique combination is found. The HRU approach involves modeling all possible combinations of land surface features present within each county for a unit area drainage catchment and then storing these results in a database. These HRU results can been be scaled geospatially across the entire county without developing a detailed hydrologic model. This method is consistent with the *Bay Area RAA Guidance Document* (BASMAA, 2017b).

The generic HRUs are modeled using USEPA's Stormwater Management Model (SWMM) to obtain an average annual runoff volume per acre for the identified baseline period of record (water year [WY] 2000 – 2009) for each HRU. Certain HRU inputs (imperviousness, soil parameters) are adjusted as needed to calibrate the HRUs on an average annual basis to identified flow gauges in the counties.

The average annual runoff volume per acre associated with a specific HRU can then be multiplied by the area represented by that HRU across each county (or a selected smaller planning area, such as a watershed or jurisdictional boundary). The resulting volumes associated with each represented HRU within the specified geospatial area can then be summed for the identified area to obtain the estimated total average annual runoff volume.

### 2.2.2 Water Quality Model

Identified HRUs across each county are combined with the RWSM land use classifications layer to determine pollutant loading rates. The RWSM provides average annual concentrations of PCBs and mercury that wash off from various land use categories. On an average annual basis, this approach approximates the total load.

Average annual runoff volume associated with the geospatial HRUs is multiplied by the PCBs and mercury average annual concentration (based on the RWSM land use categories for the identified area) to obtain average annual pollutant load using the following equation:

$$Load_{Baseline} = \sum\left(\sum Unit\ Runoff_{HRU} \times Area_{LU,HRU}\right) \times Concentration_{LU} \times 0.00123 \qquad \text{Eqn. 1}$$

Where:

| | | |
|---|---|---|
| $Load_{Baseline}$ | = | The total average annual baseline pollutant load for the identified area for calculation [grams/year] |
| $Unit\ Runoff_{HRU}$ | = | The average annual runoff per acre for a given HRU within the identified area for calculation [ac-ft/acre/yr] |
| $Area_{LU,HRU}$ | = | The total area of the HRU within the RWSM land use category within the identified area for calculation [acres] |
| $Concentration_{LU}$ | = | The average annual pollutant concentration associated with the RWSM land use category [ng/L] |
| 0.00123 | = | Conversion factor [(L/ac-ft)*(g/ng)] |

## 2.3 Green Infrastructure Performance Model

Volume reduction (via retention in the green infrastructure facility) and pollutant load reduction (via filtration through media and discharge through an underdrain) are modeled utilizing a combination of hydraulic modeling in SWMM and currently available empirical GI performance data.

### 2.3.1 Hydraulic GI Models

GI control measure hydraulic performance is modeled in SWMM with a 100% impervious tributary area for three GI facility types: (1) bioretention[3] with a raised underdrain, (2) bioretention with no underdrain, and (3) lined bioretention. The model is run with varying footprint sizes and varying underlying infiltration rates (i.e., the rate at which treated runoff infiltrates into native soils underlying the BMP facility). Average annual volume retained, volume treated, and volume bypassed by the GI measure are recorded for each GI model run.

Volume-based performance[4] corresponding to the generic 100% impervious tributary area can be applied to the effective area in GI drainage areas made up of identified HRUs. The effective area is also known as the "runoff generating area" and is calculated as the tributary area multiplied by the long-term or average annual runoff coefficient.

### 2.3.2 Green Infrastructure Pollutant Reduction Calculations

To calculate pollutant load reduction associated with GI implementation, the hydraulic model results are combined with water quality performance data. The annual estimate of pollutant load reduction from the modeled drainage area is equivalent to the difference between the influent load and the sum of the pollutant load that bypasses the GI measure and the effluent load (Eqn. 2). Equations corresponding to the pollutant reduction calculation are provided below and the water balance is illustrated in Figure 1. In summary, influent load is calculated as the pollutant load produced by the 100% impervious tributary area for each RWSM land use category using Eqn. 3. The pollutant load that bypasses the facility is calculated as the proportion of runoff that bypasses the facility per the hydraulic GI model output, multiplied by the influent concentration (Eqn. 4). The effluent load is calculated as the proportion of runoff that is captured by the facility per the hydraulic GI model output, combined with an effluent concentration (Eqn. 5 and Eqn. 6).

[3] The bioretention is assumed to include: 6-inch or 12-inch ponding depth, 1.5 ft of filter media with a 5 in/hr flow through rate, and 1 ft of gravel beneath the media.

[4] Volume-based performance refers to how much runoff volume the GI facility captures and retains or treats and discharges through the underdrain, typically represented as a percentage of the average annual runoff volume.

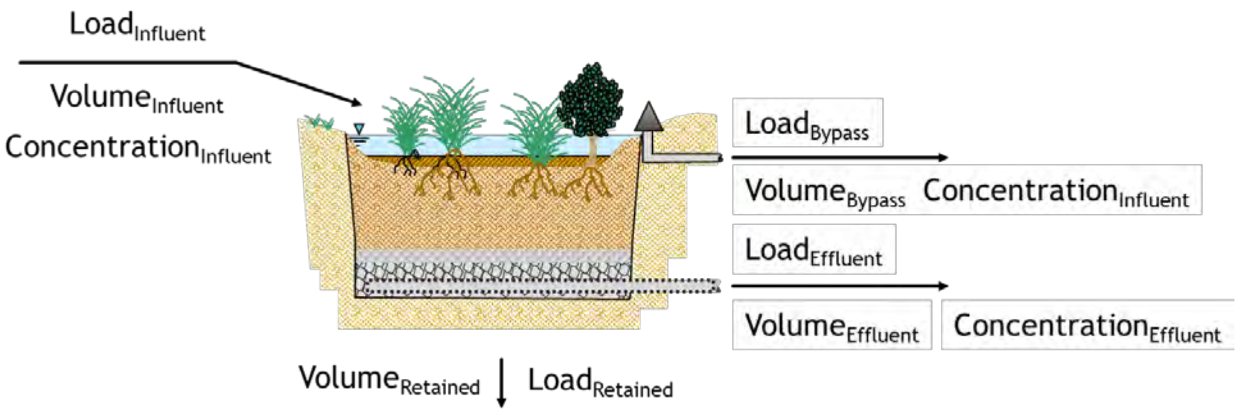


**Figure 1: Illustration of GI Facility Pollutant Load Reduction Calculations**

$$Load_{Reduced} = Load_{Influent} - Load_{Bypass} - Load_{Effluent} \quad \text{Eqn. 2}$$

$$Load_{Influent} = Volume_{Influent} \times Concentration_{Influent} \times C \quad \text{Eqn. 3}$$

$$Load_{Bypass} = Volume_{Bypass} \times Concentration_{Influent} \times C \quad \text{Eqn. 4}$$

$$Load_{Effluent} = (Volume_{Captured} - Volume_{Retained}) \times Concentration_{Effluent} \times C \quad \text{Eqn. 5}$$

$$Volume_{Captured} = Volume_{Influent} - Volume_{Bypass} \quad \text{Eqn. 6}$$

Where:

$Load_{Reduced}$ = The total average annual pollutant load reduced by the GI facility [g/year]

$Load_{Influent}$ = The total average annual pollutant load produced by the facility drainage area [g/year]

$Load_{Bypass}$ = The pollutant load that bypasses the facility [g/year]

$Load_{Effluent}$ = The pollutant load discharged from the facility after treatment [g/year]

$Volume_{Influent}$ = The runoff produced by the drainage area to the GI facility [ac-ft/year]

$Volume_{Bypass}$ = The proportion of influent runoff that bypasses the facility [ac-ft/year]

| | | |
|---|---|---|
| $Volume_{Captured}$ | = | The proportion of influent runoff that is captured by the facility [ac-ft/year] |
| $Volume_{Retained}$ | = | The proportion of captured runoff that is retained by the facility through infiltration and/or evapotranspiration [ac-ft/year] |
| $Concentration_{Influent}$ | = | The pollutant concentration associated with the GI drainage area [ng/L] |
| $Concentration_{Effluent}$ | = | The concentration discharged from the facility after treatment [ng/L] |
| C | = | Conversion factor constant = 0.00123 [(L/ac-ft)*(g/ng)] |

### 2.4 RAA Scenario Loading Model

The loading corresponding with RAA future condition scenarios (2020, 2030, 2040) will be developed using the same volume and concentration combination approach used for the baseline condition. HRU outputs developed for the baseline model will scaled across the county corresponding to anticipated land use and development changes for each of the future conditions. Similarly, the RWSM land use classifications layer will be updated corresponding to each future condition scenario.

The outputs of the future hydrology scaling combined with the concentrations corresponding with future RWSM land use classification provides the land use-based loading estimated for each of the future conditions. To obtain the discharged load corresponding to each future GI scenario, load reductions associated with anticipated GI (developed as described above) will be subtracted from the land use-based load.

## 3. MODEL INPUTS AND DATA USED

This section describes the inputs to each component of the model and the data used.

### 3.1 Baseline Loading Model

#### 3.1.1 Hydrologic Model

Generic HRU models are developed in SWMM to estimate average annual runoff volume per acre values that can be applied to all land surfaces within each county. The land surface feature inputs that will be varied to model the generic HRUs are described in the sections below and summarized in Table 3.

*Climate Inputs*

HRU climate inputs provide the total amount of precipitation that falls on the land surface and the amount of precipitation that is lost to the atmosphere via evapotranspiration before running off the land surface. Multiple gauges from across Alameda and Contra Costa counties that had continuous hourly precipitation data were chosen to represent distinct rainfall regions within both counties. For precipitation, these regions are based on 30-year annual rainfall regimes as identified by PRISM[5]. For evapotranspiration rates, the California Irrigation Management Information System (CIMIS) evapotranspiration zones were used within each county. The combination of the identified precipitation regions and evapotranspiration regions were combined to yield "climate zones" used for generic HRU models. Precipitation zones, evapotranspiration zones, and climate zones are shown in Exhibit 1 through Exhibit 3 (see Appendix A). Table 1 provides a summary of precipitation gauges used and average annual rainfall corresponding to the entire period of record and WY 2000 - 2009. Table 2 provides a summary of the CIMIS data used for the daily reference evapotranspiration rate for each evapotranspiration zone.

**Table 1: HRU Precipitation Gauges WY2000-2009**

| Gauge ID | Gauge Name | Average Annual Precipitation (inches) WY 2000 - 2009 | Gauge Source |
|---|---|---|---|
| KHWD | Hayward Air Terminal (ASOS) | 16.3 | ASOS[1] |
| KLVK | Livermore Municipal Airport (ASOS) | 14.6 | ASOS |
| KOAK | Oakland Airport (ASOS) | 19.0 | ASOS |
| DBF | Dublin Fire Station, San Ramon | 17.3 | CCCFCD[2] |
| FCD | Flood Control District, Martinez | 16.2 | CCCFCD |
| LSM | Los Medanos, Pittsburg | 11.8 | CCCFCD |
| SMC | Saint Mary's College, Moraga | 28.9 | CCCFCD |

1. Automated Surface Observation System (ASOS) data were used for Alameda County gauge sites for the period of WY2000-2009 since NCDC gauge data was not available for the baseline period. ASOS sites sometimes co-occur with NCDC gauge sites (e.g., airports), but are maintained and delivered by separate government entities.
2. Contra Costa County gauge data is collected by the Flood Control District but was provided to Geosyntec by Dubin Engineering.

[5] Parameter-elevation Relationships on Independent Slopes Model (PRISM), developed and managed by the PRISM Climate Group, Oregon State University http://prism.oregonstate.edu/.

**Table 2: CIMIS Reference Evapotranspiration**

| ET Zone | Monthly Evapotranspiration (in/day)[1] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| 1 | 0.03 | 0.05 | 0.08 | 0.11 | 0.13 | 0.15 | 0.15 | 0.13 | 0.11 | 0.08 | 0.04 | 0.02 |
| 2 | 0.04 | 0.06 | 0.1 | 0.13 | 0.15 | 0.17 | 0.16 | 0.15 | 0.13 | 0.09 | 0.06 | 0.04 |
| 3 | 0.06 | 0.08 | 0.12 | 0.16 | 0.17 | 0.19 | 0.18 | 0.17 | 0.14 | 0.11 | 0.08 | 0.06 |
| 6 | 0.06 | 0.08 | 0.11 | 0.16 | 0.18 | 0.21 | 0.21 | 0.2 | 0.16 | 0.12 | 0.08 | 0.06 |
| 8 | 0.04 | 0.06 | 0.11 | 0.16 | 0.2 | 0.23 | 0.24 | 0.21 | 0.17 | 0.11 | 0.06 | 0.03 |
| 14 | 0.05 | 0.08 | 0.12 | 0.17 | 0.22 | 0.26 | 0.28 | 0.25 | 0.19 | 0.13 | 0.07 | 0.05 |

1. CIMIS reference evapotranspiration, which is based on irrigated turf grass, was scaled by 0.6 to represent the local mix of vegetated cover including urban vegetation, native xeric adapted plants, and unirrigated vegetated open space areas.

*Slope*

Slope affects how quickly rainfall will run off a modeled land surface and therefore how much is able to be infiltrated into the subsurface. The available digital elevation model (DEM)[6] for the counties was analyzed to obtain percent slope values for each ~30m by ~30m square of land surface. These percent slope values were classified into three distinct slope zones as summarized in Table 3 and shown in Exhibit 4 (see Appendix A).

*Underlying Soil Inputs*

Physical characteristics of the soil underlying the land surface affect the amount of rainfall that may be infiltrated into the subsurface. Infiltration was simulated in SWMM using the Green-Ampt infiltration model option. The physical soil input parameters for the Green-Ampt infiltration model were varied based on hydrologic soil group (HSG) as identified by the National Resource Conservation Service (NRCS[7]) soil survey and were modified as described below for developed areas. Soil parameters used as model inputs include suction head, hydraulic conductivity, and initial moisture deficit. Developed areas that are assumed to have been compacted and therefore result in less infiltration to the subsurface are modeled using 75 percent of the HSG hydraulic conductivity value. Soil parameters are not reported here, as this input is adjusted as part of

[6] U.S. Geological Survey. National Elevation Dataset (NED) 1/3 arc-second. 2013

[7] Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. link: https://websoilsurvey.sc.egov.usda.gov/

baseline model calibration. Details about soil inputs are provided in Table 3. A map of hydrologic soil group is provided as Exhibit 5 (see Appendix A).

Areas of development were identified based on the land use of the surface. Soils within urban and agricultural use areas were considered to have been compacted by the site preparation and activities.

*Imperviousness*

Imperviousness (i.e., the percentage of impervious area) affects area on the land surface where rainfall may be infiltrated and therefore the quantity of runoff produced. The runoff from a range of land use imperviousness values is modeled by area-weighting the results of a pervious surface runoff result (i.e., pervious HRU output) with a corresponding impervious surface runoff result (i.e., impervious HRU output) (see Table 3 and Exhibit 6 (see Appendix A)).

The baseline model HRU imperviousness is developed by geospatially combining the land uses identified by Association of Bay Area Governments (ABAG, 2005) with the National Land Cover Dataset (NLCD, 2006) data. Each feature of the ABAG dataset is assigned a single imperviousness value that is used to determine the average hydrologic response of that land surface. A lookup-table containing NLCD based imperviousness for each ABAG land use code was used as a starting value for HRU calibration. These initial values may be adjusted within an appropriate range as part of baseline model calibration.

### 3.1.2 Developing HRUs across each County

Each identified combination of land surface features is modeled for a generic unit-acre drainage area in SWMM for the baseline period of record (i.e., WY 2000 – 2009), utilizing a batch-processing method (which allows for inputs to be altered, model files run, and results extracted for many models automatically). The average annual runoff volume per acre is then extracted for each generic HRU modeled.

**Table 3: Land Surface Feature Inputs for Generic HRU Hydrologic Models**

| Variables | Description | Number of Varying Features | Feature Representations | Source |
|---|---|---|---|---|
| Hourly Annual Precipitation | Rainfall Gauge and Rainfall Zone | 7 | Contra Costa County Gauges: DBF, FCD, LSM, SMC<br>Alameda County ASOS Gauges: KHWD, KLVK, KOAK | PRISM[1], NCDC/ County-maintained rainfall gauges |
| Daily Evapotranspiration Rate | Evapotranspiration Zone | 5 | Zones 1, 2, 3, 6, 8, 14 | CIMIS[2] |
| Slope Zone | Representation of Slope | 3 | <5%, 5-15%, 15%+ | USGS[3] |
| Developed/ Undeveloped Areas | Representation of Compaction of Underlying Soils (Pervious Areas Only) | 2 | Undeveloped (Ksat * 1)<br>Developed (Ksat * 0.75) | ABAG Land Use 2005[4] |
| Hydrologic Soil Group | Representation of Underlying Soil Type (pervious areas only) | 6 | HSG A, B, C, D[5], Rock, Water | NRCS[6] |
| Imperviousness | Representation of Imperviousness | 2 | 0% and 100% | NLCD and ABAG 2005 |

1. PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, 30-year normal mean annual precipitation
2. California Irrigation Management Information System (CIMIS) Reference Evapotranspiration; digitized from http://www.cimis.water.ca.gov/App_Themes/images/etozonemap.jpg
3. U.S. Geological Survey. National Elevation Dataset (NED) 1/3 arc-second. 2013
4. ABAG land uses are proposed to be used for identifying developed and undeveloped condition and will have an imperviousness value assigned based on a geospatial analysis of the NLCD Imperviousness layer. The impervious value for each ABAG land use feature will then be carried into the HRU model calibration and adjusted accordingly.
5. "Urban" representation will be re-classified based on the dominant adjacent HSG.
6. U.S. Department of Agriculture, Natural Resources Conservation Service. Soil Survey Geographic (SSURGO) database. 2016

HRUs are determined geospatially based on the climate zone, slope zone, developed/undeveloped areas, and HSG, along with land use-based imperviousness. Exhibits 1 through 5 (see Appendix A) display the data used to develop climate zones, county slope zones, and the HSG distribution across each county. Imperviousness designations will occur based on land use at the parcel level, by combining the geospatial ABAG land use layer[8] with the other hydrologic input regions. This results in a "patchwork" of HRUs across the counties[9].

The resulting patchwork of HRUs can be combined at the scale of choice to provide total runoff volumes for a specific area, such as a watershed or jurisdictional boundary. To estimate the total runoff for the identified area, the total acreage of each designated HRU present within a watershed or jurisdiction will be multiplied by the average annual runoff per acre associated with each HRU and then summed (i.e., area-weighting the average annual runoff volume per acre for all HRUs present).

### 3.1.3 HRU Input Calibration

Calibration of hydrologic models is required by the *Bay Area RAA Guidance Document*. Calibration of the generic HRU models will be conducted utilizing available stream flow records and based solely upon the annual discharge volume between WY 2000-2009. This annual calibration means that the HRU runoff estimates are representative of the approximate annual runoff volume but will not be used to estimate or compare discharge rates at smaller timesteps, such as the hourly or daily runoff hydrograph.

The list of candidate gauge sites within the counties was developed based on an assessment of the representativeness of the gauged watersheds and the mitigation of confounding factors that interfere with calibration such as missing data and upstream impoundments. For the purposes of calibration, the candidate gauge sites that were selected included stream depth rating curves and at least daily mean records for the historical period of interest. The USGS flow gauges considered for calibration are provided in Table 4 and shown in Exhibit 8 (see Appendix A).

[8] ABAG land use features will used to aggregate the imperviousness for the land surface. The relationship between AGAB feature and its imperviousness will be developed based upon other local sources (SMCWPPP, 2017) and analysis of national public data sets such as the National Land Cover Dataset (NLCD)

[9] This will be done once all the HRU input files are finalized, including the imperviousness layers.

**Table 4: Flow Gauge Considered for RAA Model Calibration**

| Gauge ID | Gauge Name | Location | County | Data Frequency |
|---|---|---|---|---|
| 11337600 | Marsh Creek | Brentwood | Contra Costa | Daily |
| 11182500 | San Ramon Creek | San Ramon | Contra Costa | Daily |
| 11181390 | Wildcat Creek | Richmond / San Pablo | Contra Costa | Daily |
| 11181040 | Lan Lorenzo Creek | San Lorenzo | Alameda | Daily |
| 11181008 | Castro Valley Creek | Hayward | Alameda | Daily |
| 11181000 | San Lorenzo Creek | Hayward | Alameda | Daily |
| 11180700 | Alameda Creek Flood Channel | Union City | Alameda | Daily |
| 11179000 | Alameda Creek | Fremont | Alameda | Daily |
| 11176900 | Arroyo de la Laguna | Verona | Alameda | Daily |
| 11173575 | Alameda Creek Below Welch Creek | Sunol | Alameda | Daily |
| 11173510 | Alameda Creek Below Calaveras Creek | Sunol | Alameda | Daily |

The effective area tributary to each flow gauge is used to calibrate the HRUs to the stream gauge records. Annual flow predicted by area-weighting HRU runoff output for the watersheds draining to the stream gauges was compared to annual flow in the stream records for the identified period of record.

Calibration of land surface runoff hydrology to stream gauge records requires that baseflow be computed and accounted for throughout the period of record. A variety of methods exist for separating baseflow from runoff, including the fixed-interval method and the local-minimum method (Sloto and Crouse, 1996). The most appropriate method for separating baseflow is determined on a gauge by gauge basis depending on the variability in the flow record, and the occurrence of confounding factors that affect baseflow such as dam releases and other dry weather inflows.

The average percent difference between the area-weighted HRU total average annual runoff volume for the watershed and the average annual flow (converted to volume) measured for the WY 2000 – 2009 period will be calculated. The acceptable ranges included in the RAA Guidance document are provided in Table 5 below.

**Table 5: Allowable Difference between Simulated and Observed Annual Volumes**

| Model parameters | Average % difference between simulated annual results and observed data | | |
|---|---|---|---|
| | Very Good | Good | Fair (lower bound, upper bound) |
| Hydrology/Flow | <10 | 10-15 | 15-25 |

If the average percent difference between simulated and measured annual storm flow volumes is greater than 25%, HRU model parameters are adjusted until the percent difference is within the acceptable range. The primary model parameters adjusted include underlying soil hydraulic conductivity and land use imperviousness, but other hydrologic model parameters, such as depression storage, may be adjusted as appropriate.

Once average percent differences in all identified watersheds are within the acceptable range, the HRU model parameters are finalized and the HRU results database will be regenerated. HRUs and resulting average annual baseline volume will be applied across each county to obtain the baseline volume discharged by each county.

### 3.1.4 Water Quality Model

RWSM values used to develop pollutant loading estimates across each county are:

**Table 6: Regional Watershed Spreadsheet Model PCBs and Mercury Concentrations in Runoff**

| Land Use Category | Total PCBs (ng/L) | Total mercury (ng/L) |
|---|---|---|
| Ag, Open | 0.2 | 80 |
| New Urban | 0.2 | 3 |
| Old Residential | 4 | 63 |
| Old Commercial/ Transportation | 40 | 63 |
| Old Industrial and Source Areas | 204 | 40 |

Water quality calculations are also used to perform baseline pollutant loading validation. The calculated pollutant load draining to Regional Monitoring Program stations will be validated by calculating the volume-weighted watershed pollutant concentration using the modeling results and comparing it to the observed concentrations in the Regional Monitoring Program data. The equation used to calculate concentration (in ng/L) at an end-of-watershed location is as follows:

$$Concentration_{Baseline} = \frac{\sum Runoff_{HRU} \times Area_{HRU} \times Concentration_{LU,HRU}}{\sum Runoff_{HRU} \times Area_{HRU}} \quad \text{Eqn. 7}$$

Pollutant concentration and loading data from the Regional Monitoring Program will be compared to the result of Equation 7 for several watersheds for validation purposes.

## 3.2 Green Infrastructure Performance Model

### 3.2.1 Long-Term Green Infrastructure Simulations

Long term performance was assessed for each BMP configuration using continuous historical rainfall records. In Contra Costa County historical data was available at the same gauges that were used for the HRU runoff modeling between WY2000-2009, but for Alameda County other gauge sites with longer histories were used for long term BMP performance modeling. The rainfall gauges used to model BMP performance are shown in Table 7.

**Table 7: Long Term GI Performance Precipitation Gauges**

| Gauge ID | Gauge Name | Period of Record | Average Annual Precipitation (inches) | Gauge Source[1] |
|---|---|---|---|---|
| 040693 | Berkeley (NCDC) | 1948-1990 | 19.8 | NCDC |
| 041060 | Brentwood (NCDC) | 1950-1985 | 14.9 | NCDC |
| 043863 | Hayward (NCDC) | 1948-1988 | 24.3 | NCDC |
| 046335 | Oakland Airport (NCDC) | 1948-1985 | 16.4 | NCDC |
| 047821 | San Jose Airport (NCDC) | 1948-2010 | 13.6 | NCDC |
| DBF | Dublin Fire Station, San Ramon | 1973-2016 | 15.0 | CCCFCD |
| FCD | Flood Control District, Martinez | 1971-2016 | 16.5 | CCCFCD |
| LSM | Los Medanos, Pittsburg | 1974-2016 | 10.6 | CCCFCD |
| SMC | Saint Mary's College, Moraga | 1972-2016 | 26.8 | CCCFCD |

1. NCDC data was used for Alameda County and San Jose gauge sites. Contra Costa County gauge data is collected by the Flood Control District and was provided to Geosyntec by Dubin Engineering.

### 3.2.2 Hydraulic Green Infrastructure Model

Hydraulic GI models were developed in SWMM to estimate hydraulic performance for a 100% impervious tributary area. Hydraulic model inputs that were varied to model the GI facility performance for the counties are described below and summarized in Table 8.

1. BMP Configuration – three GI facility types were assumed: (1) bioretention with a raised underdrain, (2) bioretention with no underdrain, and (3) lined bioretention with an underdrain.

2. BMP Footprint Size – the BMP footprint size was varied as a percent of impervious area to model different levels of hydraulic capture performance depending on facility sizing.
3. BMP Underlying Infiltration Rate – the infiltration rate of the soils underneath the bioretention facility was varied for the bioretention with a raised underdrain and bioretention with no underdrain configurations (I.e., the unlined facility types).

**Table 8: Land Surface Feature Inputs for Generic GI Performance Hydraulic Models**

| Variables | Description | Number of Varying Features | Feature Representations |
|---|---|---|---|
| Hourly Precipitation | Rainfall Gauge | 9 | NCDC:<br>040693 (Berkeley)<br>046335 (Oakland Airport)<br>043863 (Hayward)<br>047821 (San Jose)<br>041060 (Brentwood)<br>Contra Costa County:<br>DBF, FCD, LSM, SMC |
| Daily Evapotranspiration Rate | Evapotranspiration Zone | 4 | CIMIS Zones:<br>1, 6, 8, 14 |
| BMP Configurations | BMP profiles and underdrain | 3 | Lined Bioretention with underdrain<br>Unlined Bioretention with elevated underdrain<br>Infiltration Basin without underdrain |
| BMP Surface Ponding Depth | Depth (feet) | 2 | 0.5, 1 |
| BMP Footprint Sizes | % of Impervious Area | 12 | 0.25, 0.5, 0.75, 1, 1.5, 2, 2.5, 3, 3.5, 4, 5, 6 |
| BMP Infiltration Rates | Ksat of underlying soil (in/hr) | 7<br><br>3 | Unlined Bioretention:<br>0.024, 0.05, 0.1, 0.2, 0.24, 0.3, 0.4, 0.5<br>Infiltration Basin:<br>0.5, 1, 2 |

The BMP cross-sections that were modeled each include:

- 6-inches or 12-inches ponding depth (both were modeled),
- 1.5 ft of filter media with 25% porosity with a 5 in/hr flow through rate, and

- 1 ft of gravel beneath the media with 40% porosity.

Two of the modeled BMP configurations include underdrains. In the lined bioretention facility, the underdrain is located at the bottom of the gravel layer. In the unlined bioretention facility, the underdrain was modeled at the top of the gravel layer. BMP configurations are shown in Exhibits 9 through 11 (see Appendix A).

### 3.2.3 Green Infrastructure Pollutant Reduction Calculations

As described in Section 2.3.2, pollutant load reduction associated with GI is calculated by combining the hydraulic model results with water quality performance data. The annual estimate of pollutant load reduction from the modeled drainage area is equivalent to the difference between the influent load and the sum of the pollutant load that bypasses the GI measure and the effluent load. The effluent load is calculated as the proportion of runoff that is treated by the GI measure multiplied by an effluent concentration.

Water quality performance data from selected, representative studies were used to determine a method to predict effluent concentrations in stormwater following treatment through a biofiltration (bioretention or tree well filters) GI measure. The data used to develop the relationship came from three studies: a) 2011 monitoring study of the El Cerrito Rain Gardens (Gilbreath, Pearce, and McKee, 2012), b) Clean Watersheds for a Clean Bay (CW4CB)[10] (Geosyntec and EOA, 2017), and c) a study at Echo Lake in King County, WA (King County, 2017). A summary of the paired influent-effluent data associated with each study is provided in table:

**Table 9: Data used to Develop Effluent Concentrations**

| Project Name | Project Sponsor | Facility ID | Influent-Effluent Data Pairs (n pairs) | |
|---|---|---|---|---|
| | | | PCBs | Mercury |
| El Cerrito Green Streets – CW4CB | El Cerrito | ELC-B1 | 3 | 3 |
| El Cerrito Green Streets – SFEI | SFEI | ELC-B1 | 4 | 4 |
| PG&E Substation 1st and Cutting Bioretention Cells – CW4CB | Richmond | LAU-3 | 8 | 8 |

[10] The CW4CB study included additional monitoring of the El Cerrito rain gardens.

| Project Name | Project Sponsor | Facility ID | Influent-Effluent Data Pairs (n pairs) | |
|---|---|---|---|---|
| | | | PCBs | Mercury |
| Monitoring Stormwater Retrofits in the Echo Lake Drainage Basin Bioretention Planter Boxes – SAM Effectiveness Study | King County, Dept. of Natural Resources and Parks | BPB-1 | 4 | 0 |
| | | BPB-2 | 4 | 0 |
| | | BPB-3 | 4 | 0 |
| | | BPB-4 | 2 | 0 |
| West Oakland Industrial Area Tree Wells – CW4CB | Oakland | ETT-TW2 | 4 | 4 |
| | | ETT-TW6 | 4 | 4 |
| Monitoring Stormwater Retrofits in the Echo Lake Drainage Basin Tree Well – SAM Effectiveness Study | King County, Dept. of Natural Resources and Parks | FLT-1 | 4 | 0 |
| | | Total Data Pairs | 41 | 23 |

These data were statistically evaluated to identify an appropriate method for predicting effluent concentrations of PCBs and total mercury. The data analysis first evaluated whether available influent and effluent concentration data were significantly different and, if so, whether a monotonic relationship existed (i.e., effluent generally increased when influent increased).

A Wilcoxon non-parametric hypothesis test was run on the PCBs and total mercury paired influent-effluent data to determine if influent and effluent concentrations were statistically different at a 5% significance level. This difference was found to be significant for PCBs, and significant for total mercury when corresponding influent suspended solids concentration was greater than 20 mg/L.

Spearman's rho and Kendall's tau, which are non-parametric rank correlation coefficients, were used to identify the direction and strength of correlation between influent and effluent concentrations. As shown in Table 10, both correlation coefficients suggest that effluent concentrations are positively correlated with influent concentrations for both PCBs and mercury.

**Table 10: Influent/Effluent Correlation Coefficients.**

| Correlation Coefficient | Total PCBs | Total Mercury |
|---|---|---|
| Spearman's rho | 0.725 | 0.547 |
| Kendall's tau | 0.527 | 0.396 |

The Kendall-Theil Robust Line (KTRL) method (Granato, 2006) was used to determine the best fit line between influent and effluent data. This non-parametric method uses the median of all possible pairwise slopes between points, which is more robust to outliers than a simple linear regression. Because stormwater data tend to be lognormal, the analysis was focused on linear and log-linear relationships. After the KTRL was generated, the lower portion of the curve was adjusted to assume that neither PCBs nor total mercury can be exported from biofilters under normal circumstances, i.e., that the maximum effluent concentration of PCBs or total mercury is equal to the influent concentration. The resulting KTRL for PCBs is shown Figure 2. The resulting KTRL for total mercury is shown in Figure 3. Each figure also includes a constant average effluent concentration line with data fit statistics: root mean square error (RMSE) and median absolute deviation (MAD). As indicated, the KTRL provide a better fit of the data. However, the resulting effluent concentrations are not much different between the two lines except when influent PCBs are low (<10 ng/L) and total mercury concentration are high (>50 ng/L). For total mercury, concentration reductions are only predicted to occur when influent concentrations are greater than about 30 ng/L. Due to observed export of total mercury for several events, particularly for the 1st and Cutting bioretention cell (LAU-3), the moderate concentration reductions assumed by the KTRL at higher influent concentrations is reasonably conservative.

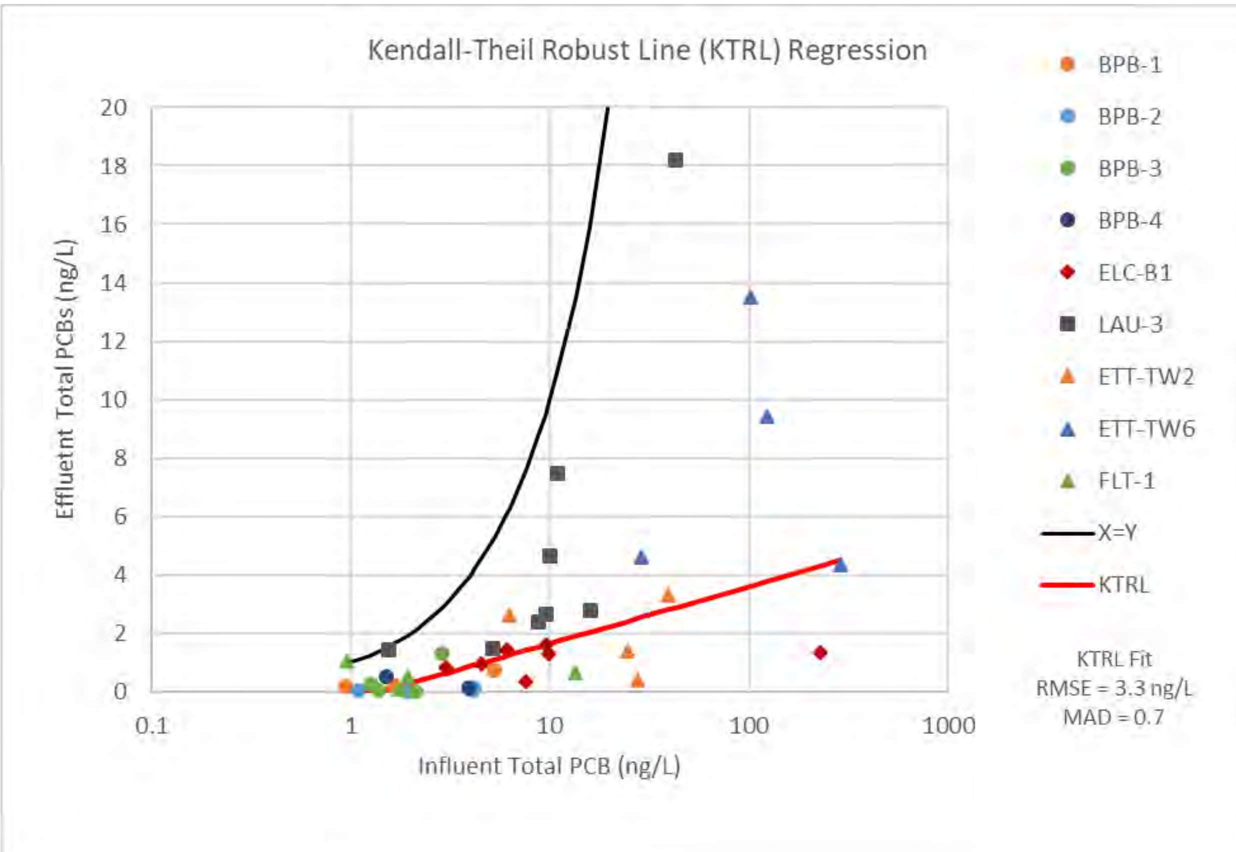


**Figure 2: PCBs Influent vs Effluent Concentration Relationship Determined by KTRL Regression**

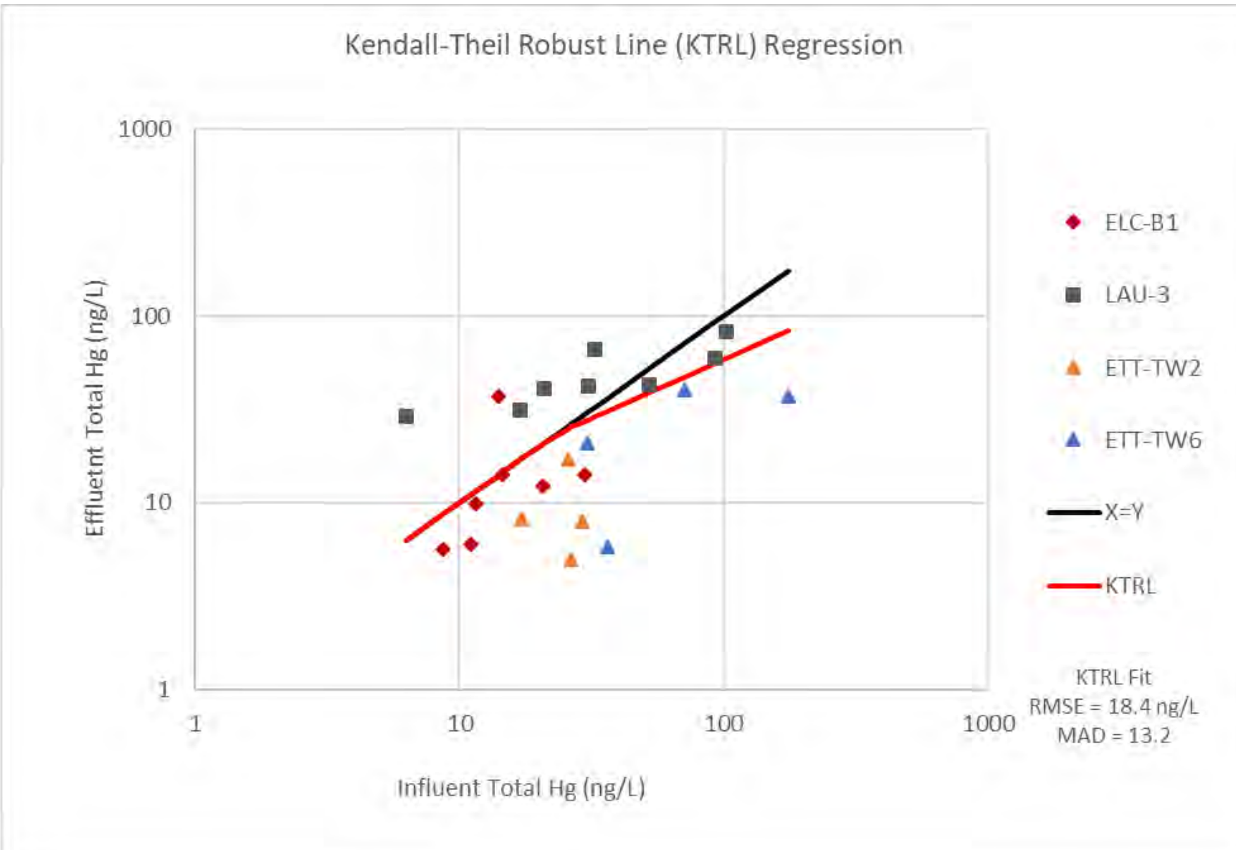


**Figure 3: Mercury Influent vs Effluent Concentration Relationship Determined by KTRL Regression**

### 3.3 RAA Scenario Loading Model

To model RAA future scenarios, future condition land use is needed. Future condition land use will be estimated using predictions of private parcel new development and redevelopment in combination with GI implementation on public parcels and rights-of-way.

Load reductions estimated for implementation of GI will be applied to future condition RAA scenario models based on estimated locations of GI and the tributary drainage areas to those GI. Effective area will be used to relate the HRUs, which can have a variety of imperviousness values, to the GI performance which will be based on a unit of effective area with 100% imperviousness. The GI performance curves can thus be applied to many different HRU types and/or combinations of HRUs that make up the tributary drainage areas for future GI measures.

# 4. QUANTITATIVE RELATIONSHIP BETWEEN GI IMPLEMENTATION AND PCBS LOADS REDUCED

The results of the hydraulic and pollutant reduction modeling of GI measures were used to develop a quantitative relationship between GI implementation and PCBs that can be applied to RAA future scenario models. An example quantitative relationship is provided for GI models run for the Berkeley gauge (040693). Utilizing output from hydraulic modeling, GI measure volumetric percent capture was calculated on an average annual basis. Volumetric model results for runs with GI measures sized to achieve 80%, 85%, 90%, and 95% capture were combined with water quality inputs to obtain pollutant load reduction for varying PCBs influent concentration.

The results of this analysis are shown in nomographs[11] provided in Figure 4, Figure 5, and Figure 6, which correspond to infiltrating bioretention (i.e., with no underdrain), bioretention with a raised underdrain, and lined bioretention, respectively. All facilities shown in the figures below have a 6-inch ponding depth. For bioretention with a raised underdrain, the facility configuration with an underlying infiltration rate of 0.24 in/hr only is shown (see Table 8 for all modeled infiltration rates). Facilities sized to achieve 80%, 85%, 90%, and 95% capture from the 100% impervious tributary catchment are shown in series, with pollutant load reduction in grams per effective acre[12] displayed as a function of influent concentration. Constant influent lines corresponding with RWSM land use-based influent concentrations are shown.

[11] A nomograph is a graphical relationship between two variables that can be used to quickly estimate one value from another.

[12] Effective area is calculated as the area multiplied by the runoff coefficient.

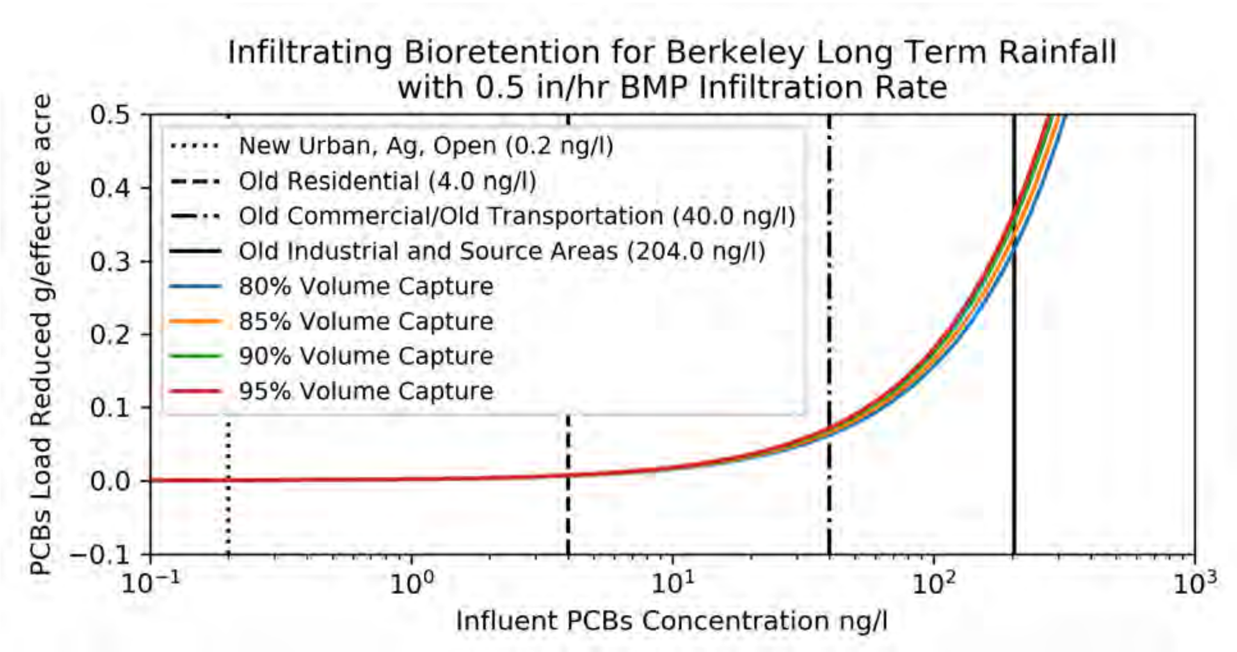


**Figure 4: Modeled PCBs Load Removal Performance for Infiltrating Bioretention Basin**

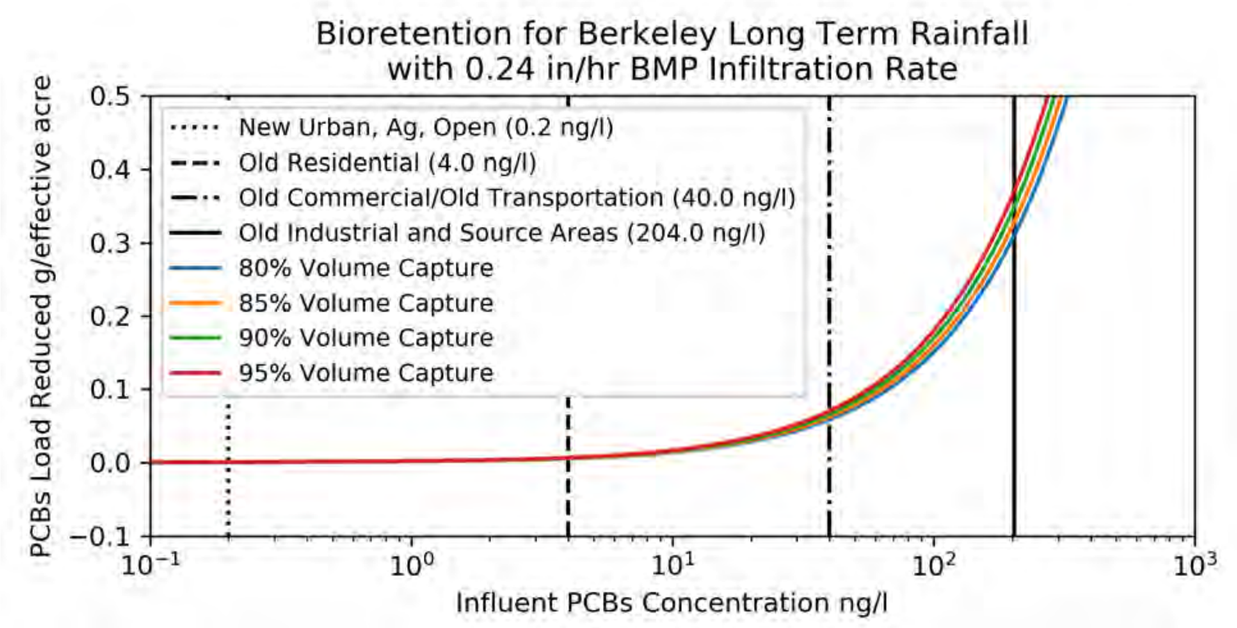


**Figure 5: Modeled PCBs Load Removal Performance for Bioretention Basin with Elevated Underdrain**

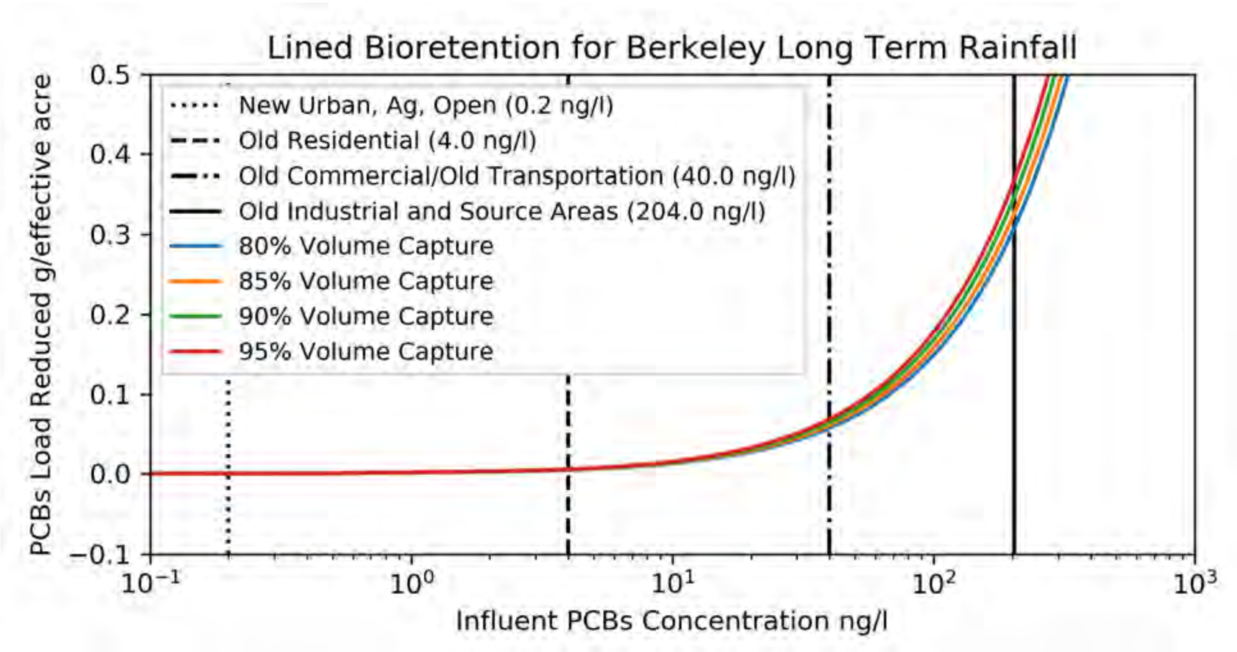


**Figure 6: Modeled PCBs Load Removal Performance for Lined Bioretention Basin with Underdrain**

The intersection points between the load reduction series and the constant influent lines represent the load reduced in grams per acre for each specific RWSM land use category. These intersection points are listed in Table 11.

**Table 11: PCBs Load Reduction for RWSM Land Use Categories for Berkeley Gauge for Different BMP Percent Capture Values**

| Facility Configuration | Land Use Category | PCBs Load Reduced (g/effective ac) | | | |
|---|---|---|---|---|---|
| | | 80% Capture[1] | 85% Capture[1] | 90% Capture[1] | 95% Capture[1] |
| Infiltrating Bioretention (0.5 underlying infiltration rate) | New Urban, Ag, Open | 3.12E-04 | 3.30E-04 | 3.49E-04 | 3.61E-04 |
| | Old Residential | 0.00623 | 0.0066 | 0.00698 | 0.00722 |
| | Old Commercial / Old Transportation | 0.0623 | 0.066 | 0.0698 | 0.0722 |
| | Old Industrial and Source Areas | 0.318 | 0.337 | 0.356 | 0.368 |
| Bioretention with Raised Underdrain (0.24 underlying infiltration rate) | New Urban, Ag, Open | 3.08E-04 | 3.26E-04 | 3.47E-04 | 3.67E-04 |
| | Old Residential | 0.00518 | 0.0055 | 0.00589 | 0.00633 |
| | Old Commercial / Old Transportation | 0.0586 | 0.0621 | 0.0661 | 0.0703 |
| | Old Industrial and Source Areas | 0.311 | 0.329 | 0.350 | 0.371 |

| Facility Configuration | Land Use Category | PCBs Load Reduced (g/effective ac) | | | |
|---|---|---|---|---|---|
| | | 80% Capture[1] | 85% Capture[1] | 90% Capture[1] | 95% Capture[1] |
| Lined Bioretention | New Urban, Ag, Open | 3.08E-04 | 3.26E-04 | 3.46E-04 | 3.67E-04 |
| | Old Residential | 0.00484 | 0.00513 | 0.00545 | 0.00577 |
| | Old Commercial / Old Transportation | 0.0574 | 0.0608 | 0.0647 | 0.0685 |
| | Old Industrial and Source Areas | 0.309 | 0.327 | 0.348 | 0.368 |

1. Average Annual Facility Volumetric Runoff Capture

## 5. QUANTITATIVE RELATIONSHIP BETWEEN GI IMPLEMENTATION AND MERCURY LOADS REDUCED

Mercury load reduction results for the Berkeley Gauge are shown in nomographs[13] in Figure 7, Figure 8, and Figure 9, which correspond to infiltrating bioretention (i.e., with no underdrain), bioretention with a raised underdrain, and lined bioretention, respectively. All facilities shown in the figures below have a 6-inch ponding depth. For bioretention with a raised underdrain, the facility configuration with an underlying infiltration rate of 0.24 in/hr only is shown (see Table 9 for all modeled infiltration rates). Facilities sized to achieve 80%, 85%, 90%, and 95% capture from the 100% impervious tributary catchment are shown in series, with pollutant load reduction in grams per acre displayed as a function of influent concentration. Constant influent lines corresponding with RWSM land use-based influent concentrations are shown.

[13] A nomograph is a graphical relationship between two variables that can be used to quickly estimate one value from another.

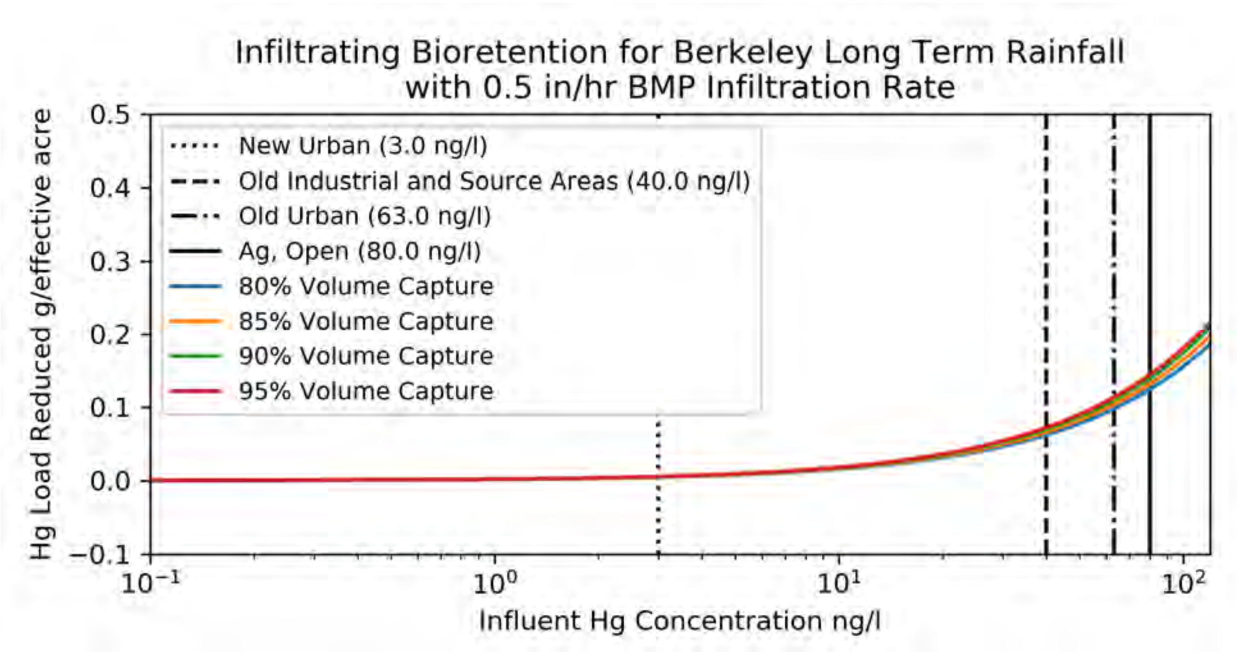


**Figure 7: Modeled Mercury Load Removal Performance for Infiltrating Bioretention Basin**

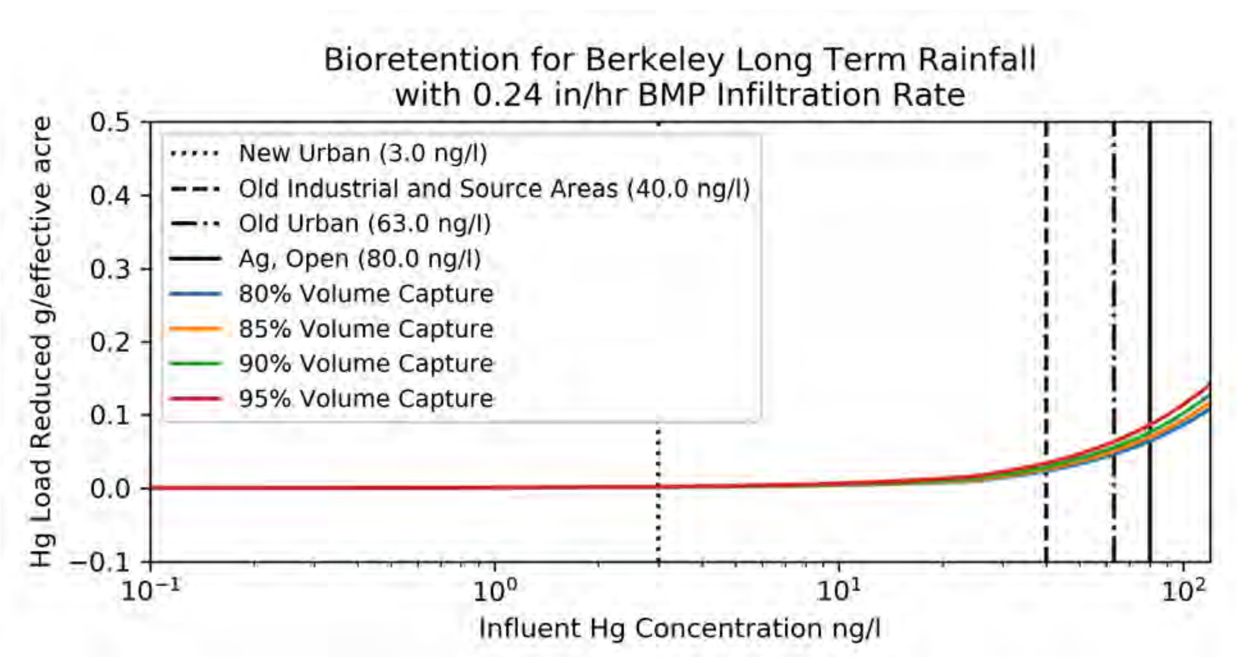


**Figure 8: Modeled Mercury Load Removal Performance for Bioretention Basin with Elevated Underdrain**

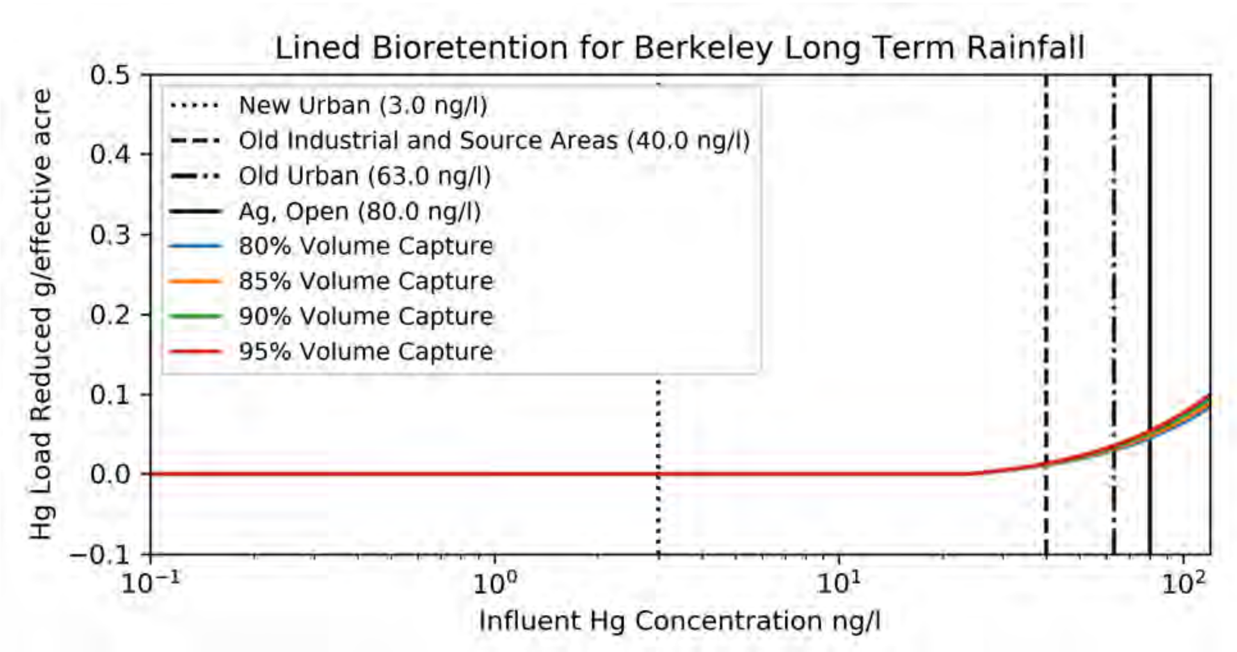


**Figure 9: Modeled Mercury Load Removal Performance for Lined Bioretention Basin with Underdrain**

The intersection points between the load reduction series and the constant influent lines represent the load reduced in grams per acre for each specific RWSM land use category. These intersection points are summarized in Table 12.

**Table 12: Mercury Load Reduction for RWSM Land Use Categories for Berkeley Gauge for Different BMP Percent Capture Values**

| Facility Configuration | Land Use Category | Mercury Load Reduced (g/effective acre) | | | |
|---|---|---|---|---|---|
| | | 80% Capture[1] | 85% Capture[1] | 90% Capture[1] | 95% Capture[1] |
| Infiltrating Bioretention (0.5 underlying infiltration rate) | New Urban | 0.00467 | 0.00495 | 0.00524 | 0.00541 |
| | Old Industrial and Source Areas | 0.0623 | 0.066 | 0.0698 | 0.0722 |
| | Old Urban | 0.0981 | 0.104 | 0.110 | 0.114 |
| | Ag, Open | 0.125 | 0.132 | 0.140 | 0.144 |
| Bioretention with Raised Underdrain (0.24 underlying infiltration rate) | New Urban | 0.00113 | 0.0013 | 0.00153 | 0.00192 |
| | Old Industrial and Source Areas | 0.0234 | 0.0258 | 0.029 | 0.0341 |
| | Old Urban | 0.0462 | 0.0503 | 0.0556 | 0.0634 |
| | Ag, Open | 0.0643 | 0.0696 | 0.0765 | 0.0862 |

| Facility Configuration | Land Use Category | Mercury Load Reduced (g/effective acre) | | | |
|---|---|---|---|---|---|
| | | 80% Capture[1] | 85% Capture[1] | 90% Capture[1] | 95% Capture[1] |
| Lined Bioretention | New Urban | 0 | 0 | 0 | 0 |
| | Old Industrial and Source Areas | 0.0108 | 0.0115 | 0.0123 | 0.0130 |
| | Old Urban | 0.0296 | 0.0314 | 0.0335 | 0.0353 |
| | Ag, Open | 0.0449 | 0.0476 | 0.0507 | 0.0536 |

[1] Average Annual Facility Volumetric Runoff Capture

## 6. REFERENCES


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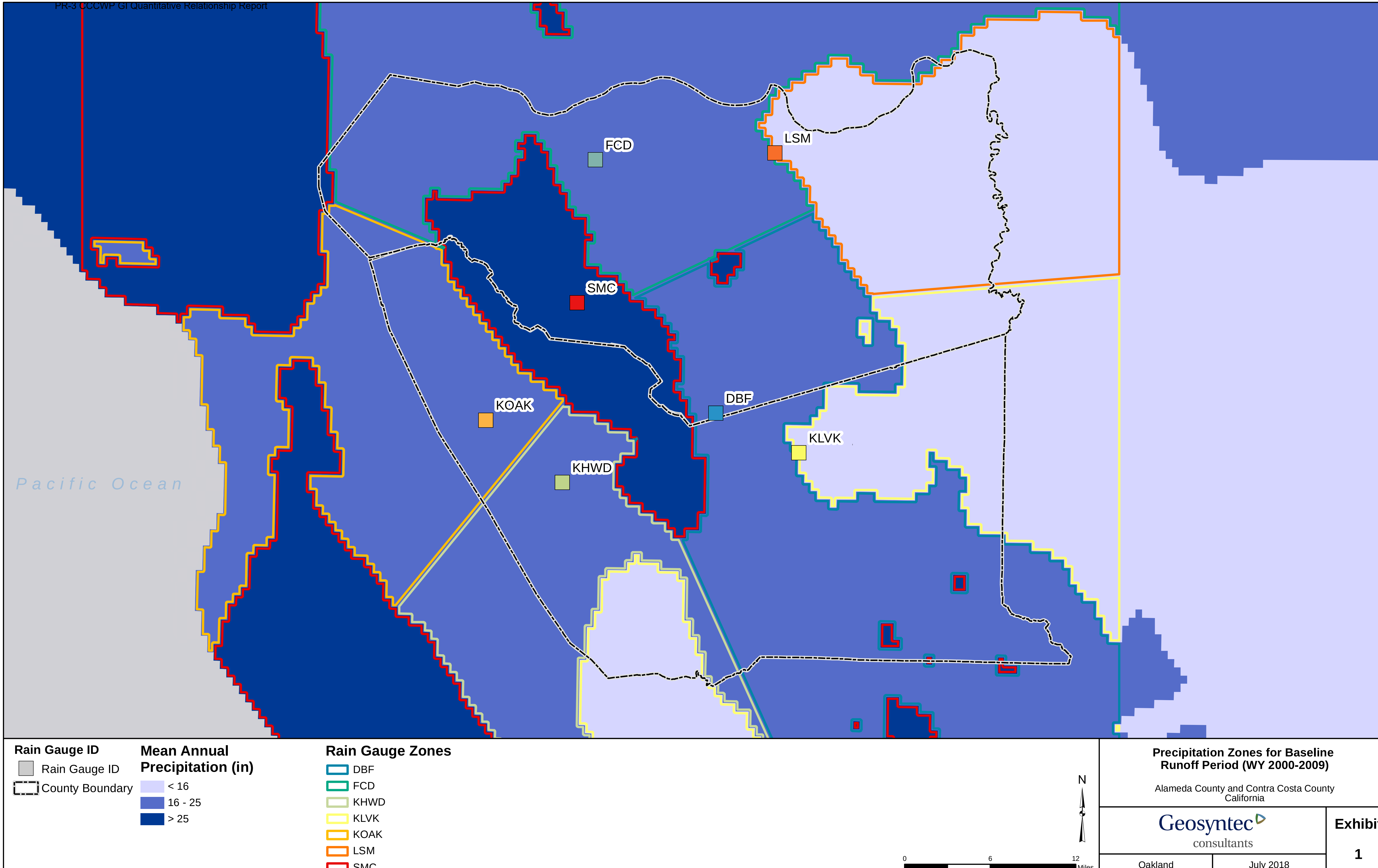
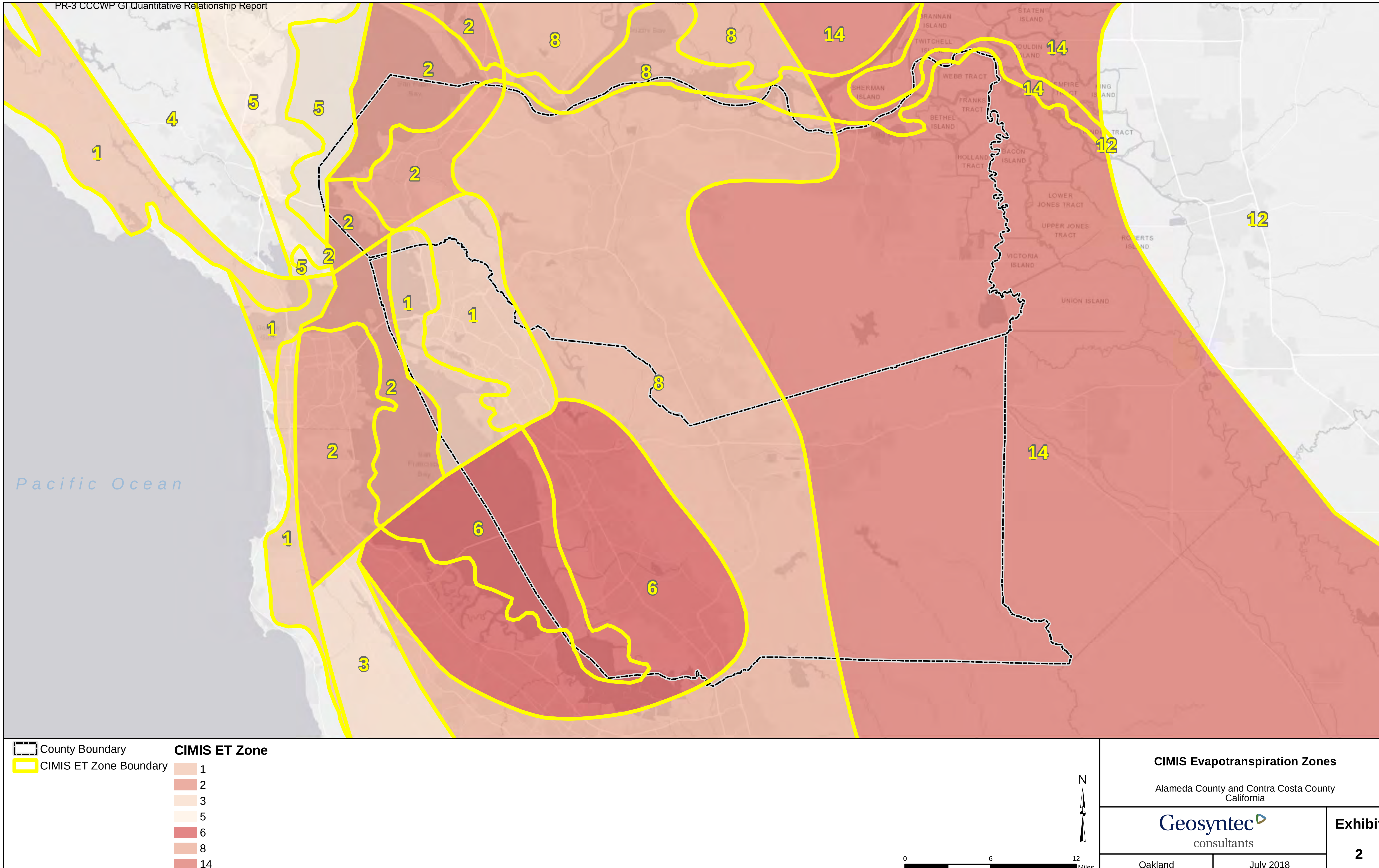
# APPENDIX A

# Modeling Inputs and Data Exhibits


FCD
LSM
SMC
DBF
KOAK
KLVK
KHWD
Pacific Ocean
Rain Gauge ID
Rain Gauge ID
County Boundary
Mean Annual Precipitation (in)
< 16
16 - 25
> 25
Rain Gauge Zones
DBF
FCD
KHWD
KLVK
KOAK
LSM
SMC
N
0
6
12
Miles
Precipitation Zones for Baseline Runoff Period (WY 2000-2009)
Alameda County and Contra Costa County
California
Geosyntec
consultants
Oakland
July 2018
Exhibit
1



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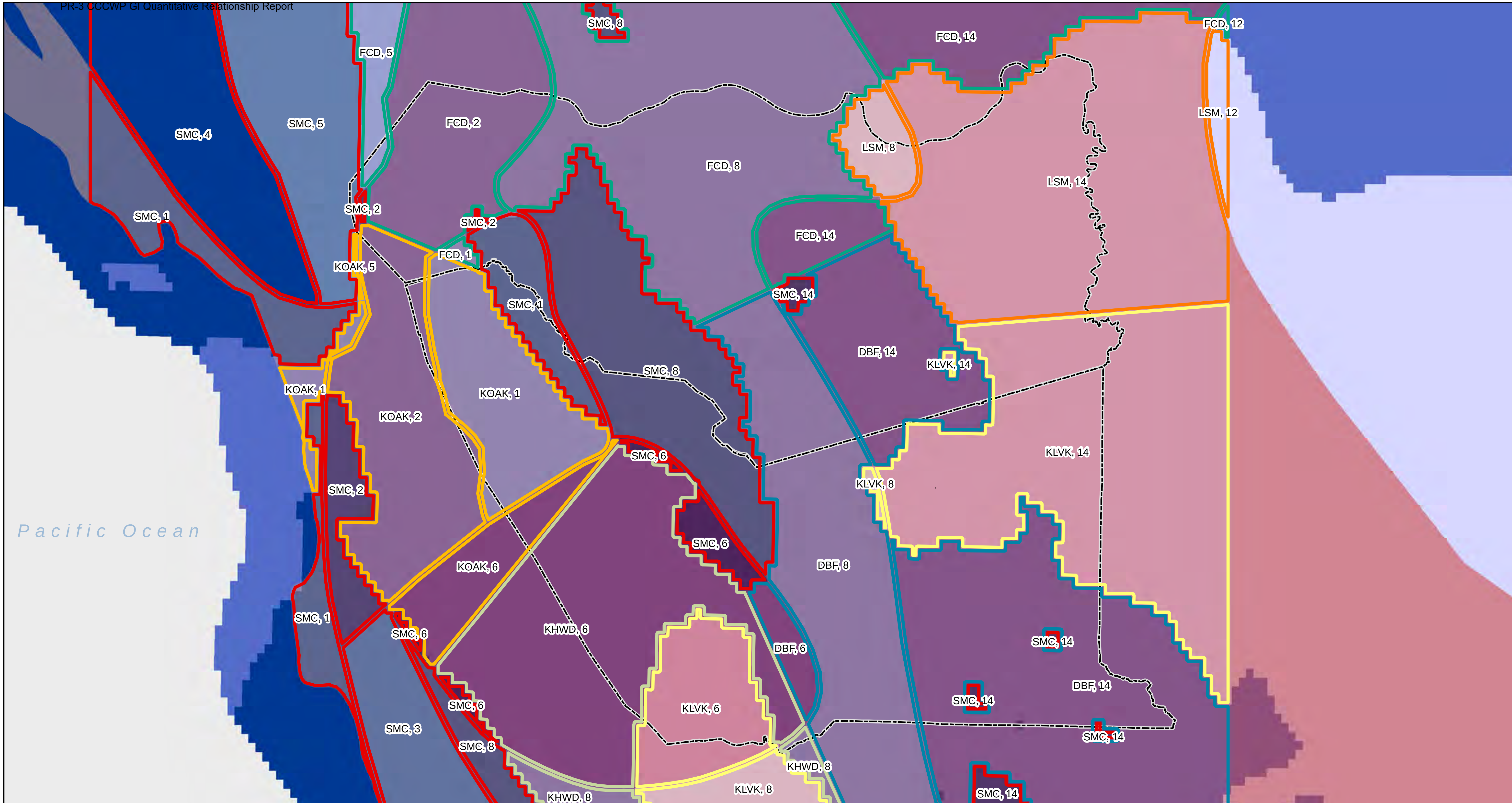



County Boundary

**Mean Annual Precipitation (in)**

- < 16
- 16 - 25
- > 25

**CIMIS ET Zone**

- 1
- 2
- 3
- 5
- 6
- 8
- 14

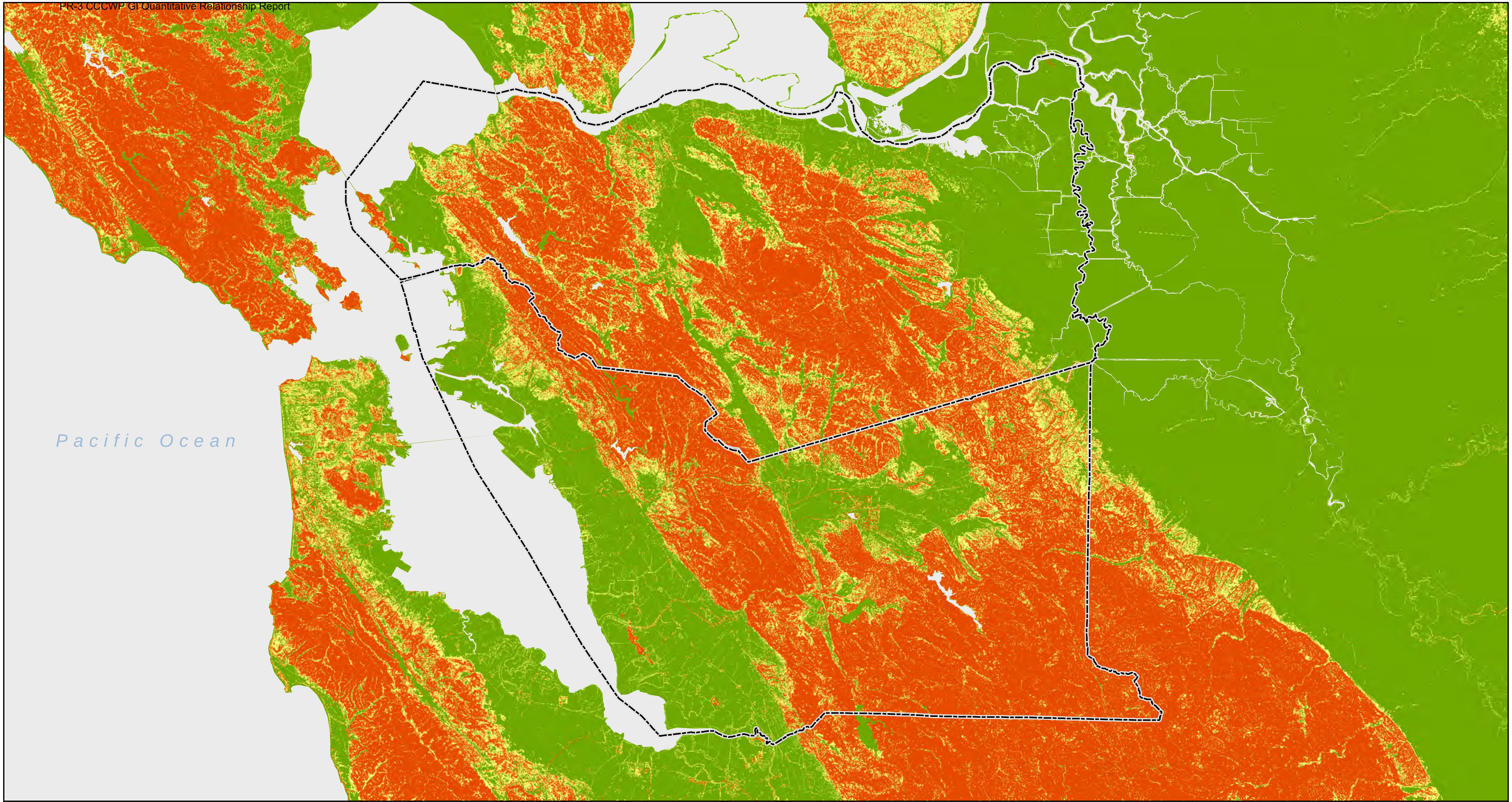
Climate Zones are created by overlapping precipitation zones and ET zones.The unique climate zones that occur in Contra Costa and Alameda County are labeled as "Gauge ID, ET Zone".

**Climate Zones for Baseline Runoff Period (WY 2000-2009)**

Alameda County and Contra Costa County
California

Geosyntec consultants

| | | |
|---|---|---|
| Oakland | July 2018 | **Exhibit** 3 |




County Boundary

**% Slope**

- < 5
- 5-15
- > 15

N

0 6 12 Miles

**Slope Zones**

Alameda County and Contra Costa County
California

Geosyntec consultants

Oakland | July 2018

**Exhibit 4**



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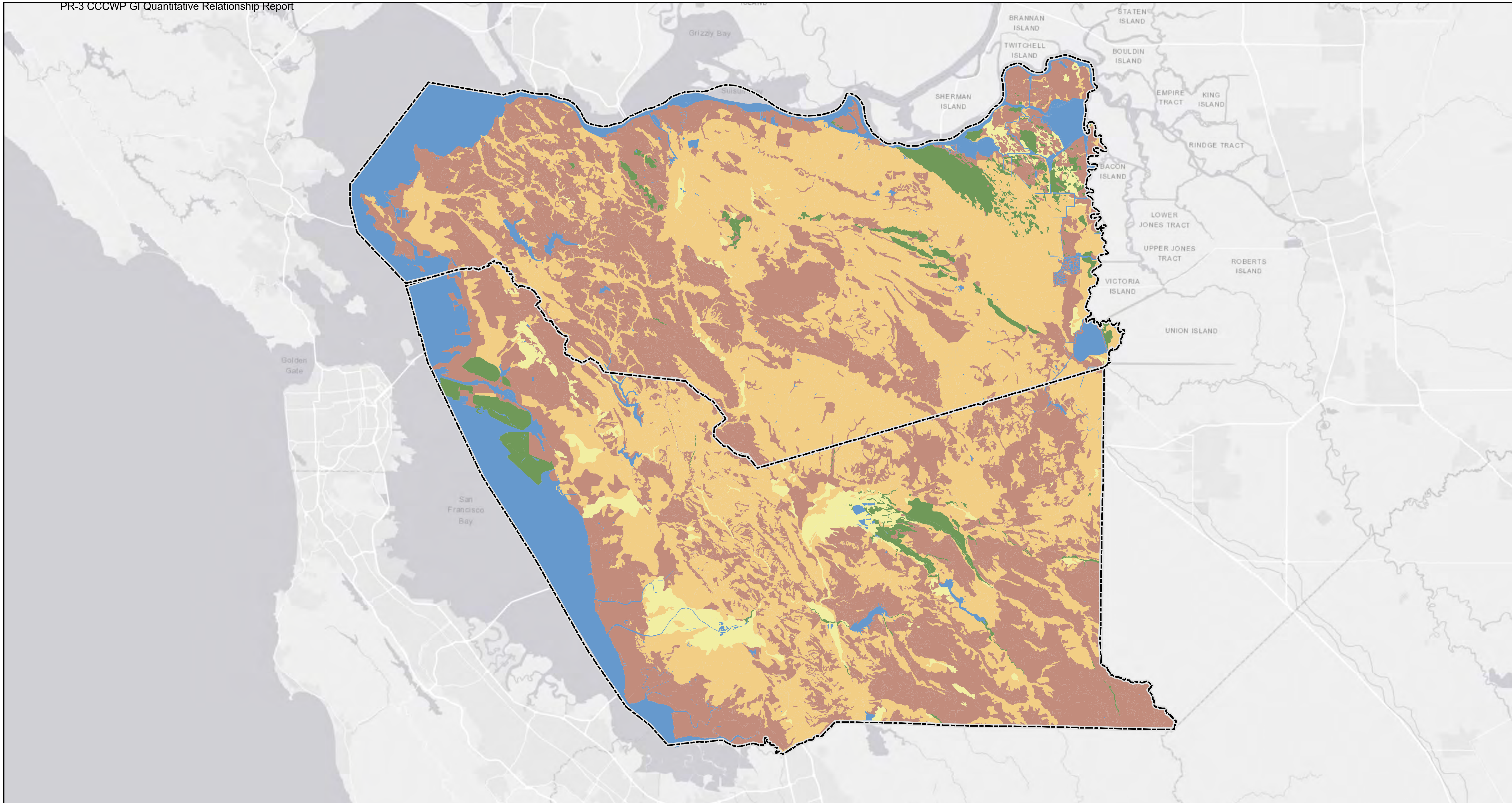



County Boundary

**HSG**

- A
- B
- C
- D
- W

Note: Area within the county with no HSG assignment was assigned the HSG of the most prominant adjacent soil group.

N

0 6 12 Miles

**Hydrologic Soil Group**

Alameda County and Contra Costa County
California

Geosyntec consultants

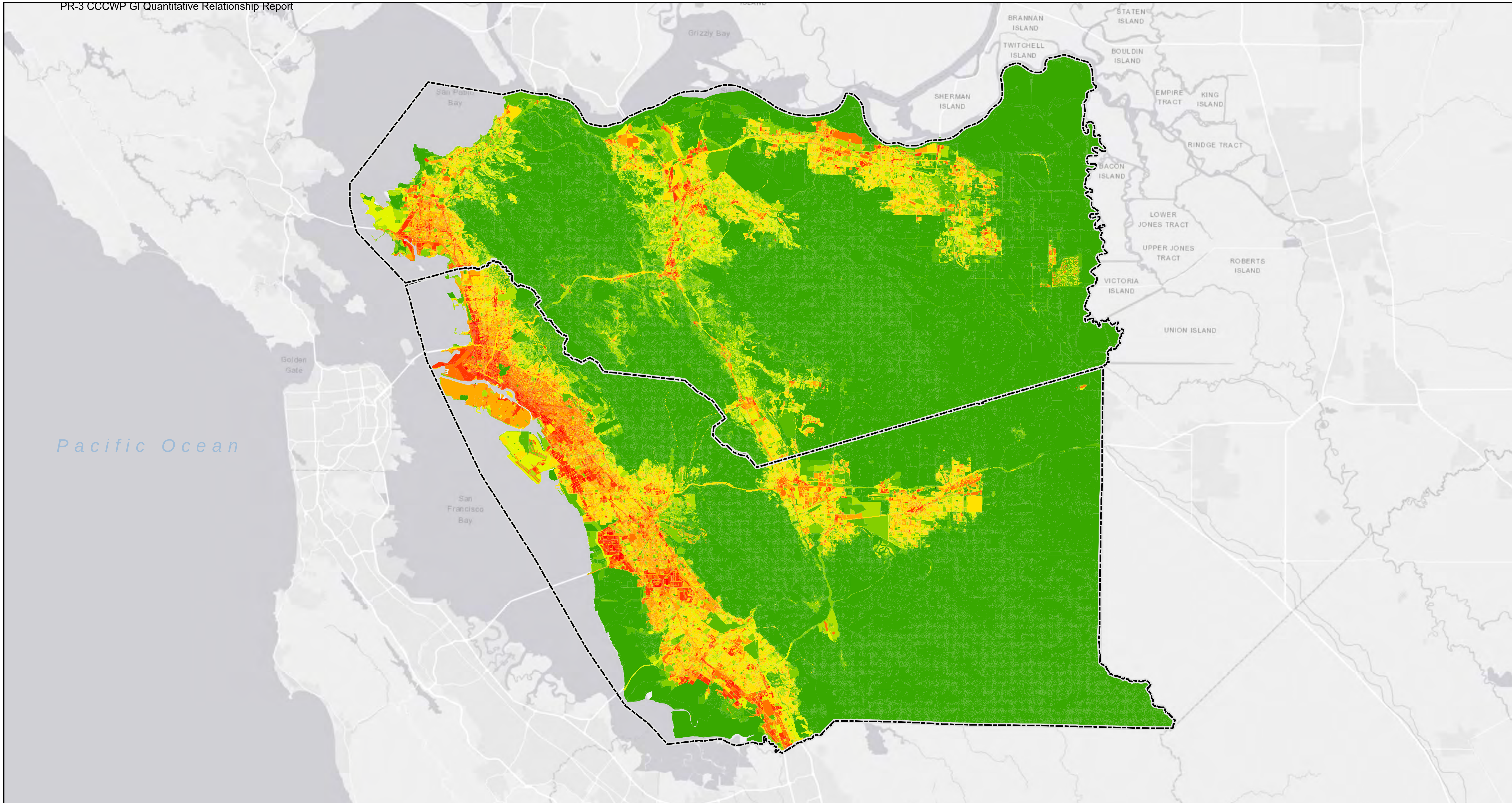
Oakland | July 2018

**Exhibit**

**5**



P:\GIS\Bay_Area_RAA\Project\GI_Load_Reduced_Report_Exhibits\Figure_6_Hydrologic_Soil_Group.mxd 7/5/2018 6:00:38 PM




County Boundary

**ABAG 2005 Imperviousness**

- 0 - 10
- 11 - 20
- 21 - 30
- 31 - 40
- 41 - 50
- 51 - 60
- 61 - 70
- 71 - 80
- 81 - 90
- 91 - 100

Note:
Imperviousness is assigned to ABAG 2005 landuse based on the NLCD 2006 Impervious Cover layer. These values may be adjusted during calibration for certain categories of ABAG landuse.

For purposes of calculating runoff from areas with compacted soil, developed areas and agricultural uses were assumed to be compacted to 0.75 times the underlying saturated soil conductivity (ksat). These areas generally have percent imperviousness > 20%.

N

0 6 12 Miles

**Regional Imperviousness**

Alameda County and Contra Costa County
California

Geosyntec consultants

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**Exhibit 6**



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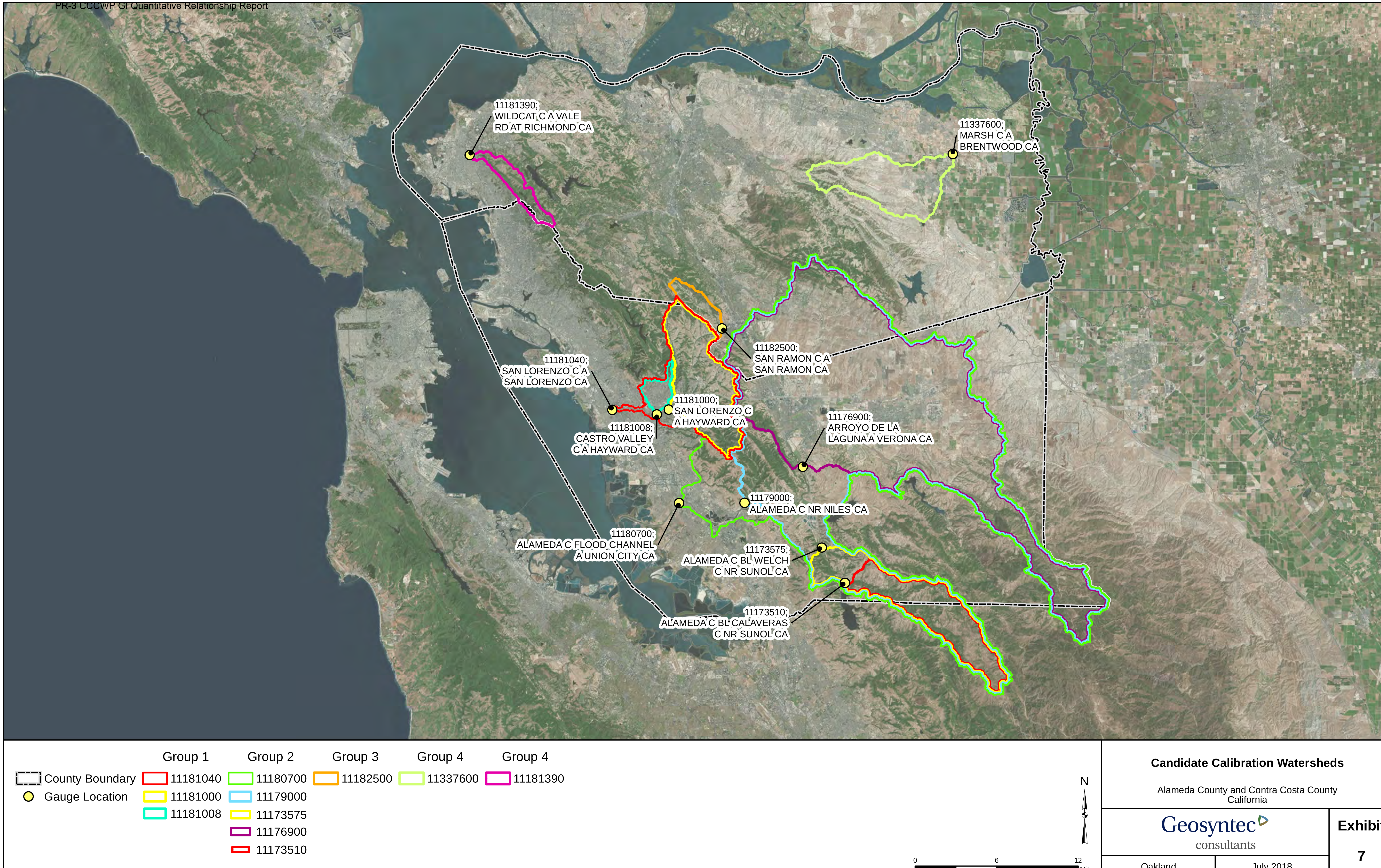


**Candidate Calibration Watersheds**

Alameda County and Contra Costa County
California

Geosyntec consultants

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Exhibit 7



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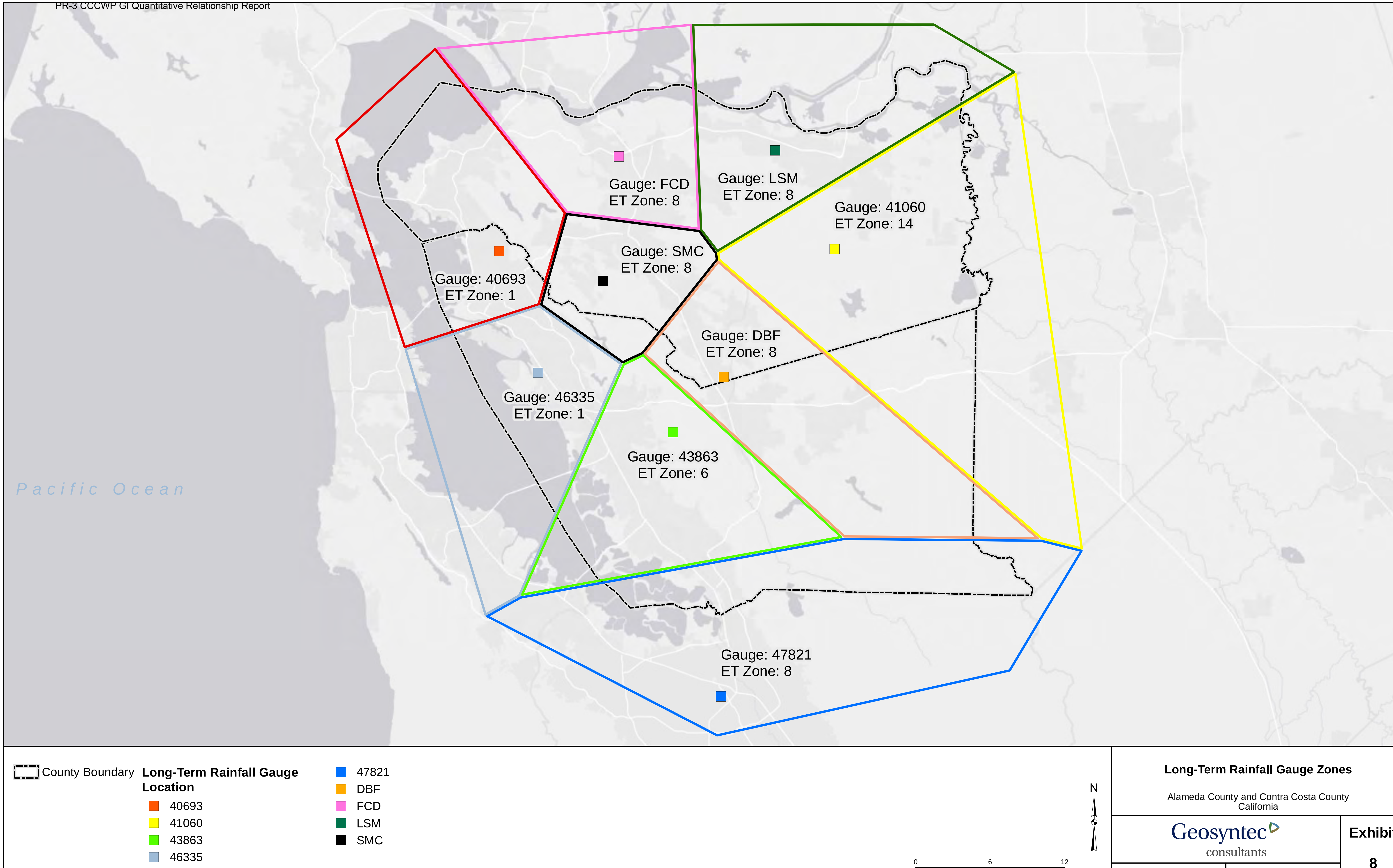


**Long-Term Rainfall Gauge Zones**

Alameda County and Contra Costa County
California

Geosyntec consultants

Oakland | July 2018

Exhibit 8



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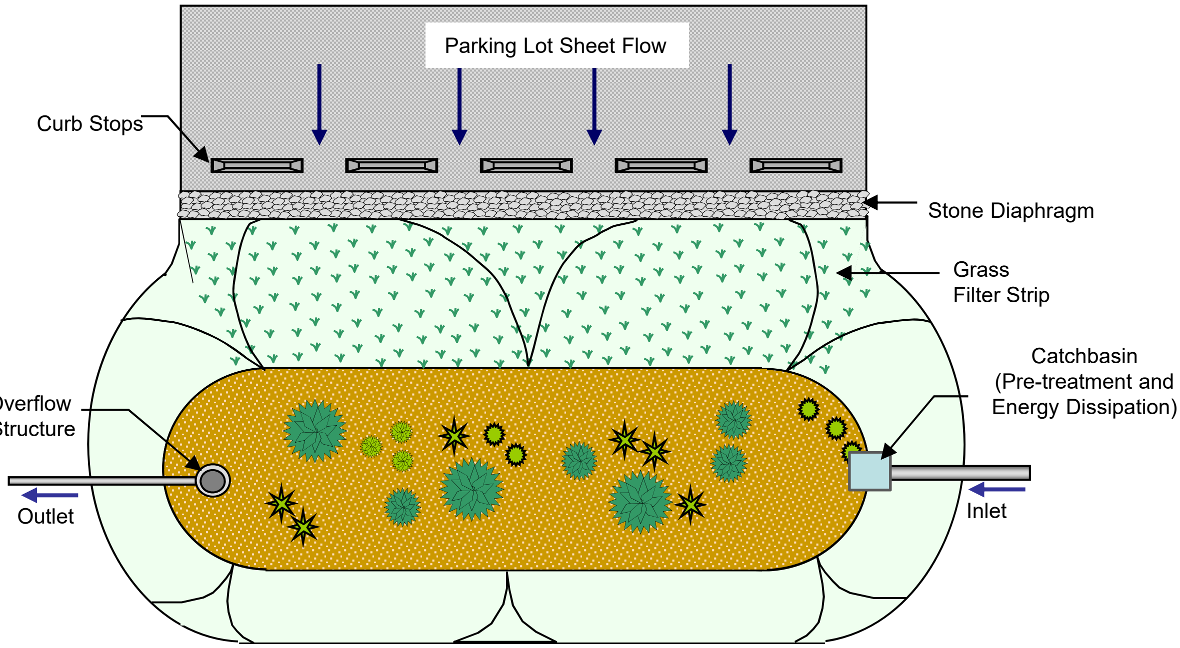
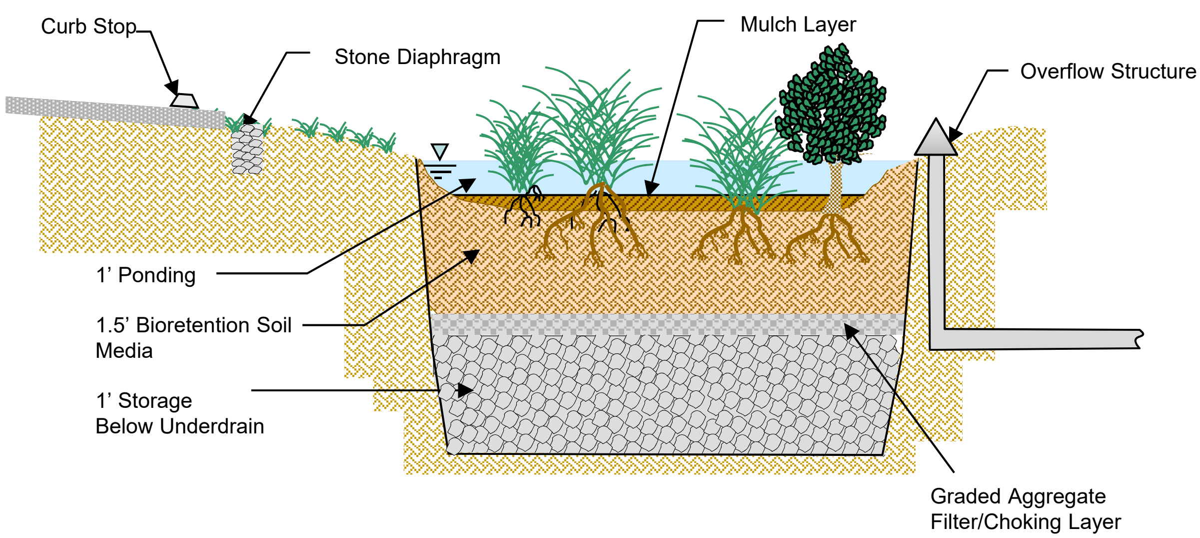
# Plan View



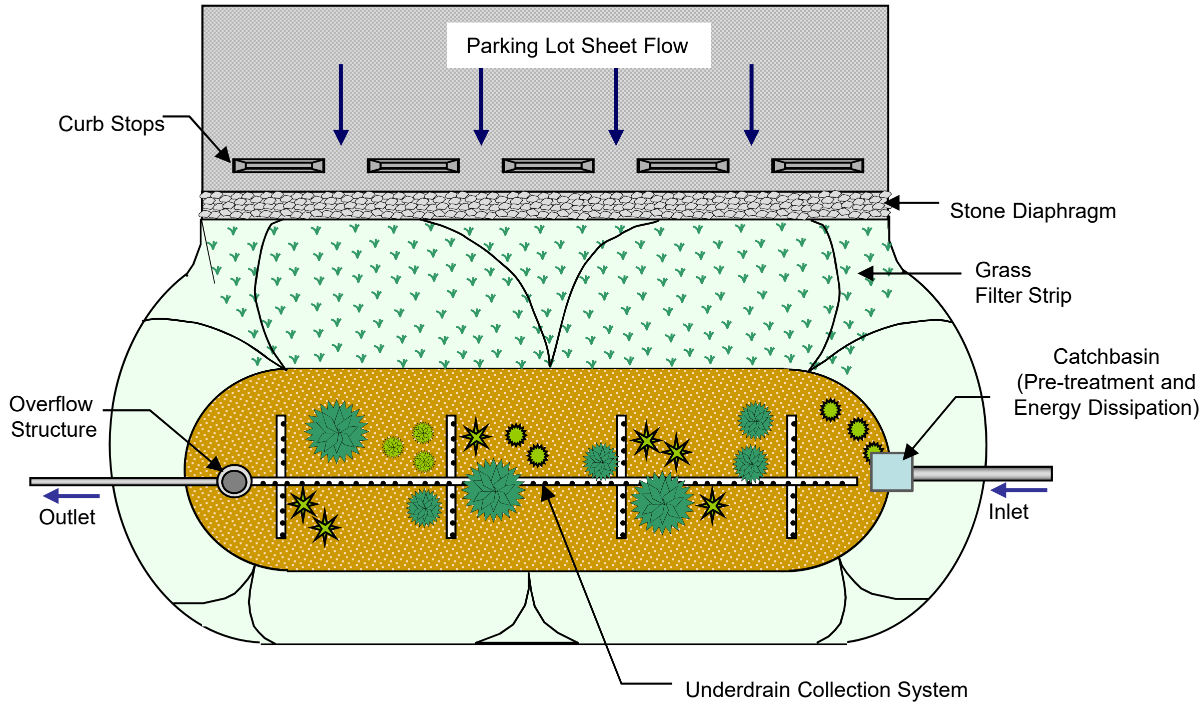

# Profile



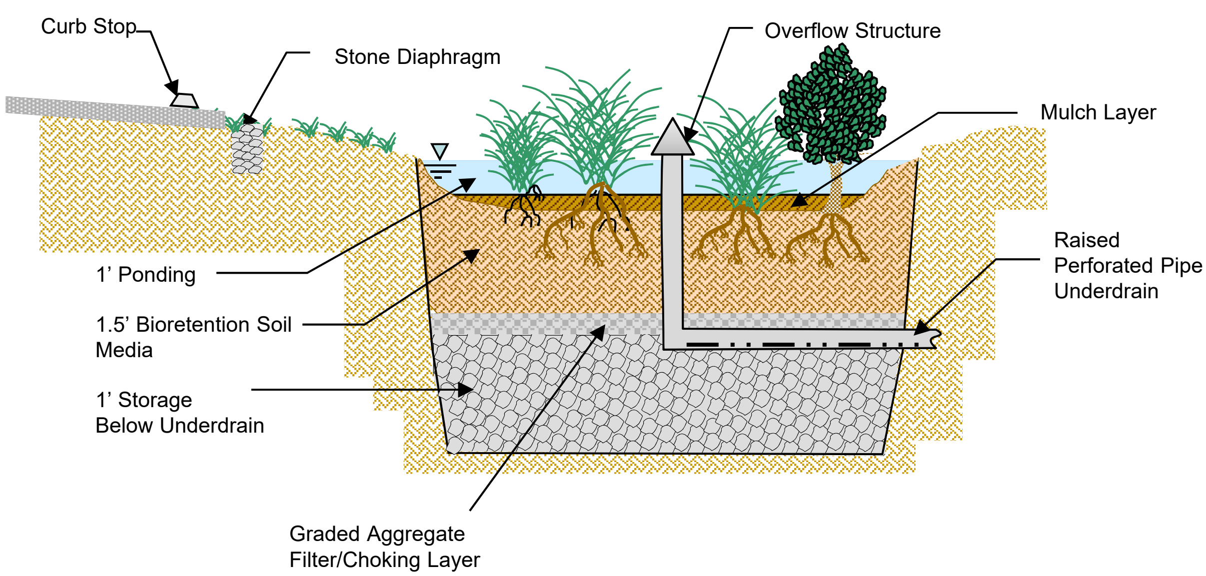

**Note: Plan and Profile views are not to scale**

| **Conceptual Illustration of an Infiltration Facility** | | |
|---|---|---|
| Geosyntec consultants | | Exhibit 9 |
| Oakland | July 2018 | |

# Plan View



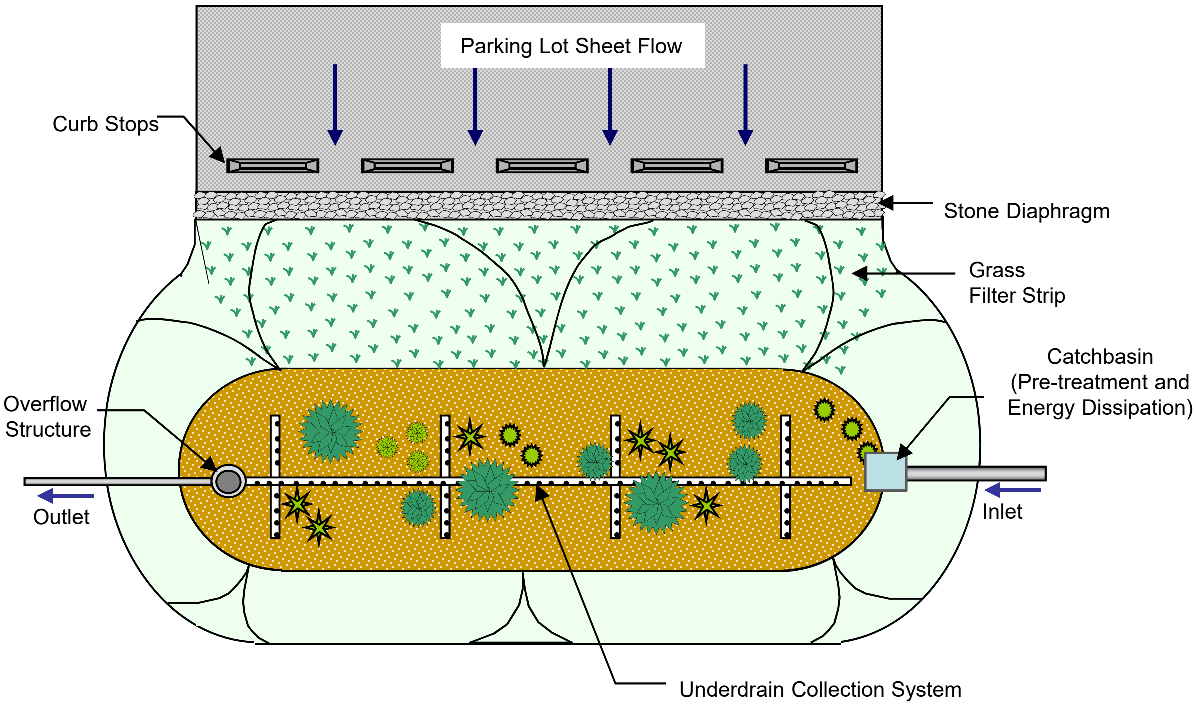

# Profile



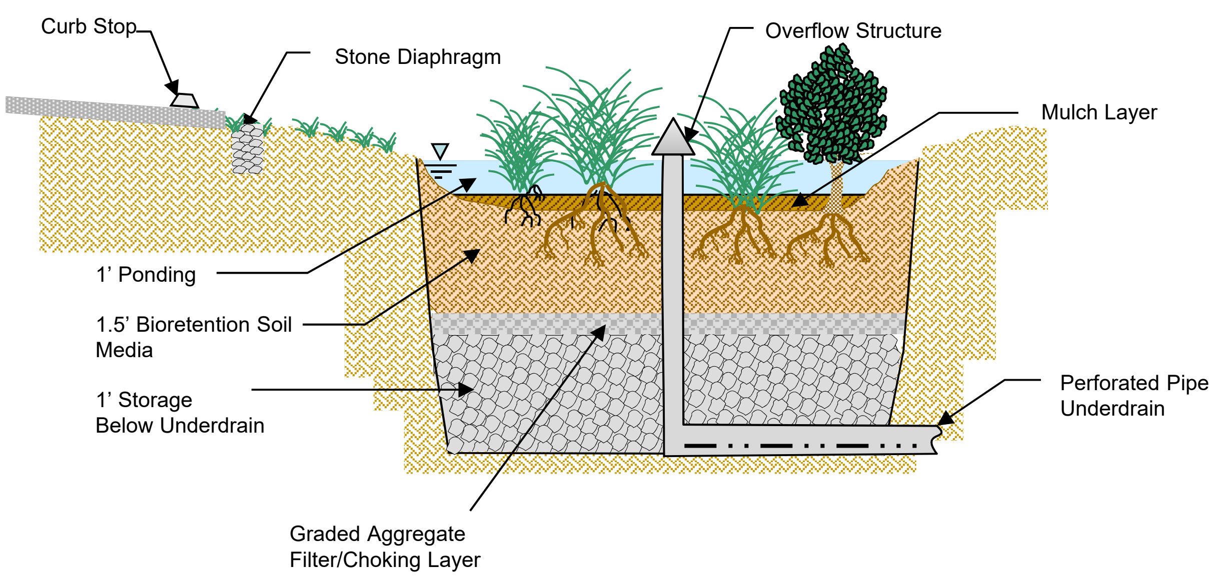

**Note: Plan and Profile views are not to scale**

| **Conceptual Illustration of a Bioretention/Bioinfiltration Facility** | | |
|---|---|---|
| Geosyntec consultants | | Exhibit 10 |
| Oakland | July 2018 | |

# Plan View




# Profile




**Note: Plan and Profile views are not to scale**

| **Conceptual Illustration of a Biofiltration Facility** | | |
|---|---|---|
| Geosyntec consultants | | Exhibit 11 |
| Oakland | July 2018 | |

# PR-4 USEPA Stormwater Management Model Manual Excerpts

falls directly on them and do not capture runoff from other impervious areas in their subcatchment.

The second approach allows LID controls to be strung along in series and also allows runoff from several different upstream subcatchments to be routed onto the LID subcatchment. If these single-LID subcatchments are carved out of existing subcatchments, then once again some adjustment of the Percent Impervious, Width and also the Area properties of the latter may be necessary. In addition, whenever an LID occupies the entire subcatchment the values assigned to the subcatchment's standard surface properties (such as imperviousness, slope, roughness, etc.) are overridden by those that pertain to the LID unit.

Normally both surface and drain outflows from LID units are routed to the same outlet location assigned to the parent subcatchment. However one can choose to return all LID outflow to the pervious area of the parent subcatchment and/or route the drain outflow to a separate designated outlet. (When both of these options are chosen, only the surface outflow is returned to the pervious sub-area.)

## 3.4 Computational Methods

SWMM is a physically based, discrete-time simulation model. It employs principles of conservation of mass, energy, and momentum wherever appropriate. This section briefly describes the methods SWMM uses to model stormwater runoff quantity and quality through the following physical processes:

- Surface Runoff
- Groundwater
- Flow Routing
- Water Quality Routing
- Infiltration
- Snowmelt
- Surface Ponding

### 3.4.1 Surface Runoff

The conceptual view of surface runoff used by SWMM is illustrated in Figure 3-7 below. Each subcatchment surface is treated as a nonlinear reservoir. Inflow comes from precipitation and any designated upstream subcatchments. There are several outflows, including infiltration, evaporation, and surface runoff. The capacity of this "reservoir" is the maximum depression storage, which is the maximum surface storage provided by ponding, surface wetting, and interception. Surface runoff per unit area, Q, occurs only when the depth of water in the "reservoir" exceeds the maximum depression storage, $d_s$, in which case the outflow is given by Manning's equation. Depth of water over the subcatchment (d) is continuously updated with time by solving numerically a water balance equation over the subcatchment.

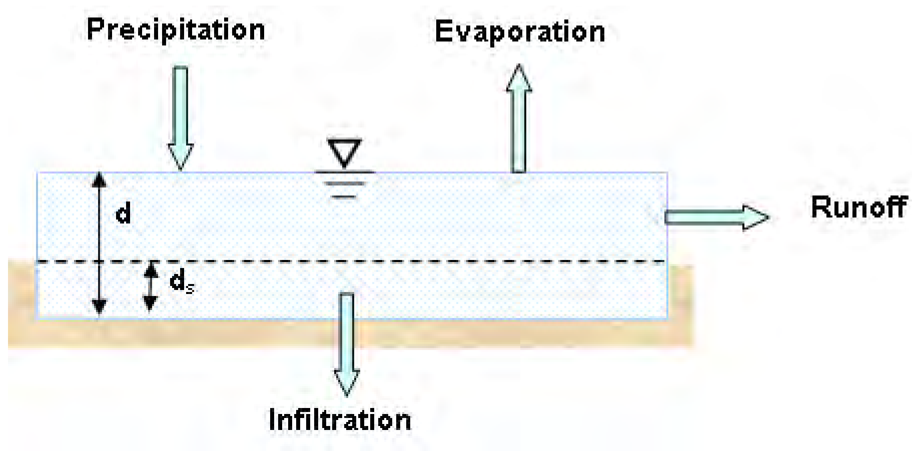



**Figure 3-7 Conceptual view of surface runoff**

### 3.4.2 Infiltration

Infiltration is the process of rainfall penetrating the ground surface into the unsaturated soil zone of pervious subcatchments areas. SWMM offers four choices for modeling infiltration:

**Horton's Method**

This method is based on empirical observations showing that infiltration decreases exponentially from an initial maximum rate to some minimum rate over the course of a long rainfall event. Input parameters required by this method include the maximum and minimum infiltration rates, a decay coefficient that describes how fast the rate decreases over time, and a time it takes a fully saturated soil to completely dry.

**Modified Horton Method**

This is a modified version of the classical Horton Method that uses the cumulative infiltration in excess of the minimum rate as its state variable (instead of time along the Horton curve), providing a more accurate infiltration estimate when low rainfall intensities occur. It uses the same input parameters as does the traditional Horton Method.

**Green-Ampt Method**

This method for modeling infiltration assumes that a sharp wetting front exists in the soil column, separating soil with some initial moisture content below from saturated soil above. The input parameters required are the initial moisture deficit of the soil, the soil's hydraulic conductivity, and the suction head at the wetting front. The recovery rate of moisture deficit during dry periods is empirically related to the hydraulic conductivity.

**Modified Green-Ampt Method**

This method modifies the original Green-Ampt procedure by not depleting moisture deficit in the top surface layer of soil during initial periods of low rainfall as was done in the original method. This change can produce more realistic infiltration behavior for storms with long initial periods where the rainfall intensity is below the soil’s saturated hydraulic conductivity.

**Curve Number Method**

This approach is adopted from the NRCS (SCS) Curve Number method for estimating runoff. It assumes that the total infiltration capacity of a soil can be found from the soil's tabulated Curve Number. During a rain event this capacity is depleted as a function of cumulative rainfall and remaining capacity. The input parameters for this method are the curve number and the time it takes a fully saturated soil to completely dry.

SWMM also allows the infiltration recovery rate to be adjusted by a fixed amount on a monthly basis to account for seasonal variation in such factors as evaporation rates and groundwater levels. This optional monthly soil recovery pattern is specified as part of a project's Evaporation data.

### 3.4.3 Groundwater

Figure 3-8 is a definitional sketch of the two-zone groundwater model that is used in SWMM. The upper zone is unsaturated with a variable moisture content of $\theta$. The lower zone is fully saturated and therefore its moisture content is fixed at the soil porosity $\phi$. The fluxes shown in the figure, expressed as volume per unit area per unit time, consist of the following:

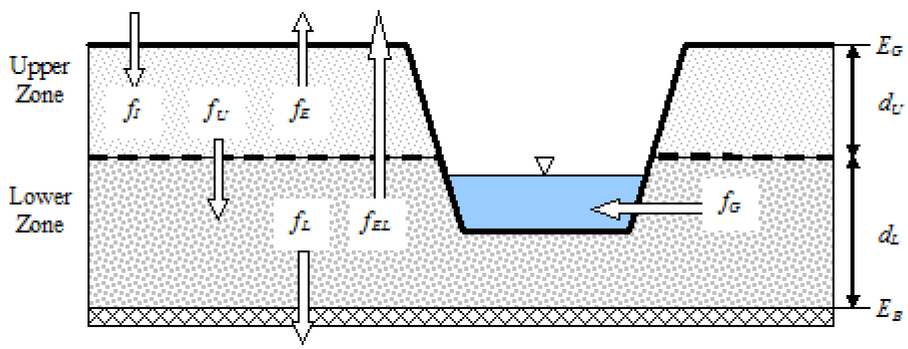



**Figure 3-8 Two-zone groundwater model**

**$f_I$** infiltration from the surface

**$f_{EU}$** evapotranspiration from the upper zone which is a fixed fraction of the un-used surface evaporation

**$f_U$** percolation from the upper to lower zone which depends on the upper zone moisture content $\theta$ and depth **$d_U$**

**$f_{EL}$** evapotranspiration from the lower zone, which is a function of the depth of the upper zone **$d_U$**

**$f_L$** seepage from the lower zone to deep groundwater which depends on the lower zone depth **$d_L$**

**$f_G$** lateral groundwater interflow to the drainage system, which depends on the lower zone depth **$d_L$** as well as the depth in the receiving channel or node.

where C = IMD . S, ft of water,
t = time, sec, and
1,2 = subscripts for start and end of time interval respectively.

This equation must be solved iteratively for $F_2$, the cumulative infiltration at the end of the time step. A Newton-Raphson routine is used.

The infiltration volume during time step $(t_2 - t_1)$ is thus $(t_2 - t_1) \times i$ if the surface does not saturate and $(F_2 - F_1)$ if saturation has previously occurred and a sufficient water supply is at the surface. If saturation occurs during the time interval, the infiltration volumes over each stage of the process within the time steps are calculated and summed. When rainfall ends (or falls below infiltration capacity) any water ponded on the surface is allowed to infiltrate and added to the cumulative infiltration volume.

**Recovery of Infiltration Capacity (Redistribution)**

Evaporation, subsurface drainage, and moisture redistribution between rainfall events decrease the soil moisture content in the upper soil zone and increase the infiltration capacity of the soil. The processes involved are complex and depend on many factors. In SWMM a simple empirical routine is used as outlined below; commonly used units are given in the equations to make the description easier to understand.

Infiltration is usually dominated by conditions in the uppermost layer of the soil. The thickness of this layer depends on the soil type; for a sandy soil it could be several inches, for a heavy clay it could be less. The equation used to determine the thickness of the layer is:

$$L = 4 \cdot \sqrt{K_s} \qquad (20\text{-}73)$$

where L = thickness of layer, in, and
$K_s$ = saturated hydraulic conductivity, in/hr.

Thus for a high $K_s$ of 0.5 in/hr (12.7 mm/hr) the thickness is 2.83 inches (71.8 mm). For a soil with a low hydraulic conductivity, say $K_s$ = 0.1 in/hr (2.5 mm/hr), the computed thickness is 1.26 inches (32.1 mm).

A depletion factor is applied to the soil moisture during all time steps for which there is no infiltration from rainfall or depression storage. This factor is indirectly related again to the saturated hydraulic conductivity of the soil and is calculated by:

$$DF = \frac{L}{300} \qquad (20\text{-}74)$$

where DF = depletion factor, $hr^{-1}$, and



L = depth of upper zone, in.

Hence, for $K_s$ = 0.5 in/hr (12.7 mm/hr), DF = 0.9% per hour; for $K_s$ = 0.1 in/hr (2.5 mm/hr) DF = 0.4% per hour. The depletion volume (DV) per time step is then:

$$DV = DF \cdot FU_{max} \cdot \Delta t \qquad (20\text{-}75)$$

where $FU_{max}$ = L · $IMD_{max}$ = saturated moisture content of the upper zone, in,
$IDM_{max}$ = maximum initial moisture deficit, in/in, and
$\Delta t$ = time step, hr.

The computations used are:

$$FU = FU - DV \quad for \quad FU \geq 0 \qquad (20\text{-}76)$$

$$F = F - DV \quad for \quad F \geq 0 \qquad (20\text{-}77)$$

where FU = current moisture content of upper zone, in, and
F = cumulative infiltration volume for this event, in.

To use the Green-Ampt infiltration model in continuous SWMM, it is necessary to choose a time interval after which further rainfall will be considered as pn independent event. This time is computed as:

$$T = \frac{6}{100 \cdot DF} \qquad (20\text{-}78)$$

where T = time interval for independent event, hr.

For example, when $K_s$ = 0.5 in/hr (12.7 mm/hr) the time between independent events as given in the last equation is 6.4 hr; when $K_s$ = 0.1 in/hr (2.5 mm/hr) the time is 14.3 hr. After time T has elapsed the variable F is set to zero, ready for the next event. The moisture remaining in the upper zone of the soil is then redistributed (diminished) at each time step by the two previous equations in order to update the current moisture deficit (IMD). The deficit is allowed to increase up to its maximum value ($IMD_{max}$, an input parameter) over prolonged dry periods. The equation used is

$$IMD = \frac{FU_{max} - FU}{L} \; for \; IMD \leq IMD_{max} \qquad (20\text{-}79)$$

When light rainfall $(i \leq K_s)$ occurs during the redistribution period, the upper zone moisture storage, FU, is increased by the infiltrated rainfall volume and IMD is again updated using the last equation.

Guidelines for estimating parameter values for the Green-Ampt model are given elsewhere in this manual. As is also the case for the Horton equation, different soil types can be modelled for different subcatchments.

**Program Variables**

The infiltration computations are performed in subroutines WSHED and GAMP in the RUNOFF Module. Correspondence of program variables to those of this subsection is as follows:

| | |
|---|---|
| S = SUCT(J) | L = UL(J) |
| $IMD_{max}$ = SMDMAX (J) | DF = DF(J) |
| $K_s$ = HYDCON(J) | i = RI |
| $FU_{max}$ = FUMAX(J) | t = time |
| FU = FU(J) | $\Delta t$ = DELT |
| IMD = SMD(J) | DV = DEP |
| F = F(J) | $F_s$ = FS |

### 20.5.4 Green-Ampt Infiltration Input Data

Although not as well known as the Horton equation, the Green-Ampt equation (1911) has the advantage of physically based parameters that, in principle, can be predicted a priori. The Mein-Larson (1973) formulation of the Green-Ampt equation is a two-stage model. The first step predicts the volume of water, $F_s$ which will infiltrate before the surface becomes saturated. From this point onward, infiltration capacity, $f_p$, is predicted directly by the Green-Ampt equation. Thus,

$$For\ F < F_s : f = i\ and\ F_s = \frac{S_u\ IMD}{i / K_s - 1}\ for\ i > K_s; \tag{20-80}$$

No calculation of $F_s$ for $i \leq K_s$.

$$For\ F \geq F_s : f = f_p\ and\ f_p = K_s(1 + \frac{S_u\ IMD}{F}) \tag{20-81}$$

where
- $f$ = infiltration rate, ft/sec,
- $f_p$ = infiltration capacity, ft/sec,
- $i$ = rainfall intensity, ft/sec,
- $F$ = cumulative infiltration volume, this event, ft,
- $F_s$ = cumulative infiltration volume required to cause surface saturation, ft,
- $S_u$ = average capillary suction at the wetting front (SUCT), ft water,
- IMD = initial moisture deficit for this event (SMDMAX), ft/ft, and

# PR-5 Alameda Countywide Clean Water Program and Contra Costa Clean Water Program Reasonable Assurance Analysis Model Calibration and Validation Memo

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# Memorandum

| | |
|---|---|
| Date: | November 13, 2019 |
| To: | Jim Scanlin, Alameda Countywide Clean Water Program, and Courtney Riddle, Contra Costa Clean Water Program |
| Copy: | Karin Graves and Lucile Paquette, Contra Costa Clean Water Program |
| From: | Kelly Havens, Senior Engineer, Austin Orr, Engineer, Lisa Austin, Principal, and Marc Leisenring, Principal |
| Subject: | Alameda Countywide Clean Water Program and Contra Costa Clean Water Program Reasonable Assurance Analysis Model Calibration and Validation<br>Geosyntec Project Numbers: WW2127 and WW2407 |

## 1. INTRODUCTION

This memorandum provides an expanded description and summary results for the calibration and validation conducted as for the development of the Alameda Countywide Clean Water Program (ACCWP) and Contra Costa Clean Water Program (CCCWP) Reasonable Assurance Analysis (RAA) model. This memorandum provides additional information to that provided in the Alameda Countywide Clean Water Program Quantitative Relationship Between Green Infrastructure Implementation and PCBs/Mercury Load Reductions Report and the Contra Costa Clean Water Program Quantitative Relationship Between Green Infrastructure Implementation and PCBs/Mercury Load Reductions Report (i.e., "GI Quantitative Relationship Reports"; ACCWP, 2018 [PR-2] and CCCWP, 2018 [PR-3]) for the purpose of peer review. As such, this memorandum references information and sections in those reports.

## 2. CALIBRATION APPROACH AND PARAMETERS

As described in the GI Quantitative Relationship Reports [PR-2; PR-3], the baseline pollutant loading model utilized for the RAA is based on continuous simulation hydrology model run in EPA's Stormwater Management Model (SWMM) version 5.1, combined with land use-based runoff concentrations to obtain the average annual loading of mercury and PCBs in stormwater runoff from Alameda and Contra Costa counties during the TMDL baseline period (i.e., 2003 – 2005). The hydrologic model utilizes generic hydrologic response units (HRUs), as described in Sections 2.2.1 and 3.1.1 of the GI Quantitative Relationship Reports [PR-2; PR-3]. Calibration of the generic HRU models was conducted on the average annual discharge volume for water years

(WYs) 2000-2009, utilizing available stream flow records. The objective of the calibration was to reasonably match the average annual runoff volume for this 10-year period.

The acceptable percent difference between simulated and observed annual volumes included in the *Bay Area RAA Guidance Document* (BASMAA, 2017) are provided in Table 1 below. These ranges were used to verify model results and evaluate whether parameters have been adequately calibrated.

**Table 1: Allowable Difference between Simulated and Observed Annual Volumes**

| Model parameters | Average % difference between simulated annual results and observed data | | |
|---|---|---|---|
| | Very Good | Good | Fair (lower bound, upper bound) |
| Hydrology/Flow | <10 | 10-15 | 15-25 |

A summary of the observed data and the parameters used to conduct the calibration with the simulated (modeled) results are provided in the following subsections.

## 2.1 Observed Data

### 2.1.1 Flow Gauges Used for Calibration

A list of candidate flow gauge sites were identified for potential use in calibration in the GI Quantitative Relationship Reports [PR-2; PR-3]. For the purposes of calibration, the candidate gauge sites that were identified in the GI Quantitative Relationship Reports included stream depth rating curves and daily mean records for the WY 2000 – 2009 period, and all are USGS gauges. The flow gauges used in calibration are summarized in Table 2 and shown in Figure PR-5A (all figures are provided at the end of the memo).

**Table 2: Flow Gauges Used for RAA Model Calibration**

| Gauge ID | Gauge Name | Location | County | Data Frequency |
|---|---|---|---|---|
| 11182500 | San Ramon Creek | San Ramon | Contra Costa | Daily |
| 11181390 | Wildcat Creek[1] | Richmond / San Pablo | Contra Costa | Daily |
| 11181040 | San Lorenzo Creek | San Lorenzo | Alameda | Daily |
| 11181008 | Castro Valley Creek | Hayward | Alameda | Daily |
| 11181000 | San Lorenzo Creek | Hayward | Alameda | Daily |
| 11180700 | Alameda Creek Flood Channel | Union City | Alameda | Daily |
| 11179000 | Alameda Creek | Fremont | Alameda | Daily |
| 11176900 | Arroyo de la Laguna | Verona | Alameda | Daily |

1. The Wildcat Creek gauge record is incomplete and contains data only for the four-year period WY 2006-2009. Geosyntec used the available years of gauge data to inform the calibration effort, but it was not ultimately used to assess the overall fitness of the model at representing the RAA baseline period regional hydrology.

Three other gauges were identified for potential use in calibration in the GI Quantitative Relationship Reports, but were ultimately not used for calibration, as described below. These included:

- Gauge number 11337600, Marsh Creek, which had considerable quantities of dry weather flows recorded with significant variability, such that baseflow removal techniques were not successful in isolating flows associated with rainfall;

- Gauge number 11173575, Alameda Creek Below Welch Creek, which contained significant data gaps in the record, as well as erratic stream flows likely caused by dam influence; and

- Gauge number 11173510, Alameda Creek Below Calaveras Creek, which contained significant data gaps in the record, as well as erratic stream flows likely caused by dam influence.

Given the data availability, calibration was conducted for both Alameda County and Contra Costa County areas simultaneously.

The area tributary to each flow gauge was delineated using the USGS StreamStats online tool (U.S. Geological Survey, 2016). These delineations were intersected with the HRU layer to select generic HRU’s from across the two counties for use in the calibration, including multiple different rainfall and climate zones, soil classifications, surface slopes, and land uses. The watershed areas tributary to the gauges used are shown in Figure PR-5A and summarized in Table 3.

**Table 3: Calibration Watershed Tributary Area Characteristics**

| Gauge ID | Gauge Name | Area (acres) | Percent Developed | Percent Impervious |
|---|---|---|---|---|
| 11182500 | San Ramon Creek | 3,878 | 21% | 2% |
| 11181390 | Wildcat Creek | 4,999 | 22% | 5% |
| 11181040 | San Lorenzo Creek | 29,989 | 38% | 12% |
| 11181008 | Castro Valley Creek | 3,531 | 93% | 44% |
| 11181000 | San Lorenzo Creek | 24,203 | 24% | 5% |
| 11180700 | Alameda Creek Flood Channel | 237,946 | 29% | 10% |
| 11179000 | Alameda Creek | 224,072 | 28% | 9% |
| 11176900 | Arroyo de la Laguna | 164,679 | 35% | 12% |

### 2.1.2 Baseflow Removal Process

Calibration of land surface runoff hydrology to stream gauge records requires that baseflow be computed and accounted for throughout the period of record, as the RAA model does not include storm flow routing, groundwater inflow/outflow, diversions, or reservoirs. Where baseflow constitutes a large percentage of total flow, baseflow accounting allows for isolation and calibration of just the flow gauge runoff response to a rainfall event, which is dependent on land surface features. A variety of methods exist for separating baseflow from runoff. For those flow gauges requiring baseflow separation, two methods were identified as appropriate for the flow gauges used for Alameda County and Contra Costa County RAA model calibration. The methods and gauge characteristics corresponding to the use of the method include:

1. Base-Flow Index (BFI) modified: BFI modified is a timeseries analysis which locates minimum values in the hydrograph over five-day increments. For each identified minimum, if 90% of its value is less than both adjacent minimums, it is identified as a hydrograph 'turning point'. The baseflow hydrograph is established by connecting the turning points with straight lines (Barlow et., al, 2015). This method was used to remove baseflow from calibration watersheds with appreciable development.
2. PART (short for partitioning): PART is an iterative timeseries analysis that identifies daily streamflow values that are not affected by surface runoff, assigns these values as baseflow, then removes baseflow from all days to compile the baseflow-corrected record used for surface runoff calibration. Daily streamflow values are identified as baseflow if they are preceded by N days of continuous streamflow recession (Barlow et., al, 2015); N is identified through the pattern of recession of streamflow measurements. This method was used to remove baseflow from large calibration watersheds influenced by significant impoundments.

The gauges for which no baseflow separation was conducted were estimated to have very little or no potential for baseflow to influence the calibration to mean annual volume since the streams are largely undeveloped, aren't actively managed with significant impoundments, and typically run dry in the month of September. The most appropriate method for separating baseflow was determined on a gauge-specific basis, depending on the variability in the flow record and the occurrence of confounding factors that affect baseflow such as dam releases and other dry weather inflows.

A summary of the baseflow separation method used for each flow gauge is provided in Table 4.

**Table 4: Calibration Flow Gauge Baseflow Removal Methods Used**

| Gauge ID | Gauge Name | Baseflow Separation and Removal Method | Notes | Total Watershed Area Including Impoundments (acres) | Impounded Area in Watershed (acres) |
|---|---|---|---|---|---|
| 11182500 | San Ramon Creek | No Baseflow Removal | Small, mostly undeveloped, typically dry in August or September | 3,878 | None |
| 11181390[1] | Wildcat Creek | No Baseflow Removal | Small, mostly undeveloped, typically dry in August or September. Data only available for WY 2006-2009 | 4,999 | None |
| 11181040 | San Lorenzo Creek | BFI Modified | Contains significant urban development | 29,989 | None |
| 11181008 | Castro Valley Creek | BFI Modified | Contains significant urban development | 3,531 | None |
| 11181000 | San Lorenzo Creek | No Baseflow Removal | Small, mostly undeveloped, typically dry in August or September | 24,203 | None |
| 11180700 | Alameda Creek Flood Channel | PART | Used only WY 2002, 2003, and 2005 – 2009 due to missing and erroneous data in other WYs. Large watershed with impoundments. | 418,788 | 180,809 |
| 11179000 | Alameda Creek | PART | Large watershed with impoundments. | 404,913 | 180,809 |
| 11176900 | Arroyo de la Laguna | BFI Modified | Contains significant urban development | 258,121 | 93,419 |

1. The USGS does not report discharge for this gauge more recently than 1996. Balance Hydrologics began recording measurements for this gauge in 2005; this record was used for WY2006-2009.

## 2.2 Modeled Results - Model Calibration Parameters

To conduct the calibration, modeled annual storm flow produced from the delineated watersheds draining to the stream gauges (see Figure PR-5A) was compared to annual flow in the stream gauge records, with baseflow separated as described in Section 2.1.2, for WYs 2000 – 2009. Modeled annual storm flow was predicted by area-weighting the runoff output from generic HRU models in proportion to the areas of those generic HRUs within the watersheds draining to the stream gauges.

HRU calibration parameters were adjusted in three phases. The first phase entailed establishing the general range and sensitivity of the hydrologic model to saturated soil hydraulic conductivity (Ksat) for HSG C and D type soils for the generic HRUs within the three undeveloped watersheds tributary to identified calibration flow gauges (see Tables 2, 3, and 4). The second phase involved exploring sensitivity to changes in soil infiltration recovery time for the identified range of Ksat values. The third phase incorporated soil parameter value combinations identified in the first two phases in models for all eight calibration watersheds. National Land Cover Dataset (NLCD) imperviousness data were initially considered as a calibration parameter but were not ultimately used (see further discussion in Section 2.2.3 below).

Identified model parameters were adjusted for each phase until the average percent difference between modeled and measured average annual storm flow volumes (with baseflow removed as described in Table 4) was less than 25% - the acceptable range as summarized in Table 1. Once the average percent difference for all the calibration watersheds were within the acceptable range, the HRU model parameters were finalized.

### 2.2.1 Soil Hydraulic Conductivity

Soil Ksat was primarily calibrated in the watersheds draining to flow gauges 11182500 (San Ramon Creek), 11181390 (Wildcat Creek), and 11181000 (San Lorenzo Creek) because these watersheds are primarily undeveloped and thus provide greater isolation of the pervious area runoff and loss response to rainfall. Given the percent total area of hydrologic soil group (HSG) C and D type soils in these watersheds, soil Ksat was adjusted only for HSG types C and D. The Ksat for soil groups A and B were assigned by area-weighting literature values corresponding with the texture classes that are present within Alameda County and Contra Costa County. It was found that adjusting HSG A and B Ksat model input values resulted in minimal changes to average annual volume in the watersheds given that A and B type soils each cover less than 5% of the Alameda County and Contra Costa County areas modeled.

### 2.2.2 Soil Recovery Pattern

The same three watersheds used for Ksat calibration were also used to calibrate soil recovery time. This parameter is associated with the soil drying effects caused by evapotranspiration and determines how many days it takes for a soil to recover its full infiltrative capacity during the dry period following a rainfall event. In SWMM, this parameter is a function of both the subbasin's Ksat and expected soil recovery time and can be defined on a monthly basis as part of the climatological parameters. See SWMM5 Users Guide 13$^{th}$ Edition pg. 462-463 (James et., al, 2010; provided in PR-4) for information on the Green Ampt Equation and the Recovery of Infiltration Capacity.

#### 2.2.3 Calibration for Developed Watersheds

Imperviousness (associated with specific Association of Bay Area Governments [ABAG] land use types, see Section 3.1.1. of the GI Quantitative Relationship Reports [PR-2; PR-3]) was considered as a parameter for calibration, but NLCD-derived imperviousness was found to produce modeled results within the acceptable range, so no adjustment to imperviousness was applied as part of calibration. Imperviousness values were assigned for each individual polygon in the ABAG 2005 Geospatial Information System (GIS) dataset by area-weighting the NLCD 2006 imperviousness values associated with the polygon. Each parcel and right-of-way (ROW) segment had roughly the same spatial resolution.

Soil parameters calibrated to undeveloped watersheds were adjusted for soil compaction assumed to occur during development (see Section 3.1.1 of the GI Quantitative Relationship Reports [PR-2; PR-3]) and were used to develop area-weighted average annual HRU runoff output for the other more developed and impervious watersheds associated with identified flow gauges. Coupled with the NLCD-derived imperviousness method for identifying representative HRUs for the watersheds, these calibrated soil parameters were found to produce results within the acceptable calibration range for the more developed and impervious watersheds used for calibration.

# 3. CALIBRATION RESULTS

## 3.1 Parameter Adjustment

To identify the region of best fit between modeled and measured average annual runoff for the identified calibration parameters, a large range of values were input into the generic HRU models representative of the areas within the calibration watersheds.

#### 3.1.1 Soil Hydraulic Conductivity and Recovery Time

Soil Ksat values between 0.025 – 0.35 inches per hour (in/hr) for HSG C and D soils were examined as part of the first phase of calibration. Varying combinations of Ksat values for the two soil types were tested for the undeveloped calibration watersheds. Each pair of parameters represent hundreds of individual continuous HRU SWMM models. This calibration exercise revealed that the best fit values for HSG C and D type soil in the three undeveloped calibration watersheds likely falls between 0.1 and 0.2 in/hr for HSG C soils, and between 0.05 and 0.125 in/hr for HSG D type soils.

This range of parameters was explored further in the second phase of calibration, in which soil recovery time was adjusted for three different values: 7 days, 14 days, and 18 days. The calibration percent difference results corresponding to the combinations of HSG C and D soil Ksat values and soil recovery times are shown in Figure PR-5B. Darker blue areas indicate a lower percent difference between modeled runoff volume and measured total discharge volume (with baseflow removed per Table 4) in the three undeveloped calibration watersheds. Over 11,800 continuous simulation HRU model runs were evaluated in order to create the grid of values, shown in Figure PR-5B.

The darkest blue areas of the three plots in Figure PR-5B indicate the least percentage difference between modeled and measured average annual runoff volume for all three undeveloped stream gauge records during the period from WY 2000 - 2009. The percentage difference in total annual average runoff volume is quite sensitive to changes in HSG C and D type soils for the range of Ksat values searched during this exercise, but the model is not very sensitive to soil recovery time as indicated by the small differences in the three plots.

From this calibration phase two investigation, it was identified that the most appropriate soil Ksat values ranged from 0.125 – 0.15 in/hr for HSG C soils, 0.075 – 0.1 in/hr for HSG D soils. A soil recovery pattern equivalent to a 14-day soil recovery time for HSG C soils was also identified to be the most appropriate for the calibration watersheds.

Phase three of the calibration used this tighter range of HSG C and D soil Ksat values to evaluate percent difference between average annual modeled runoff and measured discharge at all of the calibration gauges (as corrected for baseflow removal per Table 4). The best-fit soil Ksat parameters for all eight of the calibration gauges are shown in Table 5 below.

**Table 5: Final Soil Ksat Values for the Eight Calibration Gauge Tributary Watersheds**

| HSG | Undeveloped Soil Ksat (in/hr) | Developed Soil Ksat[1] (in/hr) |
|---|---|---|
| A[2] | 2.5 | 1.875 |
| B[2] | 0.3 | 0.225 |
| C | 0.15 | 0.1125 |
| D | 0.1 | 0.075 |

[1] Ksat is decreased by 25% to account for soil compaction expected to occur during development.

[2] Ksat assigned by area-weighting literature values corresponding with soil texture classes present in the areas modeled.

## 3.2 Resulting Percent Difference between Modeled and Measured Average Annual Runoff

Utilizing the calibrated parameter values described in Section 3.1 and summarized in Table 5, the percent difference between average annual modeled runoff and average annual measured runoff for the period of record (WY 2000 – 2009) was found to be within the required threshold (Table 1) for most of the watersheds examined, with the exception of the Wildcat Creek gauge (gauge number 11181390). This gauge has an incomplete record and contains data for only four years, from WY 2006-2009. The available data from this gauge was used to inform the calibration parameters, but given the incomplete record, the percent difference between measured and modeled average annual runoff volume was not ultimately used to assess the overall fitness of the RAA hydrologic model for the full baseline time period (WY 2000-2009).

The percent difference between average annual modeled runoff and measured runoff (accounting for baseflow corrections per Table 4) for the RAA baseline period from WY 2000-2009 for each calibration gauge is shown in Figure PR-5C. Since the entire decade was modeled, some individual years within the period of record varied more than the 25% threshold; however, these percent differences are offset between wet years and dry years to provide an acceptable percent difference between average annual modeled and measured values.

# 4. VALIDATION

Following completion of baseline hydrologic calibration, baseline loads were validated using pollutant monitoring data collected as part of the Regional Monitoring Program for Water Quality in San Francisco Bay (RMP; specifically, the Small Tributary Loading Strategy project) and the Surface Water Ambient Monitoring Program (SWAMP). Pollutant concentration data were obtained from the California Environmental Data Exchange Network (CEDEN). The validation analysis included 206 total PCBs and 291 total mercury results from various monitoring locations in Alameda and Contra Costa Counties with sample dates ranging from 2001 to 2014.

Samples were taken at load monitoring stations, mostly during wet weather. These stations are shown on Figures PR-5D (PCBs) and PR-5E (mercury) along with their respective watershed delineations. Where not provided by SFEI, watershed delineations were developed using the USGS StreamStats delineation tool (USGS, 2016). The land use composition of the validation watersheds is provided in Attachment A to this memo.

The validation exercise conducted combines the calibrated Contra Costa and Alameda County regional hydrology with the Regional Watershed Spreadsheet Model (RWSM) PCBs and mercury values estimated by SFEI (see section 2.1 and 2.2.2 of the GI Quantitative Relationship Reports [PR-2; PR-3] and Regional Watershed Spreadsheet Model Version 1.0 Results Summary Memorandum (Geosyntec, 2019). Because the RWSM concentrations used for the RAA water quality model are not modifiable for the regional RAA Modeling approaches, this validation exercise is purely qualitative, and is not expected to result in changes to the hydrologic or water quality model input parameters.

The validation process includes computing the area-weighted average annual runoff volume for each land use category within the validation watersheds and combining these results with the associated RWSM average annual pollutant concentration. The resulting land use-based pollutant loads are added together over all land uses to obtain the estimated average annual pollutant load for each validation watershed. This average annual pollutant load is divided by the average annual runoff volume for the validation watershed to obtain an average annual pollutant discharge concentration for each validation watershed. The values calculated from the model output were compared to monitoring data collected at the associated validation monitoring locations. Statistical summaries and the number of samples for PCBs and mercury concentrations measured at each validation monitoring location are shown in box plot format in Figure PR-5F and Figure PR-5G, respectively. The resulting average annual pollutant discharge concentration for each validation watershed is superimposed on the box plots of the measured values for comparison.

The modeled PCBs concentrations are within the expected ranges for the validation watersheds examined (see Figure PR-5F). In some cases, the model slightly overpredicts the PCBs concentration in runoff, notably in the Ettie Street and Zone 5 Line M watersheds, and in other cases, underpredicts, such as in the Santa Fe Channel watershed. This is expected given the highly variable spatial distribution of PCBs contamination and storm-to-storm variability in runoff characteristics. The differences are largely attributable to the use of the regionally-characteristic land use-based RWSM values for modeling PCBs runoff concentrations and comparing average annual concentrations computed from annualized loads and volumes.

The validation exercise for mercury included many more watersheds than for PCBs. In general, the modeled values for mercury concentration are significantly higher than the measured values (see Figure PR-5G). The present RWSM land use-based concentration values for mercury appear to overestimate the observed concentration of mercury in the monitored watersheds within Alameda County and Contra Costa County.

## 5. REFERENCES

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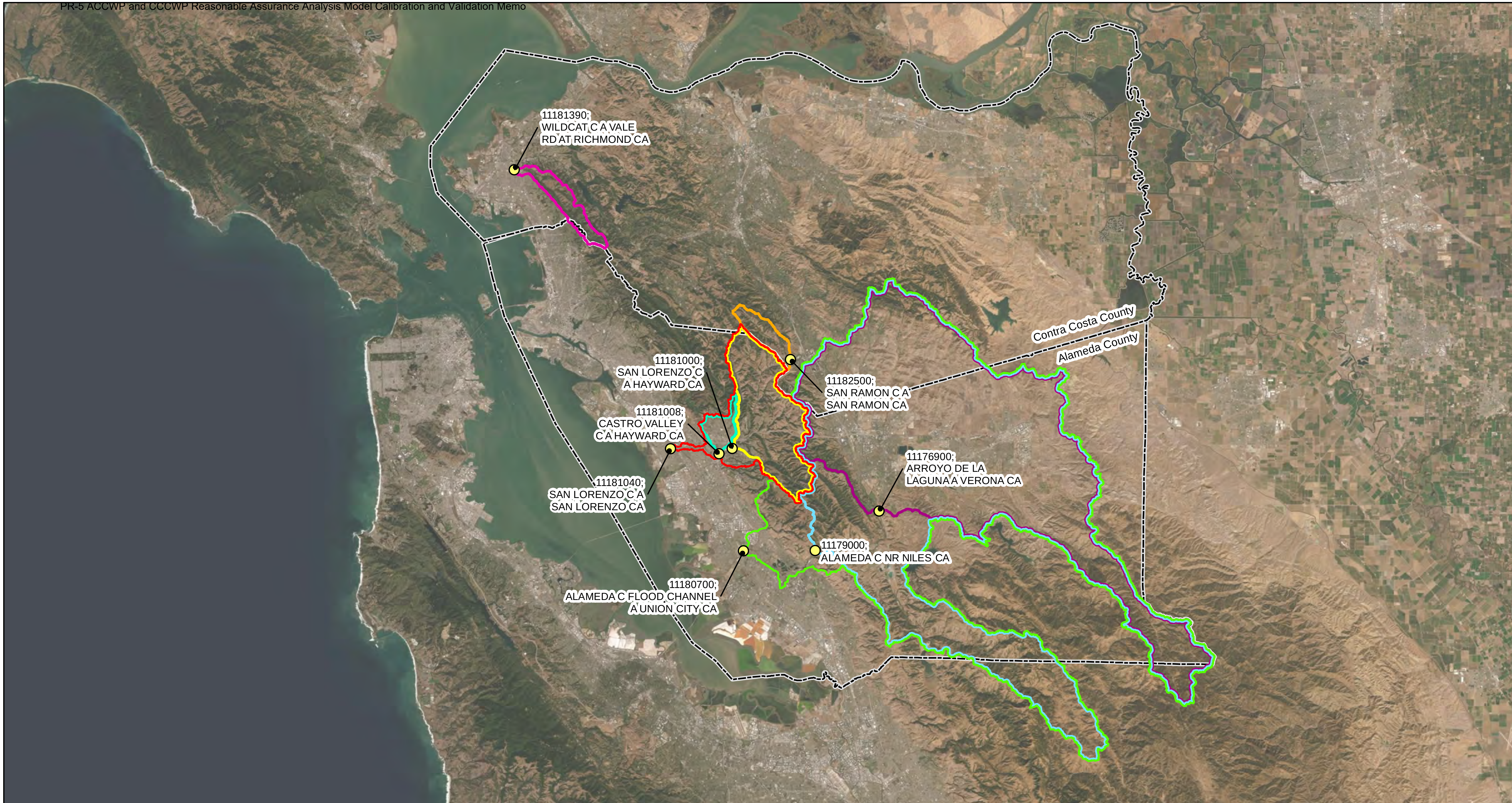
# Attachment

Alameda Countywide Clean Water Program and Contra Costa Clean Water Program Reasonable Assurance Analysis Model Calibration and Validation Memo
Attachment A: Land Use Breakdown, Validation Watersheds
November 8, 2019

| Validation Watershed | POC | Total Acres by Land Use | | | | | Total Acres | Percent Area by Land Use | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Old Industrial | Old Commercial/ Old Transportation | Old Residential | New Urban | Open Space | | Old Industrial | Old Commercial/ Old Transportation | Old Residential | New Urban | Open Space |
| Ettie Street Pump Station_A | PCBs and Hg | 356 | 187 | 580 | 47 | 13 | 1,183 | 30% | 16% | 49% | 4% | 1% |
| Santa Fe Channel-SFeCh | PCBs and Hg | 197 | 240 | 1,012 | 43 | 35 | 1,527 | 13% | 16% | 66% | 3% | 2% |
| Zone 5 Line M-Z5LM | PCBs and Hg | 162 | 79 | 645 | 100 | 858 | 1,843 | 9% | 4% | 35% | 5% | 47% |
| Hayward Ind Stdrn | PCBs and Hg | 82 | 312 | 495 | 118 | 14 | 1,021 | 8% | 31% | 48% | 12% | 1% |
| Meeker Slough | PCBs and Hg | 9 | 74 | 415 | 3 | 5 | 507 | 2% | 15% | 82% | <1% | <1% |
| San Leandro Creek | PCBs and Hg | 49 | 243 | 4,750 | 617 | 23,052 | 28,710 | <1% | <1% | 17% | 2% | 80% |
| San Lorenzo Creek | PCBs and Hg | 50 | 842 | 5,619 | 2,781 | 20,694 | 29,986 | <1% | 3% | 19% | 9% | 69% |
| Lower Marsh Creek | PCBs and Hg | 125 | | 1,113 | 6,034 | 67,837 | 75,109 | <1% | 0% | 1% | 8% | 90% |
| Walnut Creek | PCBs and Hg | 88 | 2,284 | 18,655 | 5,558 | 28,004 | 54,590 | <1% | 4% | 34% | 10% | 51% |
| Glen Echo Creek-GECr | PCBs and Hg | | 90 | 400 | 3 | 223 | 716 | 0% | 13% | 56% | <1% | 31% |
| Port Chicago Highway | Hg Only | 1,650 | 268 | 1,801 | 1,021 | 14,229 | 18,968 | 9% | 1% | 9% | 5% | 75% |
| Codornices at 2nd Street | Hg Only | 61 | 24 | 893 | 3 | 2 | 983 | 6% | 2% | 91% | <1% | <1% |
| Kirker Creek at Floodway | Hg Only | 23 | | 204 | 99 | 105 | 431 | 5% | 0% | 47% | 23% | 24% |
| El Charro | Hg Only | 981 | 1,027 | 2,792 | 4,653 | 44,201 | 53,654 | 2% | 2% | 5% | 9% | 82% |
| Cerrito at Creekside Park | Hg Only | 27 | 119 | 1,626 | 17 | 89 | 1,879 | 1% | 6% | 87% | <1% | 5% |
| Richmond Parkway | Hg Only | 36 | 165 | 868 | 47 | 4,382 | 5,497 | <1% | 3% | 16% | <1% | 80% |
| 3rd St. Bridge | Hg Only | 123 | 339 | 6,804 | 911 | 18,576 | 26,753 | <1% | 1% | 25% | 3% | 69% |
| Baxter at Booker | Hg Only | 1 | 65 | 541 | 2 | 83 | 692 | <1% | 9% | 78% | <1% | 12% |
| Above Vulcan Bridge Zone 7 | Hg Only | 28 | 96 | 1,078 | 414 | 26,592 | 28,209 | <1% | <1% | 4% | 1% | 94% |
| Arroyo Viejo Rec. Center | Hg Only | 2 | 130 | 1,841 | 64 | 1,400 | 3,438 | <1% | 4% | 54% | 2% | 41% |
| Cesar Chavez Park | Hg Only | 0 | 116 | 1,287 | 2 | 56 | 1,461 | 0% | 8% | 88% | <1% | 4% |
| Strawberry Creek Park | Hg Only | | 98 | 822 | 75 | 454 | 1,448 | 0% | 7% | 57% | 5% | 31% |
| Sausal at E.22nd | Hg Only | | 140 | 1,822 | 6 | 545 | 2,513 | 0% | 6% | 73% | <1% | 22% |
| Above Lake Temescal | Hg Only | | 37 | 817 | 49 | 202 | 1,105 | 0% | 3% | 74% | 4% | 18% |
| Kirker Creek Apartments | Hg Only | | 50 | | 10 | 3,497 | 3,558 | 0% | 1% | 0% | <1% | 98% |
| Mitchell on Oak St | Hg Only | | | 97 | 0 | 2,729 | 2,826 | 0% | 0% | 3% | 0% | 97% |

# Figures




**Legend**

County Boundaries

Flow Gauge Location

| San Lorenzo Ck. | Alameda Ck. | San Ramon Ck. | Wildcat Ck. |
|---|---|---|---|
| 11181040 | 11180700 | 11182500 | 11181390 |
| 11181000 | 11179000 | | |
| 11181008 | 11176900 | | |

**RAA Hydrologic Model Calibration**

Watersheds Tributary to Flow Gauges Used for Comparison

Alameda County and Contra Costa County
California

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Oakland | August 2019

**Figure PR-5A**



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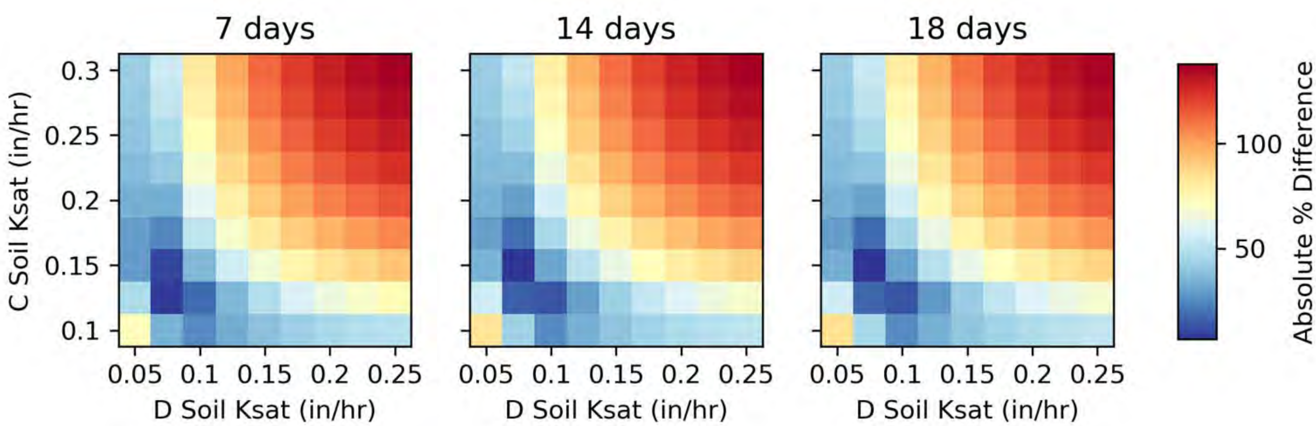


**Calibration Matrix for HSG C and D Soils and Soil Recovery Time**

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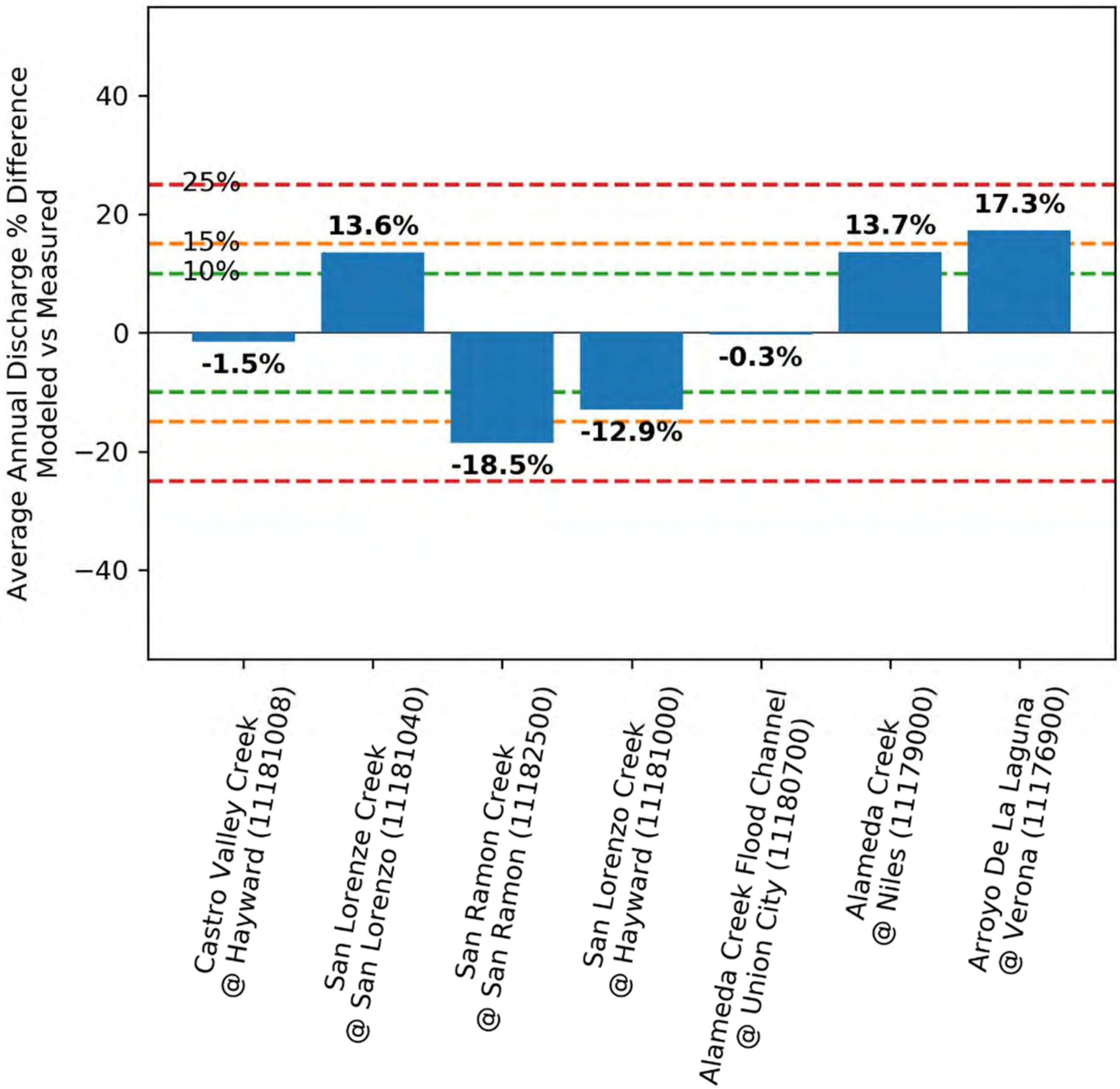
**Figure PR-5B**




**Percent Difference Between Modeled and Measured Average Annual Runoff Volume for Each Calibration Watershed**

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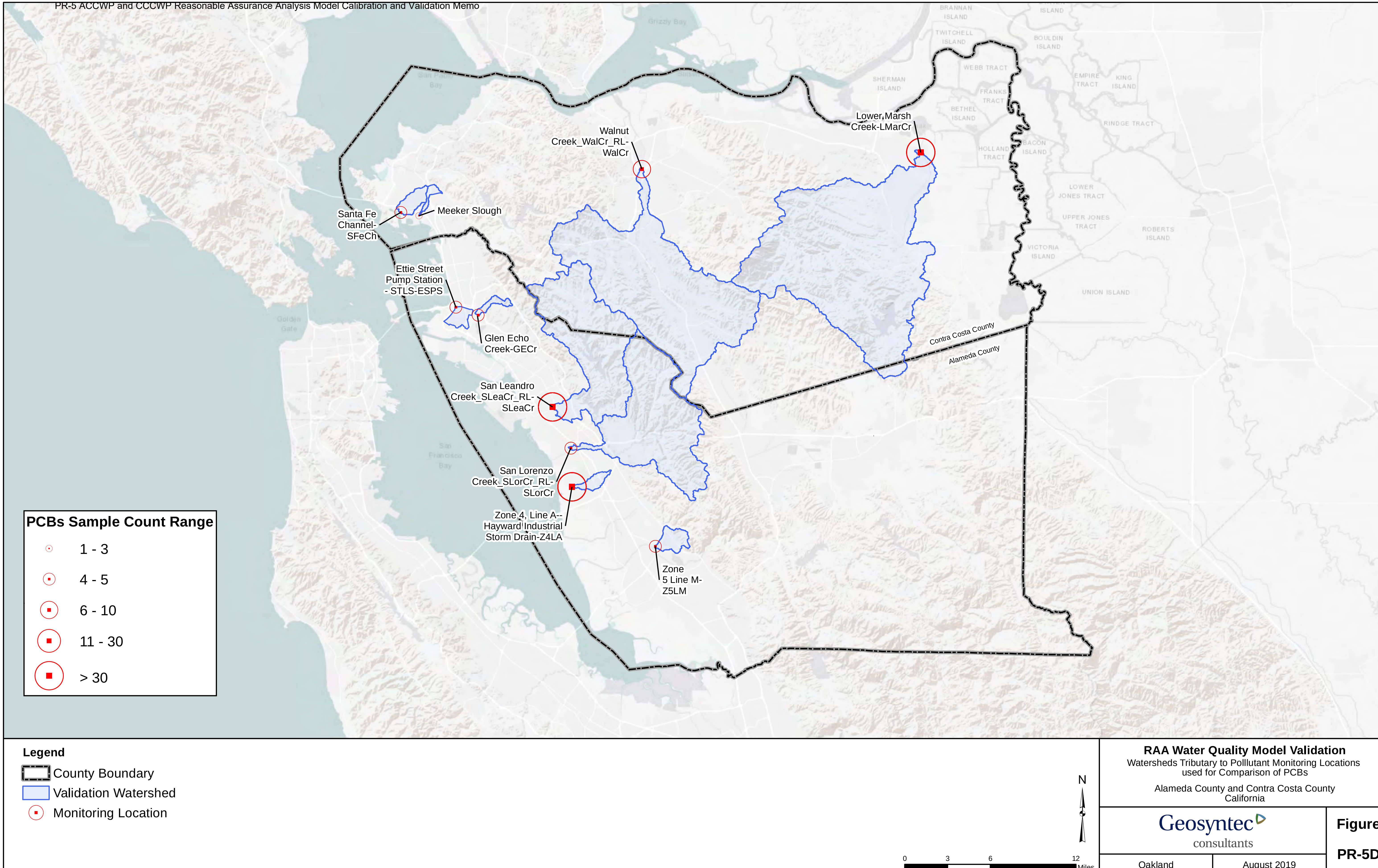
**Figure PR-5C**




RAA Water Quality Model Validation
Watersheds Tributary to Polllutant Monitoring Locations used for Comparison of PCBs
Alameda County and Contra Costa County California

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Figure PR-5D



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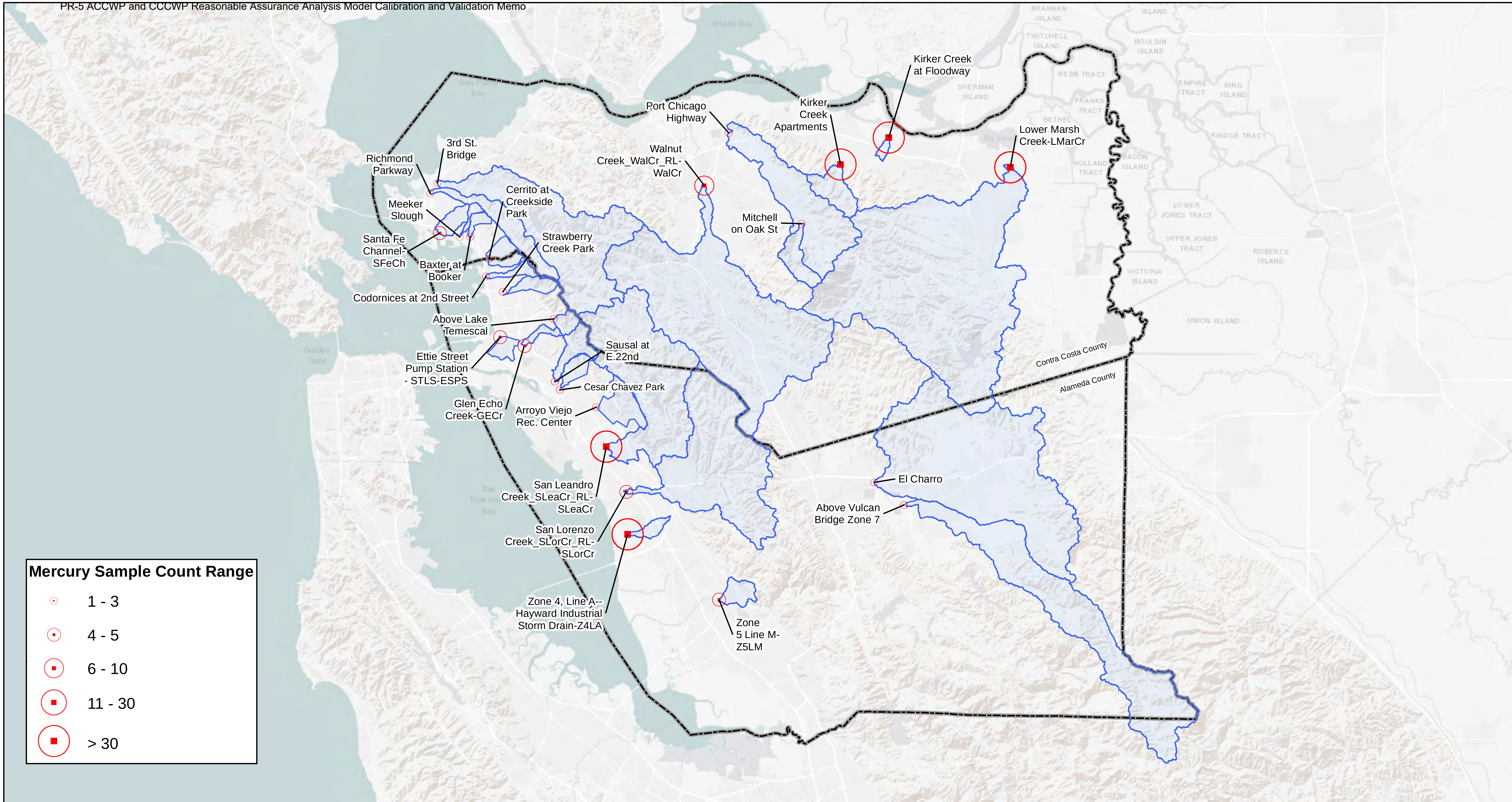


**Legend**

County Boundary

Validation Watershed

**RAA Water Quality Model Validation**

Watersheds Tributary to Polllutant Monitoring Locations used for Comparison of Mercury

Alameda County and Contra Costa County
California

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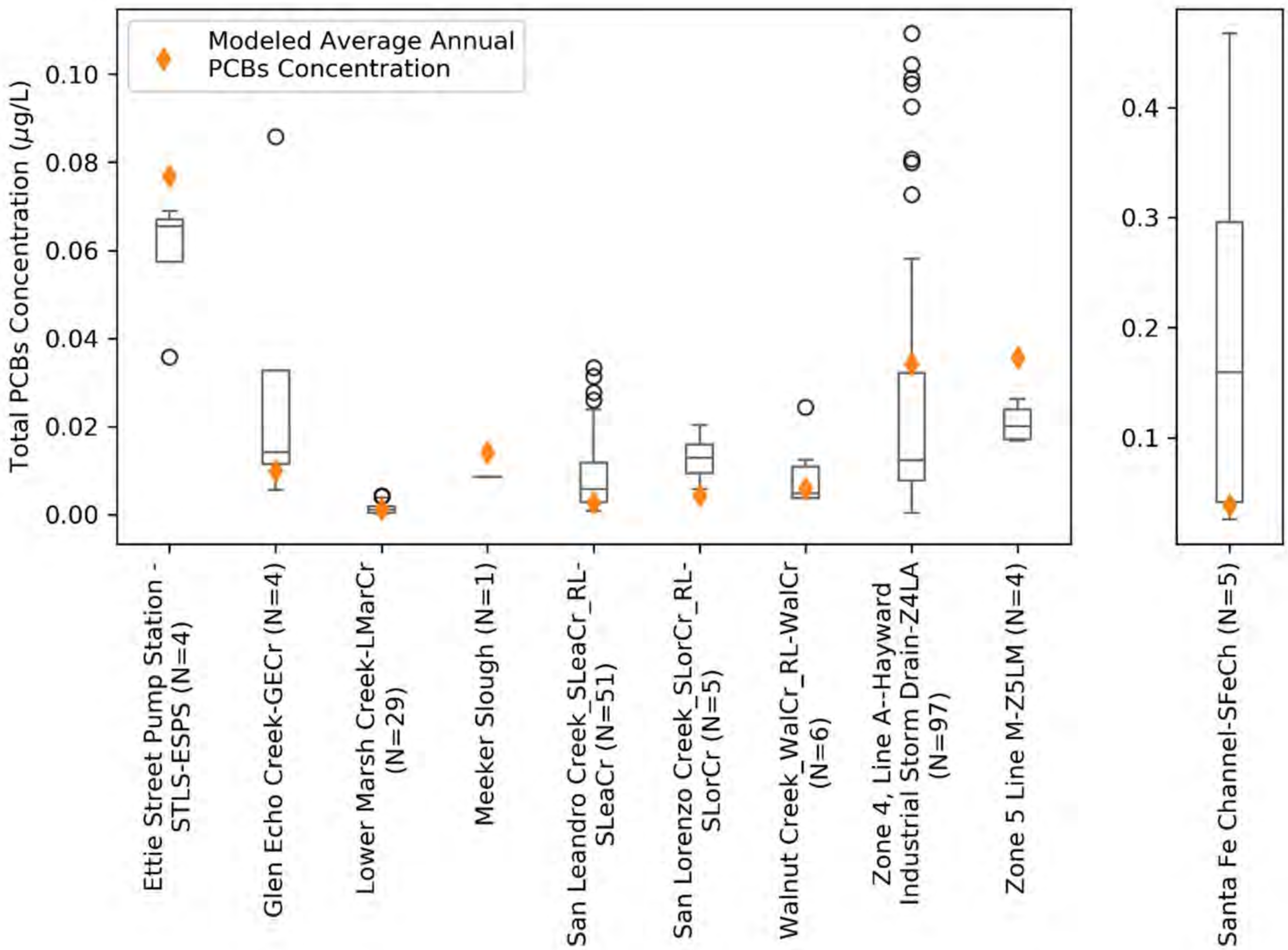
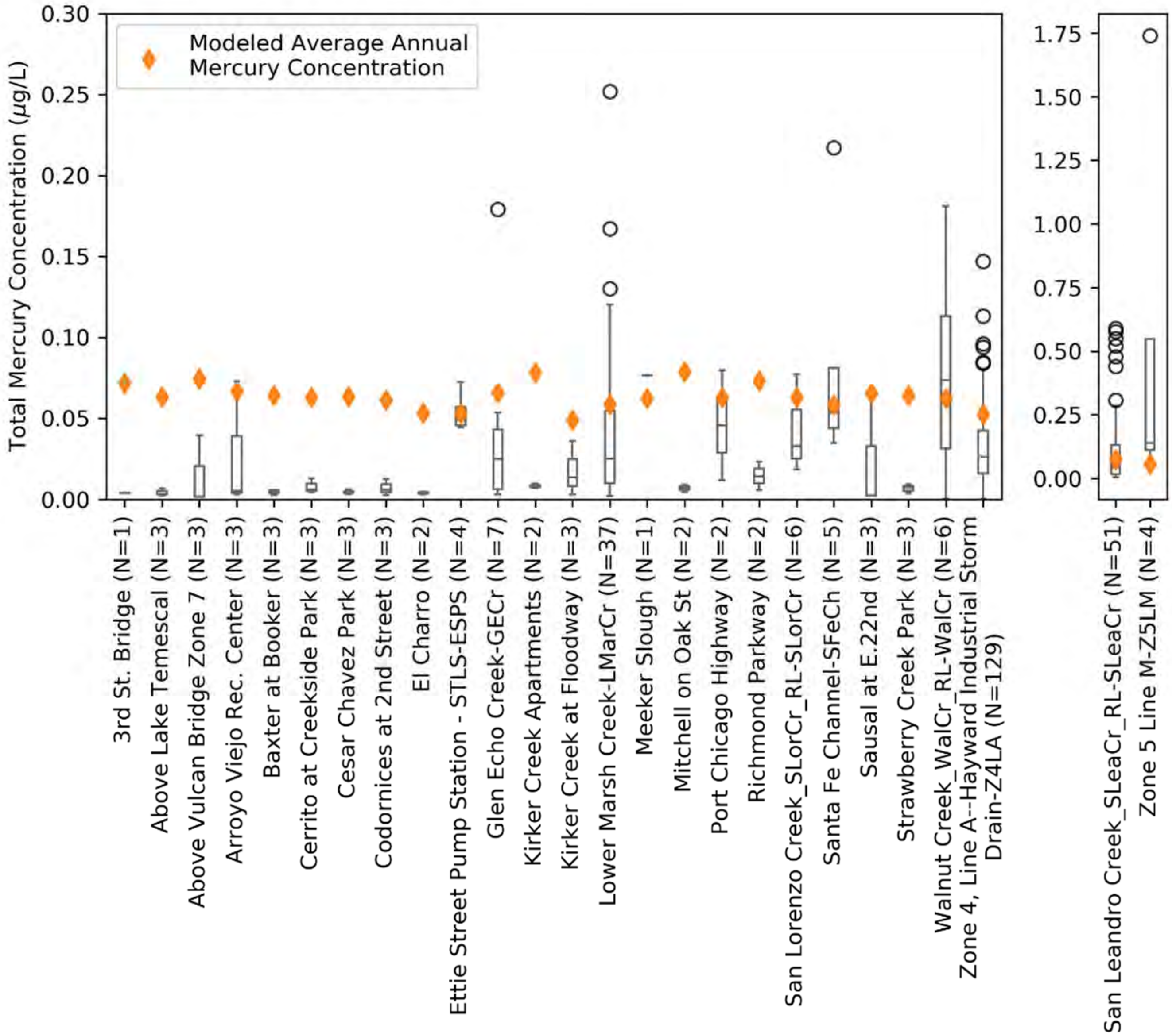
**Figure PR-5E**




**Modeled and Measured PCBs Concentrations for Monitored Watersheds in Alameda County and Contra Costa County**

| | | |
|---|---|---|
| Geosyntec consultants | | **Figure PR-5F** |
| Oakland | August 2019 | |




**Modeled and Measured Mercury Concentrations for Monitored Watersheds in Alameda County and Contra Costa County**

| | | |
|---|---|---|
| Geosyntec consultants | | **Figure PR-5G** |
| Oakland | August 2019 | |