TECHNICAL MEMORANDUM

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DATE: October 19, 2015

TO: Kyle Ericson, City of Sacramento
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Dave Tamayo, Sacramento County

CC: Dana Booth, Sacramento County
Sherill Huun, City of Sacramento

SUBJECT: **SACRAMENTO STORMWATER QUALITY PARTNERSHIP DELTA TMDL PHASE I METHYLMERCURY CONTROL STUDY PROGRESS REPORT**

The Sacramento Stormwater Quality Partnership (Partnership) has prepared this progress report to summarize the data collection and evaluation efforts completed to date for the Partnership's Methylmercury Control Study. The Methylmercury Control Study was developed to fulfill the requirements of the Sacramento-San Joaquin River Delta Estuary (Delta) Methylmercury Control Total Maximum Daily Load (TMDL) Program Phase 1 Implementation. The Partnership is comprised of the County of Sacramento and six of the incorporated cities within the County that are co-Permittees of the municipal separate storm sewer system (MS4) National Pollutant Discharge Elimination System stormwater permit (NPDES No. CAS082597, Order No. R5-2015-0023)[1]. The recently adopted MS4 permit includes a requirement to prepare this progress report by October 20, 2015. The Methylmercury Control Study Guidance[2] specifies that the progress report "includes Study progress and results to-day [sic] and amended Workplans for any additional studies" needed to address methylmercury reductions.

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[1] The Partnership agencies are the County of Sacramento and the cities of Citrus Heights, Elk Grove, Folsom, Galt, Rancho Cordova and Sacramento.

[2] Central Valley Regional Water Quality Control Board. *Methylmercury Control Study Guidance for the Delta Methylmercury Control Program Implementation Phase I*. May 15, 2012. http://www.waterboards.ca.gov/rwqcb5/water_issues/tmdl/central_valley_projects/delta_hg/stakeholder_workgroup_mtgs/hg_controlstudy_15may2012.pdf

1 METHYLMERCURY CONTROL STUDY OVERVIEW

The Partnership developed the Methylmercury Control Study Work Plan[3] (Work Plan) to evaluate the effectiveness and feasibility of measures to control methylmercury discharges in urban runoff and meet the waste load allocation (WLA) for methylmercury required by the Sacramento-San Joaquin Delta Estuary TMDL. The Partnership submitted the Work Plan to the Central Valley Regional Water Quality Control Board (Regional Water Board) and subsequently prepared a revised version incorporating comments from the Technical Advisory Committee (TAC)[4]. The original Concept Proposal proposed to evaluate a wide range of control studies and modeling techniques to determine the level of implementation needed to meet the final WLA. While this activity may still be necessary as part of Phase I of the TMDL implementation, the TAC requested that the Partnership focus on one technical study based on an understanding and assessment of available control strategies, existing control studies, and coordination with other MS4 agencies included in the TMDL. Low impact development (LID) was identified by the Partnership as the control measure that can be most widely implemented in areas of new development and redevelopment and provide reductions in the total loading of methylmercury, primarily through runoff volume reductions.

The Methylmercury Control Study results will be used in TMDL compliance and feasibility assessments. The Work Plan specifically identifies the objectives and the associated monitoring and data collection plans, the quality assurance/quality control (QA/QC) procedures, and the hypothesis testing measures to be used to evaluate success in meeting the objectives, and was approved by the Executive Officer[5].

The Methylmercury Control Study objective is to test the following hypothesis:

> H1: On a load per area basis, LID features reduce methylmercury discharged to the MS4 and receiving waters, in comparison with non-LID urban areas.

The Methylmercury Control Study evaluated LID measures as Best Management Practices (BMPs) for methylmercury control at two projects located in Citrus Heights, California, a Partnership member and NPDES co-Permittee. The Methylmercury Control Study compares urban runoff quality and loading between non-LID and LID conditions. The Methylmercury Control Study was coordinated with a Proposition 84 implementation funding grant (Grant) provided by the State Water Resources Control Board (State Water Board) for the construction and monitoring of the Citrus Heights City Hall Complex and parking facilities (City Hall Complex). The second study location is the existing Sylvan Community Center (Sylvan Center),

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[3] *Delta Methylmercury Total Maximum Daily Load Control Program Implementation: Phase I Control Study Work Plan*. April 19, 2013. Revised October 11, 2013. Prepared by Larry Walker Associates (LWA).

[4] Delta Methylmercury TMDL Technical Advisory Committee is comprised of Tom Grieb, PhD (Chair) Vice President, Tetra Tech, Inc. , Lafayette, CA; Steve Balogh, PhD, Metropolitan Council Environmental Services, St. Paul, MN; Brian Branfireun, PhD, Professor, University of Western Ontario, London, Ontario, Canada; John Cain, MLA, Conservation Director, California Floodplain Management, American Rivers, Berkeley, CA; Mark Grismer, PhD, Professor of Hydrology and Biological and Agricultural Engineering, UC Davis, Davis, CA; Dr. Carol Kelly, PhD R&K Research, Canada; and Dave Krabbenhoft, PhD, Research Hydrologist & Geochemist, US Geological Survey, Middleton, WI.

[5] Pamela Creedon, Executive Officer, Central Valley Regional Water Quality Control Board. "Delta Methylmercury Control Study Work Plan Approval" Letter communication to Dana Booth, Sacramento County and Sherill Huun, City of Sacramento. November 7, 2013.

where LID improvements have already been constructed, and an adjacent non-LID development area that drains through the Sylvan Center.

The Grant includes recognition of the TMDL requirements and coordination of the study elements according to the TMDL TAC comments. The reports submitted to meet requirements for the Grant are used as the primary basis for this progress report. The final Grant study report[6] was accepted by the State Water Board on September 17, 2015 and is included without appendices as Attachment A.[7] **Table 1** summarizes the land use conversion to LID at the City Hall Complex, which also includes the addition of some impermeable pavement (i.e., non-LID feature) and the increase in the size of the parking lot facility.

Table 1. City Hall Complex Monitoring Location Drainage Area

Monitoring Study Area	LID Area (sq. ft.)	Non-LID Area (sq. ft.)	Total Area (sq. ft.)
PL-1	74,040	0	74,040
PL-2	17,634	49,658	67,292
PL-3	59,495	29,926	89,421
Total Area (sq. ft.)	151,169	79,584	230,753
Total Area (acres)	3.47	1.83	5.30

2 COMPLETED MONITORING ACTIVITIES

To test the hypothesis H1, the Partnership conducted a multi-year stormwater monitoring study for the parking lot retrofit at three City Hall Complex locations as well as two less frequently sampled sites at the Sylvan Center to provide site replication. The installed LID features include permeable pavement that increases infiltration, bioswales that slow runoff velocity and filter runoff, and rain gardens, which detain runoff to maximize infiltration on site while maintaining landscaped areas. Over the course of the two year study, water quality samples were collected at five different locations during a total of nine sampling events. The first study year occurred prior to LID construction at the City Hall Complex and the second study year occurred after LID construction at the City Hall Complex. The monitored sites and their development status (i.e., pre-LID or LID) are shown in **Table 2**.

The City Hall Complex project site was evaluated through the measurement of runoff flow rates and the collection of water quality data from runoff both before and after the project at three locations within the study area. The assessment was performed at locations immediately upstream of the outflow to the MS4. The monitoring locations at the City Hall Complex are shown in **Figure 1**.[8]

[6] City of Citrus Heights City Hall Green Parking Lot Proposition 84 Grant Program Implementation Final Monitoring Report Grant Agreement No. 12-453-550. Prepared by Larry Walker Associates. August 2015.

[7] The electronic-only appendices and supporting data and calculations can be downloaded from the following link: http://intraftp.lwa.com:8081/CitrusHeightsProp84/20150830-Report

[8] The PL-4 drainage area drains to PL-3 through a below grade drain. The PL-4 monitoring location was not monitored as part of the Study.

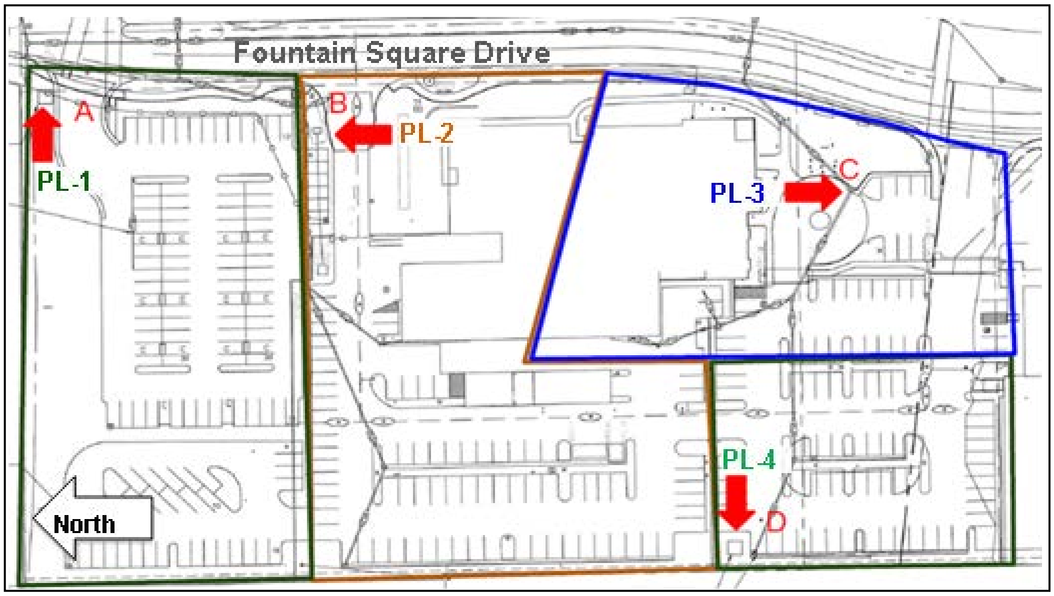

Figure 1. City Hall Complex Drainage Areas (A-D) and Monitoring Locations

The Sylvan Center was also evaluated to confirm the benefits of LID features in reducing the runoff volume and pollutant loading discharged to the MS4 system. The Sylvan Center LID site has a high density of LID features and was not expected to have many periods of outflow to the MS4, therefore, the evaluation was primarily included to confirm the expected volume reduction. An offsite drainage site at the Sylvan Center (with no LID features) was also considered as a "background" site, before runoff passes through a bioswale. The monitoring locations at the Sylvan Center are shown in **Figure 2**.

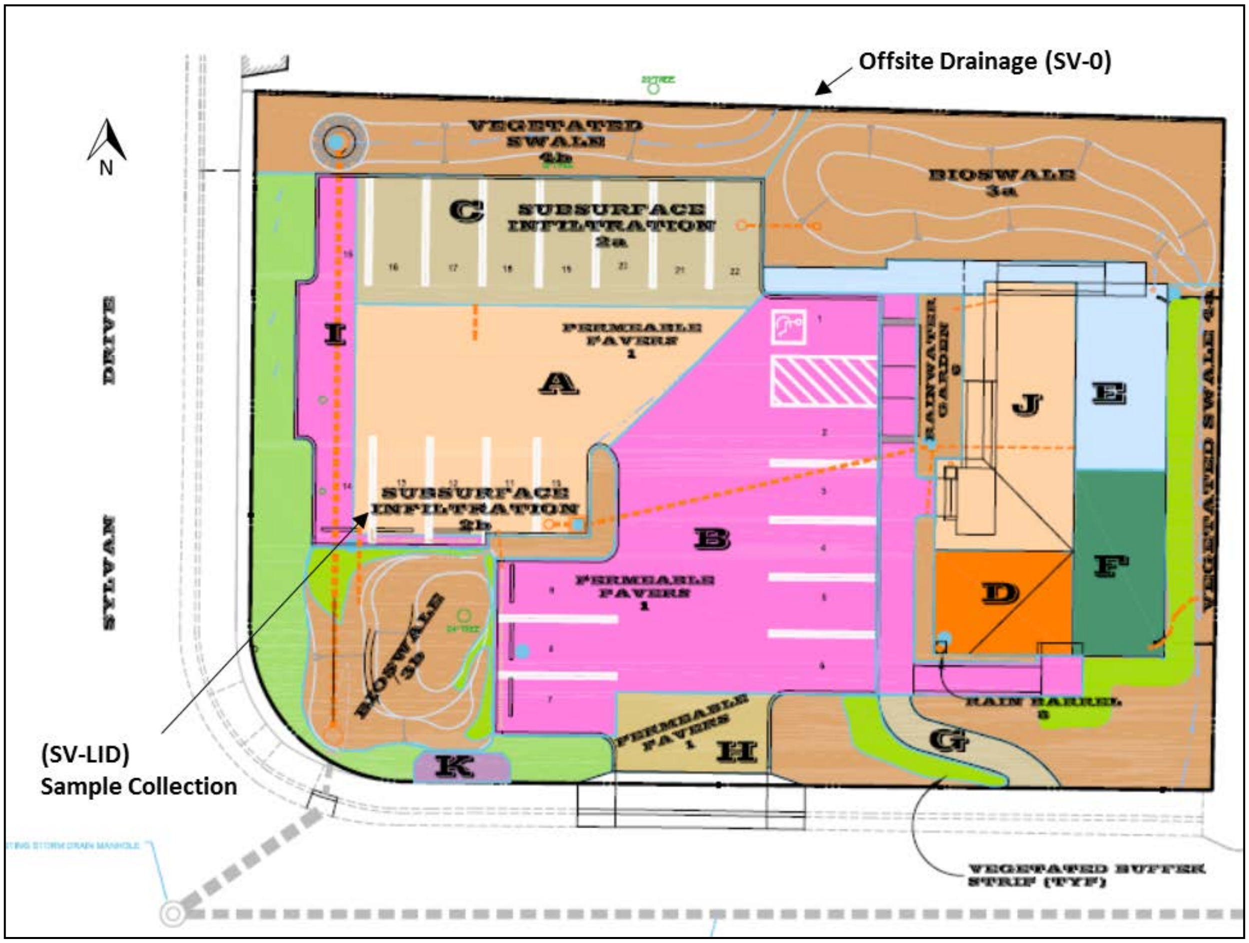

Figure 2. Sylvan Center Monitoring Locations (SV-0 and SV-LID)

Table 2. Monitoring Locations and Development Type

	Sylvan Center		City Hall Complex Police Station		
	SV-0	**SV-LID**	**PL-1**	**PL-2**	**PL-3**
Year 1	non-LID	LID	non-LID	non-LID	non-LID
Year 2	non-LID	LID	LID	partial LID[a]	LID

[a] Between Year No. 1 and Year No. 2, this area remained mostly unchanged from a drainage treatment standpoint, though lot usage patterns changed slightly, and mainly serves as a background control site for unimproved parking lot runoff. Following final design and construction of the Project, it was noted that the extensive roof runoff at this location was disconnected from the subsurface drain and routed to a rain garden.

In Year No. 1, runoff and water quality conditions were measured prior to LID BMP installation (PL-1, PL-2, and PL-3), and at the background Sylvan Center site (SV-0). During the wet season of the first study year (January through March 2014), baseline urban runoff monitoring data was collected. After the first year of monitoring and prior to the beginning of the subsequent wet season, LID features were constructed at the City Hall Complex. In Year No. 2 of the study (October 2014 through April 2015), all three City Hall Complex sites and the Sylvan Center LID site were monitored. A summary of the equipment installed at those sites in each study year is shown in **Table 3**.

V-notch weirs were installed at monitoring locations to measure outflow rate to the MS4. A rain gage and remote camera were installed at one of the City Hall Complex sites (PL-1) during both study years to monitor site conditions. Multiple methylmercury sample collection techniques were evaluated to develop recommendations to characterize methylmercury concentrations and load flux for monitoring of LID features. These methods included the use of a fluorescence dissolved organic matter (FDOM) sensor as a surrogate for methylmercury as well as a modified "microsampling" approach to reduce sample-to-sample variability compared to shorter duration composite aliquots[9]. Methylmercury and mercury are detected at low concentrations and are, therefore, subject to variability. Microsampling has been shown to have low sample bias and high accuracy in a comparison of stormwater sample collection methods, with being cost-effective.[10]

Table 3. Installed Sensor and Flow Measurement Equipment at Monitoring Locations

Study Year No.	Location	Equipment Installed
1	PL-1	V-notch weir/water level sensor, electrical conductivity (EC) sensor, turbidity sensor, pH sensor, dissolved oxygen (DO) sensor, oxidation reduction-potential (ORP) sensor, rain gage, remote camera
	PL-2	V-notch weir/water level sensor
	PL-3	V-notch weir/water level sensor
	SV-0	None, no flow quantification equipment installed
2	PL-1	V-notch weir/water level sensor , EC sensor , turbidity sensor, pH sensor, DO sensor, ORP sensor, rain gage, remote camera, FDOM sensor, automated microsampler
	PL-2	V-notch weir/water level sensor, EC sensor, turbidity sensor, pH sensor, DO sensor, ORP sensor
	PL-3	V-notch weir/water level sensor, EC sensor, turbidity sensor
	SV-LID	Water level sensor

Water quality monitoring included grab sample, continuous sensor measurement, and/or composite sample collection for the following constituents relevant to the Methylmercury Control Study:

- Total mercury
- Total reactive mercury
- Methylmercury
- Flow
- Turbidity

[9] The deployment of an automated sampler at one City Hall Complex monitoring location capable of collecting multiple samples over extended periods (five to fifteen minute capture) is referred to as "microsampling."

[10] SCCWRP, 2009 Annual Report. Evaluating stormwater sampling approaches using a dynamic watershed model. http://ftp.sccwrp.org/pub/download/DOCUMENTS/AnnualReports/2009AnnualReport/AR09_195_210.pdf

- Water temperature
- Dissolved oxygen
- Electrical conductivity
- pH
- Redox
- Total suspended solids
- Suspended sediment
- Total dissolved solids
- Total phosphorus
- Total Kjeldahl nitrogen
- Nitrate + Nitrite
- Total organic carbon
- Filtered and unfiltered Copper, Nickel, Lead, and Zinc
- Dissolved organic carbon
- Sulfate

2.1 Events Sampled

Samples were collected at nine separate events as shown in **Table 4** over the study period, though not always at every site depending on flow conditions.

Table 4. Summary of Events and Collected Samples

Year No.	Event No.	Date	Sample Collection Timeframe	Sampling Locations
1 (pre-LID)	CH01	January 30, 2014	1:50 - 2:30	PL-2
	CH02	February 9, 2014	13:00 - 16:45	PL-1, PL-3, SV-0
	CH03	February 26, 2014	19:30 - 23:00	PL-2, PL-3
	CH04	February 28, 2014	15:55 - 18:10	PL-1, PL-3
2 (post-LID)	CH05	November 29, 2014	10:50 - 11:45	PL-2, PL-3
	CH06	December 3, 2014	4:22 - 11:20	PL-1, PL-2, PL-3
	CH07	December 11, 2014	12:26 - 23:50	PL-1, PL-2, PL-3, SV-LID
	CH08	February 6, 2015	13:50 - 22:37	PL-1, PL-2, PL-3
	CH09	February 8, 2015	12:50 - 15:10	PL-1

3 CONTROL STUDY ASSESSMENT RESULTS

As part of the Proposition 84 grant, the Partnership prepared a Final Monitoring Report based on the completed pilot monitoring. Detailed field activities and sample collection, preliminary data, as well as QA/QC results are described in the Final Monitoring Report provided as Attachment A, which includes the Year No. 1 and Year No. 2 event memoranda as appendices.

3.1 Year No. 1 Flow Characterization

Year No. 1 pre-LID runoff conditions at the City Hall Complex were characterized based on the modeling[11] conducted specifically for the project (Appendix E of the Final Monitoring Report) and an initial investigation with depth sensors and weirs. The approach was designed to identify any critical flow measurement issues for consideration in Year No. 2 to ensure that the post-Project flow measurements were accurate and reliable. Flow monitoring was successful at PL-1. However, during Year No. 1, flow was measured at PL-2 and PL-3 with an acoustic Doppler water velocity sensor and a pressure transducer that was not well suited to the hydraulic conditions. The limited pre-LID assessment period did not allow additional time for flow data collection, and the hydrologic modeling was relied on to develop the pre-LID hydraulic loading rate. Water quality concentration data from the pre-LID samples was used for pre-LID loading calculations.

3.2 Year No. 2 Flow Characterization

Flow monitoring conducted during Year No. 2 characterized flow conditions for post-LID conditions. These flow data and water quality data were used to evaluate the flow and load reduction benefit of the LID projects when compared to the modeled pre-LID flow and water quality samples collected during Year No. 1. Flow measurement was reliable during Year No. 2 though some data gaps occurred because of equipment malfunction and rapid battery drain.

3.3 Runoff Coefficient Calculation

Calculation of the drainage area tributary to each monitoring location was performed to evaluate the change in the effective runoff coefficient as the volume of runoff per inch of rain and per acre of area. The pre-LID runoff coefficient was estimated to be 0.71 based on the pre-LID modeling and adjustments to consider the entire drainage area used in the monitoring study, including impervious surfaces not modified (i.e., the modeling study only evaluated the area converted to LID). Based on the Year No. 2 flow data at all three monitoring locations, the observed effective runoff coefficient was 0.45 (area weighted), which compares well to the modeled assessment when modified to account for unchanged areas (0.40). The modeled conditions are the average of a twelve year simulation period, which includes a wider range of conditions than was evaluated in the one year post-LID study period.

3.4 Loading Rate Calculation

An average effective loading rate was calculated for the pre-LID and post-LID periods using the runoff coefficients and median water quality concentrations. The constituent mass load in runoff leaving the sites can be used to evaluate the relative impact of the source to others in downstream drainages and watersheds. The Delta Methylmercury TMDL assigns a mass-based wasteload allocation to the Partnership area within the “legal” Delta area. Thus, a measure of control measure effectiveness is the reduction in loads of constituents of interest. “Loading rate” was calculated (see Equation 1) for both the pre- and post-Project conditions to “normalize” for the purpose of comparing the mass of constituents leaving the sites to the drainage area and depth of rainfall. The calculated runoff coefficient is multiplied by the median observed concentration.

[11] Jennifer J. Walker, P.E., D.WRE, CFM, QSD. Watearth. Memorandum of Modeling Results. April 11, 2014.

Calculation worksheets are included as an electronic-only Appendix I to the Final Monitoring Report and can be downloaded from the link specified within the footnote above on page 3.

$$Loading\_Rate = runoff\_coefficient * median\_concentration$$

$$\left[\frac{mass_{constituent}}{area * depth_{precipitation}}\right] = \left[\frac{volume_{runoff}}{area * depth_{precipitation}}\right] * \frac{mass_{constituent}}{volume_{sample}}$$

Equation 1. Loading Rate

The area-weighted average methylmercury loading rate for the pre-LID is 3.6×10^{-5} g/in/acre and the post-LID area-weighted average loading rate is 1.6×10^{-5} g/in/acre. These loading rate estimates are intended as general characteristics of the pre- and post-LID parking lot conditions to confirm effectiveness and should not be compared directly to the overall larger mixed land use urban area. A more detailed assessment should consider other factors influencing loading rates (rainfall rate, days since last rainfall, level of LID implementation, etc.) as well as a quantification of error. Analysis of error was not included in this assessment because of the relatively small sample size at some locations, and a more detailed assessment should be performed for incorporation into future larger watershed scale models. The purpose of this assessment is to evaluate the performance of the control measures at this specific location where the site area is primarily parking lot and a large fraction of roof area. **Table 5** and **Table** 6 show the overall export rate from the site and demonstrate the effectiveness of the control measures in reducing methylmercury.

Table 5. Export Rate Calculations for Methylmercury at the City Hall Complex

Drainage Area	Runoff Coefficient (cu. ft./sq. ft.*ft.)	Median Concentration (ng/L)	Area (acre)	Effective Export Rate (g/in)
		Year 1 Methylmercury		
PL-1	0.0077	0.16	1.7	0.0000026
PL-2	1	0.17	1.5	0.00032
PL-3	1	0.10	2.1	0.00025
Total			**5.3**	**0.00057**
		Year 2 Methylmercury		
PL-1	0.16	0.02	1.7	0.0000066
PL-2	0.71	0.04	1.5	0.000048
PL-3	0.50	0.02	2.1	0.000031
Total			**5.3**	**0.000086**
Methylmercury Percent Change				**-85%**

Table 6. Export Rate Calculations for Total Mercury at City Hall Complex

Drainage Area	Runoff Coefficient (cu. ft./sq. ft.*ft)	Median Concentration (ng/L)	Area (acre)	Effective Export Rate (g/in)
Year 1 Total Mercury				
PL-1	0.0077	10.37	1.7	0.00017
PL-2	1	11.08	1.5	0.021
PL-3	1	5.41	2.1	0.014
Total			**5.3**	**0.035**
Year 2 Total Mercury				
PL-1	0.16	3.35	1.7	0.0011
PL-2	0.71	4.48	1.5	0.0061
PL-3	0.50	6.16	2.1	0.0078
Total			**5.3**	**0.015**
Total Mercury Percent Change				**-57%**

3.5 Study Hypothesis Testing

Paired data comparisons between LID and non-LID locations were not possible as an appropriate negative control site was not available. Instead, the hypothesis was tested using un-paired comparisons between pre-LID and post-LID concentrations at the study locations. Rather than calculating the individual event loads for comparisons, it was assumed that if the concentrations decreased the load would also decrease because of the observed decrease in runoff volume following LID installation.

Concentration data were compared between years (pre- and post-LID) using a Mann-Whitney comparison. The results are shown in the table below. Box plots showing various groupings of the monitoring study data as well as historic data collected by the Partnership at other locations for both methylmercury and total mercury are provided following the table.[12] As indicated by **Figure 3** through **Figure 6** box plots, all methylmercury and total mercury concentrations decreased from pre-LID to post-LID and the lack in statistical significance in some cases is attributable to the smaller number of samples. When multiple samples were available for one event, they were averaged to best represent an event mean concentration (EMC). If all samples are considered, statistical significance increases.

[12] UR2S: Strong Ranch Slough (urban runoff in mixed use area); UR3: Sump 111 (urban runoff in light industrial, commercial, and residential area); UR4: Sump 104; UR5 STA2: North Natomas Detention Basin No. 4 (housing development, new development standards)

Table 7. Summary of p-values for pre-LID to post-LID comparisons

Sites Considered		Methylmercury		Total Mercury	
		n[a]	p-value[b]	n[a]	p-value[b]
All sites (PL1, PL2, PL3)	Pre-LID	7	0.0005*	7	0.0728
	Post-LID	12		8	
PL1	Pre-LID	2	0.1052	2	0.2453
	Post-LID	4		2	
PL2 and PL3	Pre-LID	5	0.0043*	5	0.3153
	Post-LID	8		6	

Notes:

[a] "n" refers to the count of results considered

[b] $p \leq 0.05$ is used as the statistically significant effect level .

Data were combined to best represent event mean concentrations. For site PL-1 this generally included averaging multiple "microsample" concentrations. Sites PL-2 and PL-3 were generally represented by single grab samples.

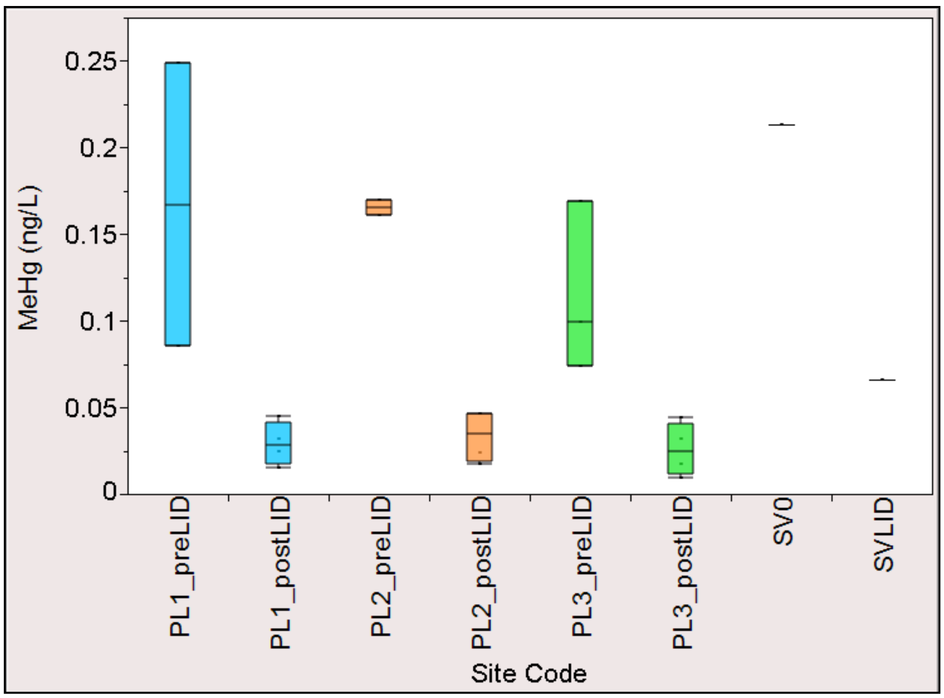

Figure 3. Methylmercury Concentration at Study Locations

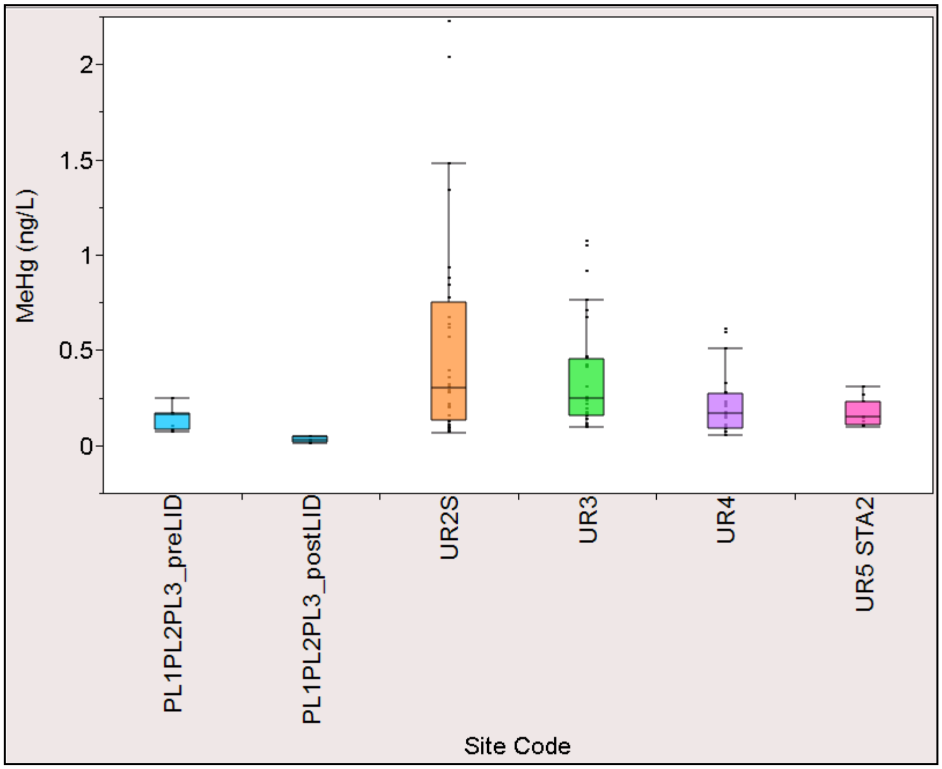

Figure 4. Methylmercury Concentration at City Hall Complex Study Locations and Historic Partnership Locations

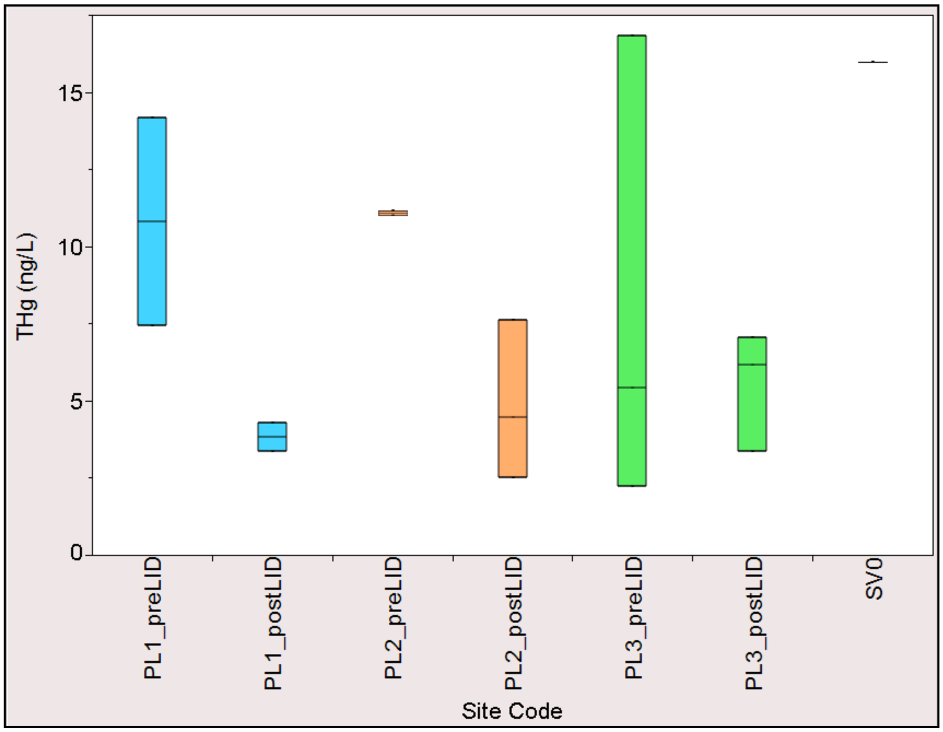

Figure 5. Total Mercury Concentration at Study Locations

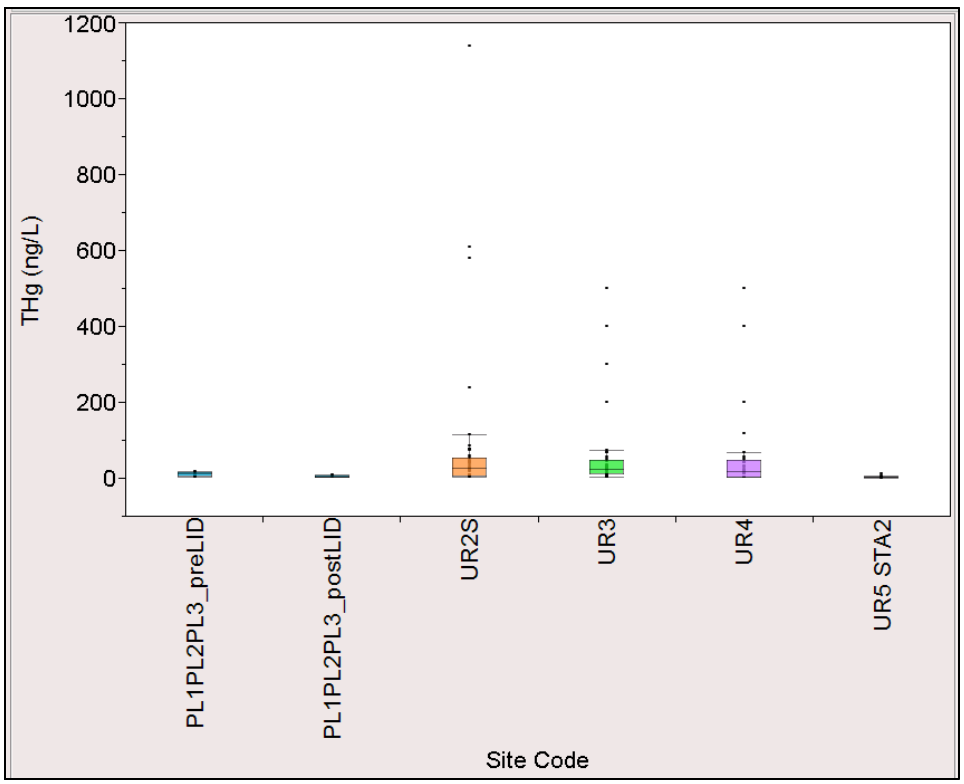

Figure 6. Total Mercury Concentration at City Hall Complex Study Locations and Historic Partnership Locations

4 METHYLMERCURY CONTROL STUDY CONCLUSIONS

The major conclusions discussed in the Final Monitoring Report relevant to methylmercury are summarized below.

- The Project reduced the effective runoff coefficient (volume per area drainage, per depth rainfall) from 0.71 (based on hydrologic modeling) to 0.45 (measured).
- The Project reduced the median methylmercury and total mercury at every location where pre- and post-LID sample collection occurred.
- The Project reduced the loading rates for methylmercury (85%), total mercury (57%), and suspended sediment concentration (52%). The loading rate to the MS4 system decreased significantly after completion of the LID features. Even though the concentrations of suspended solids increased slightly at one location, the flow reductions were significant enough to reduce the load of solids. This decrease in pollutant loading occurred despite the increase in pavement area.
- Methylmercury concentrations declined in all cases indicating that the LID features do not create conditions conducive to mercury methylation and methylmercury loads were significantly reduced by the LID features evaluated. The maximum methylmercury concentration was observed before the Project construction at one of the City Hall Complex locations. The second highest maximum value was observed from the off-site runoff adjacent to the Sylvan Community Center. Though runoff volume increased at one City Hall Complex site (PL-1) with the addition of permeable and impermeable pavement, the loading rate still decreased.
- Multiple constituent loading rate calculations methods were performed and resulted in estimates ranging by approximately 50%. Microsampling, whereby a number of samples are collected over longer durations or conditional sampling, and the use of surrogate relationships was useful in developing methods to cost effectively quantify loadings of constituents for the purpose of TMDL and WLA compliance. The continuous fluorescence-based optical sensor used to measure dissolved organic matter (FDOM sensor) data was limited by problems encountered with large debris blocking the sensor flow through “cell” and FDOM-based loading could only be calculated for certain periods. However, statistically significant correlations were developed between FDOM and methylmercury concentration.
- Reductions in flow volume observed in the study were close to, but slightly less than, the modeled projections. The differences in the observed and modeled conditions were within expected accuracy of model projections and flow measurement. The model results represent an average over a longer continuous simulation period than was monitored.

5 EXPECTED ADDITIONAL ACTIVITIES

The study objective evaluation provides additional information on the effectiveness and feasibility of using LID to reduce methylmercury discharge to the Delta, and to determine potential next steps in regional methylmercury management for the purpose of meeting the WLA and/or reducing the discharge load to the maximum extent practicable. The Partnership continues to evaluate the feasibility of WLA compliance. To reduce larger watershed loads of methylmercury, significant land use conversion may be necessary. A more detailed determination through computational modeling of the cumulative land use conversion may be necessary. The Partnership has previously used "accounting" models of source reduction as well as stochastic models to evaluate the trends and projections of future loads under various land use conversion scenarios. Additional model development may be necessary to more certainly demonstration WLA compliance. The following actions may be considered in near-term actions depending on forthcoming Regionwide Permit requirements, ongoing modeling efforts, and direction from the Regional Water Board:

- Examine the relative impact of Partnership methylmercury discharge load reductions on Delta fish tissue concentrations;
- Evaluate the cost per mass methylmercury reduced based on Sylvan Community Center, City Hall Complex, and other LID sites in comparable regions;
- Participate in regional methylmercury groups, review of other Control Study results, and participation in Delta Regional Monitoring Program (RMP) methylmercury activities;
- Develop implementation scenarios for evaluated control strategies to determine the required control strategies to comply with the WLA;
- Develop achievable implementation schedules and cost estimates for the required control strategies based on expected rates of redevelopment within the TMDL urban area; and
- Prepare an evaluation of the overall feasibility of complying with the WLA.

6 SCHEDULE OF ACTIVITIES

The activities that will need to be performed to evaluate the effectiveness and feasibility of measures to control methylmercury discharges in urban runoff and meet the WLA required under the Delta TMDL for methylmercury are described below.

Activity	Completion Date
Delta Methylmercury TMDL Control Program Implementation: Phase I Control Study Work Plan	April 19, 2013. Revised October 11, 2013
Proposition 84 grant required Final Monitoring Report	August 2015. Accepted by the State Water Board September 17, 2015
Methylmercury Control Study Progress Report	October 20, 2015
Pilot study monitoring in larger watersheds to evaluate alternate monitoring approaches that improve load calculations and trend analysis	June 30, 2016
Pilot study monitoring report including drainage load calculations	October 1, 2016
Coordinate with other TMDL stakeholders to evaluate implementation and compliance programs, including open water modeling, fish tissue objectives, and offsets/trading programs	October 20, 2018
Watershed Load Modeling to evaluate feasibility of compliance with final WLA	October 20, 2018
Final Phase 1 Feasibility Report	October 20, 2018

Attachment A. Proposition 84 Grant Final Monitoring Report for the City of Citrus Heights Green Parking Lot

A U G U S T 2 0 1 5

City of Citrus Heights

City Hall Green Parking Lot
Proposition 84 Grant Program Implementation
Final Monitoring Report
Grant Agreement No. 12-453-550

Prepared by Larry Walker Associates

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List of Acronyms

DNQ	Detected but not quantified
DO	Dissolved oxygen
DOM	Dissolved organic matter
DQO	Data quality objective
EC	Electrical conductivity
FDOM	Fluorescence-based optical sensor to measure dissolved organic matter
FDP	Qualification for any field duplicate RPD greater than the acceptability criteria
GB	Qualification for any matrix spike recovery outside of the control limits
IL	Qualification for RPD greater than the acceptability criteria for MSD or LCSD
IP	Qualification for any analyte detected in method, trip or field blank
LCS/LCSD	Laboratory control spike/laboratory control spike duplicate
LID	Low impact development
LWA	Larry Walker Associates, Inc.
MDL	Method detection limit
MS/MSD	Matrix spike/matrix spike duplicate
MS4	Municipal separate storm sewer system
NPDES	National Pollutant Discharge Elimination System
ORP	Oxidation reduction-potential
QA/QC	Quality assurance/quality control
QAPP	Quality Assurance Project Plan
ROS	Regression on order statistics
RPD	Relative percent difference
SAHM	Sacramento Area Hydrology Model
SAP	Sampling and Analysis Plan
SSC	Suspended solids concentration
SSQP	Sacramento Stormwater Quality Partnership
SWMM	Storm Water Management Model
TMDL	Total maximum daily load
TSS	Total suspended solids
USEPA	U.S. Environmental Protection Agency
USGS	United States Geological Survey
WLA	Wasteload allocation

Executive Summary

In 2013, the State Water Resources Control Board (State Board) awarded the City of Citrus Heights a Proposition 84 grant for the construction of low impact development (LID) features at the City Hall Complex Police Station facility (Project). To assess the effectiveness of the implemented LID features, the City of Citrus Heights completed a multi-year stormwater monitoring study for the parking lot retrofit and new parking lot installation. The installed LID features include permeable pavement that increases infiltration, bioswales that slow runoff velocity and infiltrate runoff and rain gardens, which detain runoff to maximize infiltration on site while maintaining landscaped areas. The project site was evaluated through the measurement of runoff flow rates at three locations and the collection of water quality data from runoff both before and after the project. The assessment was performed at locations immediately upstream of the outflow to the municipal separate storm sewer system (MS4). A secondary site in Citrus Heights, the Sylvan Community Center, was also evaluated to confirm the benefits of LID features in reducing the runoff volume and pollutant loading discharged to the MS4 system.

RUNOFF VOLUME MEASUREMENT

Flow measurement methods at the City Hall Complex in the pre-Project condition were designed based on hydrologic modeling, and an optimization of the methods and equipment was performed in Year No. 1. As expected, runoff in the highly impermeable (pavement and roof) drainage areas approached 100% of the rainfall, though the shorter study period and equipment placement and performance issues limited the confidence in at least one of the drainage areas. Flow measurement in the post-Project Year No. 2 successfully demonstrated significant reductions in runoff volume in two of the drainage areas, and only minor increases in the drainage area where a significant number of parking spaces were added. Overall, the Project area runoff coefficient, including unchanged areas, was reduced from 0.71 to 0.45 and constituent mass loading rates were significantly decreased compared to pre-Project conditions.

WATER QUALITY SAMPLE COLLECTION

Water quality samples were collected before and after Project construction to evaluate any changes in methylmercury, solids, pesticides and other constituents of interest. The evaluation focused on methylmercury and included the use of sensors to capture high frequency data during the limited runoff periods expected as a result of the LID installations. Reductions in median and average values between the pre- and post-Project monitoring periods were observed for most constituents. In one drainage area, the suspended solids concentration (SSC) increased slightly. In particular, methylmercury concentrations declined in all cases indicating that the LID installation does not create conditions conducive to mercury methylation and methylmercury loads were significantly reduced by the LID features evaluated. Multiple methylmercury sample collection techniques were evaluated to develop recommendations to characterize methylmercury concentrations and load flux for LID monitoring. These methods included the use of a dissolved organic matter sensor as a surrogate for methylmercury as well as a simplified "microsampling" approach to collect less variable storm aliquots.

LOADING RATE CALCULATIONS

Loadings rates (mass per area, per depth of rain) of key study constituents were calculated for the purpose of comparing pre- and post-Project conditions. The pre-Project modeled runoff coefficients are compared against field measured post-Project runoff coefficients for each of the three drainage areas. Water quality median values were developed for pre- and post-Project at each of the three drainages. The loading rates decreased between pre- and post-Project conditions for all constituents examined, as shown below.

Constituent	Estimated Percent Reduction in the Loading Rate between pre- and post-Project Conditions [a]
Methylmercury	85%
Total Mercury	57%
Suspended Sediment Concentration	52%
Bifenthrin	77%

[a] Refer to Section 4.5 for specific calculations.

Additional methods for calculating loads were evaluated, including the use of the continuous fluorescence-based optical sensor to measure dissolved organic matter (FDOM sensor) and surrogate relationships. FDOM sensor data was limited by problems encountered with large debris blocking the sensor flow through "cell" and FDOM-based loading could only be calculated for certain periods. The "proof-of-concept" performed in this study demonstrated that this FDOM-based loading approach better characterizes the variation in methylmercury concentrations throughout a storm and should be considered further in larger scale pilot studies of urban runoff with the appropriate installation measures to allow accurate readings and loading calculations over longer periods of time.

LID METHYLMERCURY SAMPLE COLLECTION AND STUDY DEVELOPMENT GUIDANCE

Study planning document templates were developed to assist future projects in considering some of the key components and "lessons learned" in this evaluation. The primary challenges included the accurate measurement of wide ranges of flow conditions that consider site-specific conditions, including changes in the land use, sub-grade hydraulics and determining appropriate flow measurement locations, and capturing concentration variability (changes over time) using cost effective approaches. The templates incorporate the following recommendations:

- Perform hydrologic modeling of the site prior to monitoring design to develop the range of potential flows in the pre- and post-Project conditions.
- Develop metrics to characterize LID facilities that make use of multiple types of LID features such so that sites with LID features can be better incorporated into watershed models. This Study used a composite approach to develop a loading rate, however, other approaches could be evaluated that are based on descriptive characteristics of the LID site such as the ratio of LID feature capacity to the drainage area (e.g., loading rate as a function of bioswale length per area).
- Flow monitoring should account for the expected range of flows and measurement locations should provide laminar hydraulics to more accurately collect data.
- The use of continuous sensors to collect flow measurements and water quality data should be considered, when feasible.
- Perform error analysis to adequately characterize the range of loading based on the measured flow and analytical chemistry errors.

1 Introduction

In 2013, the State Water Resources Control Board (State Board) awarded the City of Citrus Heights (City) a Proposition 84 grant (Grant) to replace impervious pavement with pervious materials and to install bioswales, rain gardens, drought tolerant landscaping and educational signage. The Grant required a comprehensive monitoring program to evaluate the performance of the improvements, especially with regard to total mercury and methylmercury. These particular mercury constituents were identified as a result of the requirements of the Delta Methylmercury Total Maximum Daily Load (TMDL) Phase 1 evaluation and the need to identify methods to reduce methylmercury in urban runoff. This Final Monitoring Report (Report) addresses the Grant requirement to evaluate the effectiveness of the improvements through the calculation of loads, both before and after implementation of the LID features, as well as comparisons of loads at specific export locations representative of LID features' combinations.

The Grant-required Quality Assurance Project Plan (QAPP) and Sampling and Analysis Plan (SAP) were previously submitted as one document to the State Board (**Appendix A**) and received provisional approval at the initiation of sample collection. The Grant also required the development of "template" monitoring planning documents for use by other municipal separate storm sewer systems. These documents are provided as **Appendix B** and include recommendations based on this Report. This Report summarizes water quality analytical results, flow measurements, and load calculations as well as provides conclusions on the effectiveness of the Project and recommendations for additional analyses to support future efforts, including the Phase 1 Methylmercury TMDL evaluation.

1.1 STUDY AREA DESCRIPTIONS

Due to the ability to characterize pre-construction conditions at the City Hall Complex facility (Police Station), this site was the primary study location, with additional data collection at the Sylvan Community Center (Sylvan Center) where LID improvements have already been constructed. The Sylvan Center site was included to provide study site replication to confirm that other sites performed similarly. The City Hall Complex LID proposed features included six bioswale segments, two rain gardens, and more than an acre of new permeable pavement. The overall project added new parking lot areas to previously permeable surfaces, and replaced impermeable pavement with permeable pavement. Although the Sylvan Center is smaller, the location includes permeable pavement, two bioswale segments, one rain garden, multiple vegetated filter strips and swales, and a subsurface infiltration structure.

1.2 MONITORING DESIGN

The monitoring design allows for a direct comparison of pre-Project loads to post-Project loads, including the consideration of changes in the effective imperviousness (flow reductions) and changes in concentrations of the study constituents. After the final design was completed, the study plan was modified slightly as reported in the Year No. 1 Event Memorandum (**Appendix C**) to focus on the City Hall Complex location where the improvements were focused on the Police Station portion of the site. The City performed a focused evaluation by conducting monitoring at three locations within the Police Station study area to accurately quantify the net export of total mercury and methylmercury as well as to pilot test alternate characterization techniques. Reduced sample collection at the Sylvan Center was justified because of the lack of pre-Project data and limited post-Project outflow from the multiple LID implementation features at that site. However, outflow from the Sylvan Center was continuously monitored by in-situ sensors and samples were collected when site outflow was expected (once in two years), which would allow the quantification of methylmercury load exported to the municipal separate storm sewer system (MS4). The Sylvan Center site is not representative of a typical LID installation because of the high density of LID features, but it represents a unique "cost" data point when considering the cost of LID implementation against the quantified benefits. This cost vs. benefit analysis will be used when planning long-term improvements. Detailed field activities and sample collection are specified in the Year No. 1 (**Appendix C**) and Year No. 2 (**Appendix D**) Event Memoranda.

1.3 DELTA METHYLMERCURY TMDL COORDINATION

The City is a member of the Sacramento Stormwater Quality Partnership (SSQP)[1], which is subject to the requirements of the Delta Methylmercury TMDL. Additional and more detailed site evaluations will be performed later as part of the Delta Methylmercury TMDL requirements, as summarized in the forthcoming October 2015 Phase 1 Control Study Progress Report and the TMDL Phase 1 report due before the end of October 2018. While the receiving waters immediately downstream from the Police Station are not part of the TMDL, they ultimately drain to the Delta. The TMDL requires a Phase 1 control study evaluation and assessment of the feasibility of compliance with the TMDL methylmercury wasteload allocations (WLA). The SSQP developed a separate Methylmercury Control Study (Study) to evaluate the effectiveness and feasibility of measures to control methylmercury discharges in urban runoff and meet the waste load allocations. The Work Plan for the SSQP Phase 1 Control Study[2] was coordinated with this Proposition 84 implementation funding for the construction and monitoring of the Citrus Heights City Hall Complex and parking facilities. The TMDL Phase 1 requires additional analysis and specific hypothesis testing that are not included in this Report, though data and conclusions from this Report will be the basis for the TMDL Phase 1 evaluation.

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[1] The Partnership agencies are subject to the Sacramento Area-wide MS4 NPDES Stormwater Permit (NPDES No. CAS082597). The Partnership agencies are the County of Sacramento and the cities of Citrus Heights, Elk Grove, Folsom, Galt, Rancho Cordova and Sacramento.
[2] Sacramento Stormwater Quality Partnership. *Delta Methylmercury Total Maximum Daily Load Control Program Implementation Phase I Control Study Work Plan*. Prepared by Larry Walker Associates. October 11, 2013 revision.

2 Site Descriptions and Study Methods

The City collected samples at five different locations during a total of nine water quality sampling events over the course of the two year study. In addition, continuous sensors and weir structures were used to accurately measure the urban runoff volume leaving the Project site. Continuous sensor arrays included other water quality parameters, such as a fluorescence-based optical sensor to measure dissolved organic matter (FDOM) sensor at one location to pilot test surrogate relationships to methylmercury.

2.1 SAMPLE COLLECTION LOCATIONS

The City Hall Complex study area includes three urban runoff monitoring locations in proximity to the Police Station: PL-1, PL-2 and PL-3. During Year No. 1 of the study, samples were collected at all three locations to evaluate the pre-LID urban runoff characteristics at the City Hall Complex. Between sampling Years No. 1 and No. 2, the areas encompassing monitoring locations PL-1 and PL-3 underwent the grant-funded retrofit and LID features were installed. Throughout the course of the study, few modifications were made to the area in proximity to monitoring location PL-2. The Sylvan Center area, an existing LID redevelopment site, includes two stormwater monitoring locations: SV-0 and SV-LID. LID features exist at monitoring location SV-LID and are absent at monitoring location SV-0. The monitoring location and development type of each study location is listed in **Table 1**.

Table 1. Monitoring Locations and Development Type

	Sylvan Center		Police Station		
	SV-0	**SV-LID**	**PL-1**	**PL-2**	**PL-3**
Year 1	non-LID	LID	non-LID	non-LID	non-LID
Year 2	non-LID	LID	LID	partial LID[a]	LID

[a] Between Year No. 1 and Year No. 2, this area remained mostly unchanged from a drainage treatment standpoint, though lot usage patterns changed slightly, and mainly serves as a background control site for unimproved parking lot runoff. Following final design and construction of the Project, it was noted that the extensive roof runoff at this location was disconnected from the subsurface drain and routed to a rain garden.

2.1.1 Sylvan Community Center Site Descriptions

The Sylvan Center LID site (SV-LID) was monitored to provide a comparison site with a higher density of LID features (study site replication), to evaluate the actual performance against the expected performance, and to test additional sample collection approaches. Based on observation and site modeling, the Sylvan Center was not expected to have significant outflow to the MS4. The offsite drainage site (SV-0) was also considered as a "background" site without LID treatment to test assumptions that LID features would not increase constituent concentrations. However, the City Hall Complex site is considered the primary study location and focus of the Grant study.

During study Years No. 1 and No. 2, runoff samples were collected at the Sylvan Center monitoring locations SV-0 and SV-LID, shown in **Figure 1**, to assess offsite drainage and the net export from the LID site area, respectively. Runoff from the Sylvan Center is routed through multiple LID features before discharging to the MS4. A diagram of the general flow of urban runoff treatment at the Sylvan Center is shown in Figure 3 of **Appendix A**. The SV-0 sampling location, which characterizes the drainage area adjacent to the Sylvan Center, is at the start of a vegetated swale that drains to an inlet that connects directly to the MS4, downstream of SV-LID (i.e., it does not comingle with Sylvan Center urban runoff on-site). The southwestern discharge point (SV-LID) is the location at the end of a series of LID features to which the Sylvan Center drainage enters the MS4. However, because discharge to the MS4 seldom occurs, samples were collected in the infiltration vault, upstream from the rain garden and outflow point.

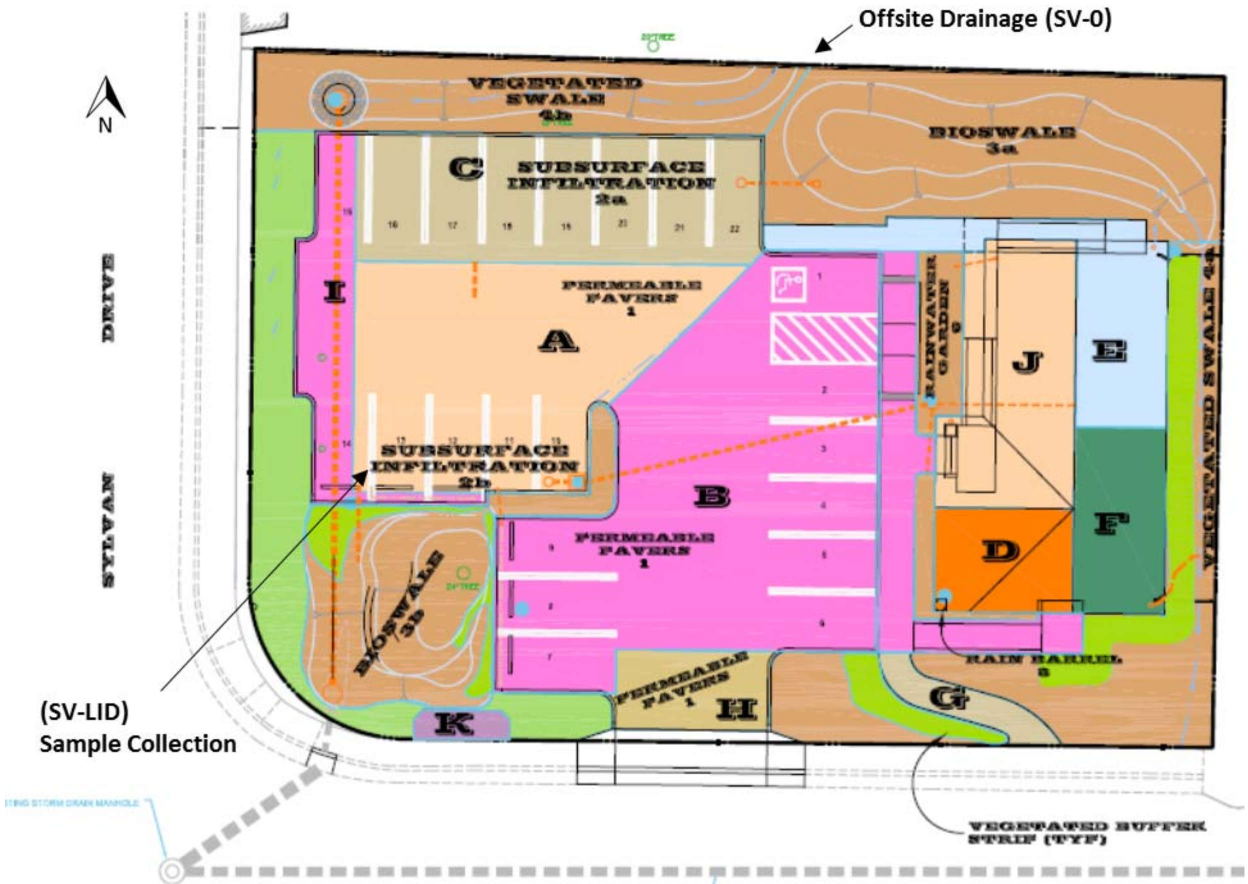

Figure 1. Sylvan Center Sampling Sites (SV-0 and SV-LID)

2.1.1.1 Sylvan Center, SV-0

The Sylvan Center site SV-0, the background site, is expected to help establish baseline "control" data for comparison with data from the Sylvan Center LID site. The sampling location is at the start of a bioswale that receives off-site runoff from adjacent parcels of primarily residential homes where runoff from roofs and landscaped yards occurs, shown in **Figure 2**. During Year No. 1, samples were collected at the entry point of the offsite drainage coming onto the site. Runoff volume was not measured at this location, though it was noted as significantly greater than the runoff volume at SV-LID. No samples were collected during Year No. 2.

2.1.1.2 Sylvan Center, SV-LID

The SV-LID location is at the end of a series of LID features and drains through an inlet to the same junction as the SV-0 flow, where the two flows comingle. During Year No. 2, SV-LID samples were collected in the Subsurface Infiltration Vault 2b (**Figure 3**). No samples were collected during Year No. 1 as outflow was not observed, based on measurements from the installed in-situ level sensor located in the Subsurface Infiltration Vault.

Figure 2. Entry Point of Offsite Runoff and Area Draining to SV-0, Sylvan Center, February 9, 2014

Figure 3. Subsurface Infiltration Vault, SV-LID Sample Location

2.1.2 City Hall Complex Site Descriptions

The City Hall Complex Police Station study area includes three monitoring locations: PL-1, PL-2 and PL-3. The four drainage areas and their respective sampling sites within the complex study area are shown in **Figure 4**. Samples were not collected from sampling site PL-4 shown in the figure, since PL-3 is the drainage point for Areas C and D (SAP, **Appendix A**).

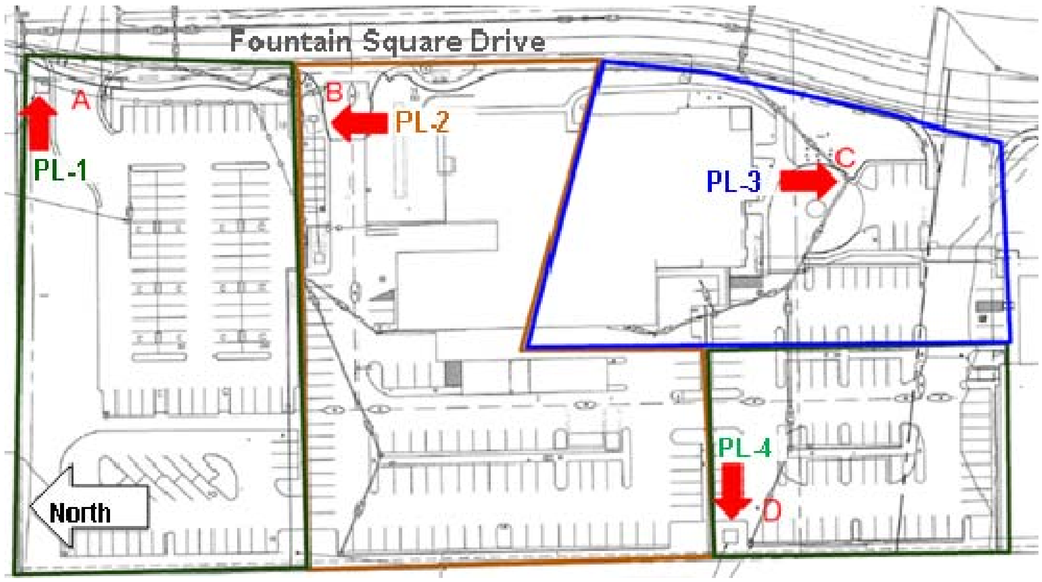

Figure 4. City Hall Complex Police Station Drainage Areas (A-D) and Sampling Sites

2.1.2.1 City Hall Complex, PL-1

Approximately 1.6 acres in the northern area of the City Hall Complex drain to PL-1. Samples were collected at the drain inlet where drainage from Area A enters the MS4 collection system. This drainage area underwent the largest modification between Year No. 1 and Year No. 2. During Year No. 1, the PL-1 drainage area was an undeveloped, unpaved storage yard composed of gravel and unimproved surfaces. Sampling during Year No. 1 was conducted to characterize pre-LID loading of methylmercury, representative of an undeveloped site in the Sacramento permitted area. As a result of implementing the improvements, runoff sampled at this location during Year No. 2 had been routed through various LID features, including permeable asphalt, a bioswale and a rain garden (**Figure 5**). In addition to the LID features, additional parking lot spaces were constructed with traditional asphalt that drained directly to the larger bioswale.

Figure 5. Bioswale Installation in Drainage Area A, Monitoring Location PL-1

2.1.2.2 City Hall Complex, PL-2

Approximately 1.7 acres of parking lot and roof runoff in the central area of the City Hall Complex drain to PL-2. Sampling was conducted below-ground in a manhole that accesses drainage. Between Year No. 1 and Year No. 2 the only LID feature added was a rain garden that treated roof runoff. At the time of monitoring plan design, PL-2 was expected to represent no LID features (i.e., a "negative control") pre- and post-Project, and it was not until final design and the hydrologic modeling report (April 2014) that the rain garden was adequately considered. The rain garden had significant benefits to flow reduction and this site could not be used as a true negative control. The parking lot area itself remained impermeable and the comparisons for this site between Year No. 1 and Year No. 2 primarily represent the influence of the rain garden.

Figure 6. Monitoring Location PL-2

2.1.2.3 City Hall Complex, PL-3

Approximately 2.2 acres at the southern end of the project site drain to PL-3; this includes drainage from 0.7 acres of PL-4 (**Figure 4**). Samples are collected below-ground from the opening of a downstream section of pipe, shown in **Figure 7**. The majority of post-construction drainage area was permeable parking lot and significant roof runoff, though the roof runoff is directly connected to the drainage system rather than routed to a rain garden as is the case for the other half of roof area in the PL-2 drainage area. Bioswales were installed that treat much of the drainage to PL-4 before entering the drainage system upstream of PL-3.

2.1.2.4 City Hall Complex, PL-4

The PL-4 location was not monitored as part of the Study. The PL-4 drainage area drains to PL-3 through a below grade drain.

Figure 7. Monitoring Location PL-3

2.2 STUDY PERIOD

The Project study was divided into two periods, Year No. 1 pre-Project and Year No. 2 post-Project (**Table 2**). Year No.1 was limited to January 2014 through March 2014 when construction began, while the Year No. 2 effort included the entire wet season (October 2014 through April 2015). During this timeframe, precipitation was recorded, and discharge at all monitoring locations was either measured or estimated from the site's measured runoff coefficient. Both years were characterized by less than normal rainfall with several larger events that accounted for much of the annual total precipitation. While the rainfall amounts observed during both years were not identical, they were similar enough for the purpose of comparing Year No. 1 and Year No. 2 results; however, lower than normal rainfall limited the opportunities to collect water quality samples.

Table 2. Study Time Period, Year No. 1 and Year No. 2

Study Year No.	Start Study	End Study
1	1/29/2014	3/11/2014
2	10/29/2014	4/30/2015

2.3 STUDY APPROACH

In-situ continuous sensors and field meters were installed at monitoring locations during Year No. 1 and Year No. 2, though the exact equipment installed varied from location to location. All locations were outfitted with a V-notch weir to measure flow and discharge volume. Location PL-1 was instrumented with a rain gage[3] and remote camera to monitor site conditions, assess the likelihood of discharge to the MS4 and gauge sampling feasibility throughout the monitoring period. Water quality parameters measured at monitoring locations included electrical conductivity (EC), turbidity, pH, dissolved oxygen (DO) and oxidation reduction-potential (ORP). Sylvan Center site SV-LID was equipped with a water level sensor to estimate discharge during Year No. 2. No other sensors were installed at the Sylvan Center.

A complete list of sensors installed at each monitoring location is provided in **Table 3**. Details on sensor equipment installation can be found in the post event monitoring summaries (**Appendix C** and **Appendix D**) and the continuous sensor data is provided in **Appendix I**. During periods of monitored discharge, data was collected and recorded every minute. During periods when water level sensors were without power or impaired, discharge volume was estimated using the drainage area's measured runoff coefficient, as calculated from measured precipitation and discharge. A complete record of precipitation and discharge is provided for each location during the period monitored.

During larger storm events, where discharge from all or many of the monitoring locations was predicted, field crews and automated samplers collected discrete for laboratory analysis. Continuous sensors were used to characterize flow and water quality parameters for the study period. Single grab samples were used at most sites, though composite samples and multiple grab samples were collected at PL-1, including the Year No. 2 use of an automated sampler to initiate sample collection remotely or based on specific turbidity or FDOM measurements (conditional sampling).

During Year No. 2, an automated microsampler with multiple bottle capability was installed at location PL-1 to better characterize the quality of runoff for the entire runoff period or to target specific FDOM or turbidity conditions. The device was equipped with programmed or manual initiation, and could collect up to four samples. The samples could then be analyzed individually, or combined as a composite sample.

A FDOM sensor was also installed at location PL-1 during Year No. 2 to better characterize methylmercury concentrations in stormwater runoff. This was implemented to explore the feasibility of using FDOM as an inexpensive, high resolution proxy for methylmercury concentration in stormwater runoff. During periods of discharge, the FDOM sensor recorded readings every minute. This data was then compared to the measured methylmercury concentration collected during grab sampling events. A regression of methylmercury versus FDOM was developed to better estimate continuous methylmercury concentration throughout the entirety of runoff.

[3] The rain gage is mounted near PL-1, in the northwest corner of City Hall Complex property.

Table 3. Equipment Installed at Sampling Locations

Study Year No.	Location	Equipment Installed
1	PL-1	V-notch weir/water level sensor, EC sensor, turbidity sensor, pH sensor, DO sensor, ORP sensor, rain gage, remote camera
	PL-2	V-notch weir/water level sensor
	PL-3	V-notch weir/water level sensor
	SV-0	None
2	PL-1	V-notch weir/water level sensor , EC sensor , turbidity sensor, pH sensor, DO sensor, ORP sensor, rain gage, remote camera, FDOM sensor, automated microsampler
	PL-2	V-notch weir/water level sensor, EC sensor, turbidity sensor, pH sensor, DO sensor, ORP sensor
	PL-3	V-notch weir/water level sensor, EC sensor, turbidity sensor
	SV-LID	Water level sensor

3 Flow Monitoring Results

Flow monitoring is a critical component of the effectiveness assessment monitoring approach. Flow meters were installed at three locations at the City Hall Complex and a level sensor was installed at the Sylvan Center, as described in the previous section. The City collected continuous study period flow rates during Year No. 2 at the City Hall Complex and tracked the occurrence of outflow from the Sylvan Center. Year No. 1 flow measurements were compared to the estimates of outflow from the pre-Project modeling from both sites to characterize the baseline (pre-Project) outflow from both sites. During the study, there were periods when data were not collected due to low sensor battery levels; these occurred primarily during extended dry periods when flow was minimal to negligible. For the periods when flow data was not measured, levels were estimated based on observed rainfall, the observed runoff coefficient and area as described below.

3.1 PRE-PROJECT FLOW MODELING

The City performed pre-Project modeling (Watearth, **Appendix E**) of the proposed design to estimate post-Project flow conditions and to comply with the proposed SSQP post-construction development standards[4], but does not use the newly developed Sacramento Area Hydrology Model (SAHM). The models for the City Hall Complex and the Sylvan Center (Watearth, **Appendix F**) were developed using the U.S. Environmental Protection Agency's (USEPA)'s Storm Water Management Model (SWMM) 5.0.022 to simulate the LID design storm. The SWMM model accounts for infiltration through various LID layers, evapotranspiration, infiltration into the native soil, and overflows and discharge from the LID facilities.

3.1.1 City Hall Complex

The continuous simulation was based on hourly rainfall data observed during 1970 to 2006 in Sacramento County (811.03 inches total)[5]. The simulation estimated that the pre-Project surface runoff would be 435.3 inches (volume per area or runoff coefficient of 0.54) and the post-Project surface runoff would be 73.8 inches (volume per area or runoff coefficient of 0.091). However, the modeled area (3.47 acres) does not include the additional two acres contributing to both PL-2 and PL-3 flows that were not modified as part of the project (i.e., unimproved areas not receiving treatment). Consideration of these areas increases the pre- and post-Project effective impervious areas and the overall runoff coefficients. Considering the unimproved impervious areas not included in the model estimate would increase the expected pre-Project impervious percent to approximately 0.71 (area weighted) and the post-Project runoff coefficient to 0.40.

3.1.2 Sylvan Community Center

The continuous simulation was based on hourly rainfall data observed during 1973 to 1985 in Sacramento County (271.43 inches total)[6]. The simulation estimated that the pre-Project surface

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[4] http://www.beriverfriendly.net/Newdevelopment/

[5] The analysis was performed based on 1970 – 2006 rainfall data obtained from the U.S. EPA's National Stormwater Calculator for the Repressa gauge, which is located in close proximity to the site,

[6] The analysis was performed based on rainfall data obtained from the Orangevale gauge, which is located in close proximity to the site.

runoff would be 160.40 inches and the post-Project surface runoff would be 61.27 inches (volume per area or runoff coefficient of 0.38).

3.2 MONITORING DRAINAGE AREA LAND USE CONVERSIONS

The City Hall Complex LID features are summarized in **Table 4**. The area within the monitored drainage that was not modified as part of the Project is summarized in **Table 5**. Treated and untreated areas represented at the three City Hall Complex monitoring locations are summarized in **Table 6**. The Sylvan Center site includes treatment of the entire site area as well as bioswale treatment of off-site drainage that passes through the site.

Table 4. City Hall Complex LID Improvements [Watearth, 2014]

LID Feature	General Location	Monitoring Study Area	Avg. LID Area (sq. ft.)	Drainage Area Treated (sq. ft.)
Bioswale 1	City Parking Lot	PL-3	1,064	11,290
Bioswale 2	City Parking Lot	PL-3	672	10,000
Bioswale 3	Police Department Lot	PL-1	2,184	17,422
Bioswale 4	Community Center Lot	PL-1	2,695	16,312
Bioswale 5	Community Center Lot	PL-1	1,040	7,278
Bioswale 6	Community Center Lot	PL-1	280	3,085
Permeable Pavement 1	City Parking Lot	PL-3	29,235	38,205
Permeable Pavement 2	Community Center Lot	PL-1	26,675	26,675
Rain Garden A	Community Center Lot	PL-1	380	3,268
Rain Garden B	Community Center Lot	PL-2	1,142	17,634
		Total Area (sq. ft.)	65,367	151,169
		Total Area (acres)	1.50	3.47

Table 5. City Hall Complex Land Use Not Modified

Untreated Areas	General Location	Monitoring Study Area	Drainage Area (sq. ft.)
Roof Runoff	Police Department Building	PL-3	25,134
Landscaped	Police Department Building	PL-3[a]	3,311
Impermeable Pavement	Police Department Lot	PL-3	4,792
Landscaped	Police Department Building	PL-2[a]	7,570
Impermeable Pavement	Police Department Lot	PL-2	49,658
		Total Area (sq. ft.)	90,465
		Total Area (acres)	2.08

Note: Areas calculated from design drawing estimated drainage areas
[a] Landscape median area adjacent to street is assumed to not drain to the monitoring location

Table 6. City Hall Complex Monitoring Location Drainage Area Treated

Monitoring Study Area	Area Treated (sq. ft.)	Area Untreated (sq. ft.)	Total Area (sq. ft.)
PL-1	74,040	0	74,040
PL-2	17,634	49,658	67,292
PL-3	59,495	29,926	89,421
Total Area (sq. ft.)	151,169	79,584	230,753
Total Area (acres)	3.47	1.83	5.30

3.3 YEAR NO. 1 FLOW CHARACTERIZATION

Year No. 1 pre-Project runoff conditions at the City Hall Complex were characterized based on the available modeling and an initial investigation with depth sensors and weirs. The approach was designed to identify any critical flow measurement issues for consideration in Year No. 2 to ensure that the post-Project flow measurements were accurate and reliable. The Sylvan Center flow rates were observed during three site visits during Year No. 1; on the same days that sampling was conducted at the City Hall Complex, only to confirm how the site functioned and to identify a flow measurement approach for Year No. 2. Monitoring was initiated at the end of January 2014 following the provisional approval of the QAPP and SAP. The data record for cumulative flow volume is show in **Figure 8**.

3.3.1 City Hall Complex

The 35% Project design submittal was completed at the end of the January 2014 and was the basis for the Year No. 1 pre-Project study. Year No. 1 was used to evaluate the sample collection and flow measurement approaches as the subgrade drains were not expected to change. Particular focus was placed on measurement of the PL-1 flow levels as the percent impervious area was expected to change the most of the three drainage areas. The PL-3 and PL-2 pre-Project drainages were nearly 100% impervious, including a large area of roof. Flow was measured using depth gages and v-notch weir inserts. A remote camera at PL-1 was also used to visually confirm flow conditions.

Table 7 summarizes the flow measurement results observed in all three drainage areas based on the weir discharge equations without modification or adjustment. As expected, outflow at PL-1 was minimal and occurred for only brief periods after heavy rainfall and when soils were saturated after multiple days of rainfall. Observed runoff volumes at PL-2 exceeded expected values for the impervious area, while much lower runoff values were observed at PL-3 given the nearly complete imperviousness of the pre-Project drainage.

PL-3 flow characterization was performed in the junction box, which appears to have introduced error underestimating the pre-Project flow baseline. To reduce the error, one recommendation was to move the level sensor from the junction box to the downstream “discharge” pipe during the Year No. 2 evaluation. Based on the area of pre-Project impervious area in the PL-3 drainage, a runoff coefficient approximating PL-2 is expected. However, because of the confirmed discrepancies with the modeled flows and the observed inaccuracies, it is not recommended that the measured values be used to characterize pre-Project conditions.

In Year No. 1, a weir insert combined with a pressure transducer level sensor was used for flow monitoring at PL-1 and PL-3 sites. These pressure level sensors showed significant drift, potentially because they were not continuously submerged, as in normal applications, and temperature cycling can cause the observed drift. The same weir inserts were used during Year No. 2 at PL-1 and PL-3 sites, but bubble level sensors were employed to resolve the pressure transducer drift. This weir/bubbler combo worked best.

During Year No. 1, flow was measured at PL-2 with an acoustic Doppler water velocity sensor in addition to a pressure transducer. However, this method was much more problematic than the weir/bubbler approach that was used at PL-2 in Year No. 2. Furthermore, noise in velocity readings due to debris and problems measuring lower flows were identified during Year No. 1 as additional issues. Therefore, the velocity sensor was not used in Year No. 2.

Table 7. City Hall Complex Year No. 1 Runoff Volume: Measured, Estimated and Total

Monitoring Location	PL-1	PL-2 [a]	PL-3 [a]
Start Study Period	1/29/2014 16:00	1/29/2014 16:00	1/29/2014 16:00
End Study Period	3/11/2014 8:00	3/11/2014 8:00	3/11/2014 8:00
Start Data Collection	2/7/2014 17:00	1/29/2014 16:00	2/14/2014 8:00
End Data Collection	3/3/2014 0:00	3/3/2014 0:00	3/11/2014 8:00
Recorded Precipitation (in)	4.92	6.00	2.82
Recorded Runoff Volume (L)	6,653	989,014	220,808
Measured Runoff Coefficient	0.0077	1.0	0.37
Precipitation During Estimated Period (in)	1.8	0.72	3.9
Estimated Runoff During Est. Period (L)	2,434	118,682	305,373
Total Precipitation (in)	6.72	6.72	6.72
Total Runoff (L)	9,087	1,107,696	526,181

Note: [a] Flow values were determined to not be representative of conditions and modeled flow values should be used for calculation of pre-Project loads or characterization of pre-Project conditions.

While the flow monitoring information collected in Year No. 1 was useful in evaluating the appropriate flow measurement approach, the data were not used to evaluate the overall Project effectiveness because accurate data were only collected for a limited period. Instead, the modeled pre-Project results are used as the "baseline" for flow and load reduction calculations.

3.3.2 Sylvan Community Center

Because observations determined that outflow was highly infrequent, the outflow at SV-LID was not quantified as a flow rate. In Year No. 1, a depth sensor was installed in the infiltration basin from February 14, 2014 to March 8, 2014, and field crews performed site visits during periods when outflow would be expected to perform field measurement of flows. Outflow was not observed, and it was recommended that a depth sensor remain in the infiltration vault that outflows to the rain garden before outflow off-site to the MS4 system. In this way, outflow could be anticipated and field crews mobilized. Significant flow was observed at SV-0, from the adjacent property(ies) (private residences), and flow rate estimates were performed. It was recommended to discontinue use of this site in Year No. 2 as a "pre-Project" characterization site because it was not representative of the site conditions. The data record for cumulative flow volume is show in **Figure 9**.

3.4 YEAR NO. 2 FLOW CHARACTERIZATION

Flow monitoring conducted during Year No. 2 characterized flow conditions for post-Project conditions at both study locations. These flow data and water quality data can be used to evaluate the flow and load reduction benefit of the LID projects when compared to the modeled pre-Project flow and water quality samples collected during Year No. 1.

3.4.1 City Hall Complex

The recommendations in Year No. 1 to use bubbler sensors for accurate measurements of the depth of water over the v-notch weirs resulted in higher quality flow data at all three locations. Data were collected for the entire wet season with only minor breaks due to low battery power that occurred primarily during dry periods and smaller rainfall results. Flows were estimated for these periods based on the runoff coefficients observed for the period of record as shown in **Table 8**.

Table 8. City Hall Complex Year No. 2 Runoff Volume: Measured, Estimated and Total

Monitoring Location	PL-1	PL-2	PL-3
Start Study Period	10/29/2014 8:25	10/29/2014 8:25	10/29/2014 8:25
End Study Period	4/30/2015 0:45	4/30/2015 0:45	4/30/2015 0:45
Start Data Collection	10/30/2014 9:10	11/6/2014 14:07	10/29/2014 8:25
End Data Collection	4/30/2015 0:45	4/30/2014 0:45	2/24/2015 16:45
Recorded Precipitation (in)	13.81	13.47	10.61
Recorded Runoff Volume (L)	361,055	1,526,423	1,121,544
Measured Runoff Coefficient	0.16	0.71	0.50
Precipitation During Estimated Period (in)	0	0.34	3.2
Estimated Runoff During Est. Period (L)	0	38,529	338,260
Total Precipitation (in)	13.81	13.81	13.81
Total Runoff (L)	361,055	1,564,952	1,459,804

3.4.2 Sylvan Community Center

From December 9, 2014 to March 26, 2015, a depth sensor was installed and functional in the infiltration vault just upstream from the rain garden that outflows off-site to the MS4. When the water elevation in the vault exceeded the overflow pipe invert elevation, outflow to the rain garden was presumed. When this occurred, field crews were mobilized to the site to estimate the discharge volume. Overflow to the rain garden occurred only once during Year No. 2 which included a number of significant rainfall events and extended dry periods. The overflow to the rain garden was recorded between December 14, 2014 00:50 to December 14, 2014 05:20 (approximately 4.5 hour duration). Field crews did not observe overflow offsite to the MS4 at the initial infiltration vault overflow, but were able to collect water quality samples of the volume entering the rain garden. The volume discharged to the MS4 system was estimated as less than 1,000 gallons based on physical dimensions of the rain garden and the duration of inflow from the infiltration vault. The actual volume was likely in the hundreds of gallons.

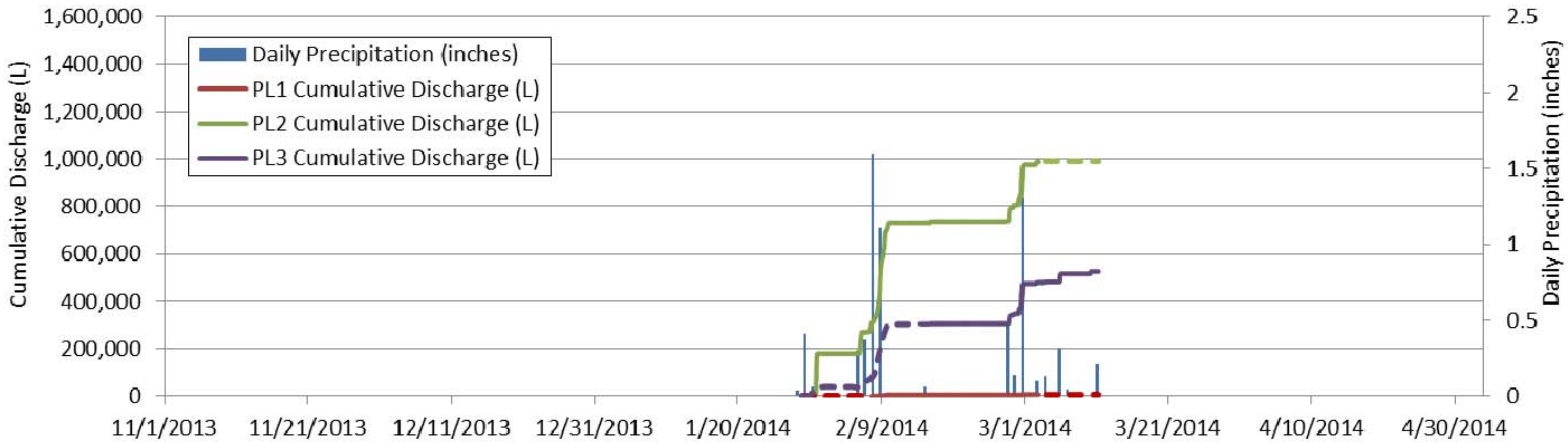


Figure 8. Cumulative Precipitation and Discharge During Year No. 1

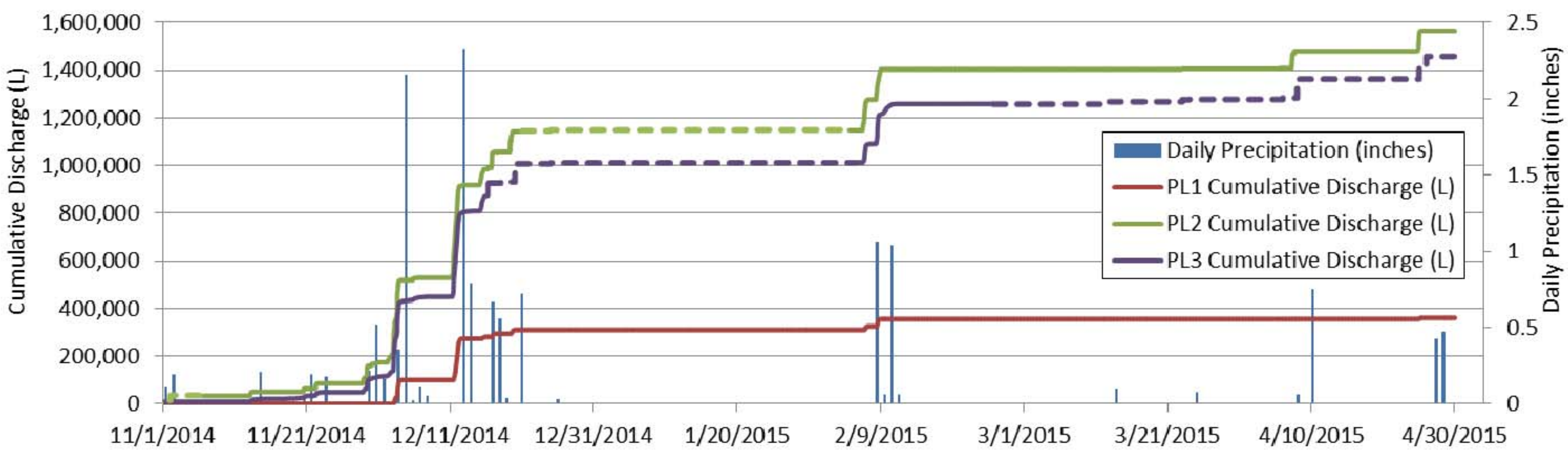


Figure 9. Cumulative Precipitation and Discharge During Year No. 2

Note: Dashed lines indicate periods when in-situ sensors lost power. Discharge for this time is estimated from measured site runoff coefficients and the on-site precipitation gage.

3.5 YEAR NO. 2 RUNOFF COEFFICIENT CALCULATION

Comparisons between the pre- and post-LID improvement runoff coefficients can be used to evaluate the effectiveness of the LID projects at reducing the volume of runoff leaving the sites. However, both projects increased parking lot surface area, including the significant change at the City Hall Complex where the PL-1 drainage area was converted from nearly complete pervious surfaces to parking lots with pervious and impervious pavement.

3.5.1 City Hall Complex

Calculation of the drainage area tributary to each monitoring location (**Table 4** to **Table 6**) is required to evaluate the change in runoff coefficient as volume of runoff per inch of rain and per acre of area. The pre-Project runoff coefficient was estimated to be 0.71 based on the pre-Project modeling and adjustments to consider the entire drainage area, including impervious surfaces not modified by the Project. Based on the Year No. 2 flow data at all three monitoring locations (**Table 8**), the effective runoff coefficient is 0.45 (area weighted). If the unchanged impervious acres are removed (**Table 5**), the post-Project measured effective runoff coefficient is estimated as 0.11 compared to the post-Project modeled estimate of 0.091. However, the modeled conditions are the average of the entire simulation period which includes a wider range of conditions than was evaluated in the one year post-Project study period.

4 Water Quality Monitoring

The City characterized water quality through the use of water quality sensors summarized in **Table 3**, grab sample collection, and the deployment of an automated sampler at PL-1 capable of collecting multiple samples over extended periods (five to fifteen minute capture), which was referred to as “microsampling”. Also, the City collected multiple samples during key water quality conditions to develop a surrogate relationship between the FDOM sensor and concentration of methylmercury.

4.1 SAMPLE COLLECTION EVENTS

A Larry Walker Associates, Inc. (LWA) field crew conducted wet weather stormwater monitoring during nine events over the two year study timeframe. During the events, stormwater discharge samples were collected for laboratory analysis. Periods of high rainfall with the highest probability of generating outflow from all monitoring locations were targeted for grab events. LWA conducted storm tracking based on weather forecasts, radar images from the National Weather Service, real-time local precipitation data from the Department of Water Resources, and real-time precipitation data from the on-site rain gage. Based on storm tracking and data provided by in-situ sensors, sample collection was targeted prior to the estimated period of peak runoff.

Four sampling events were conducted in Year No. 1, and five sampling events were conducted in Year No. 2. **Table 9** summarizes the location and date and time of sample collection during these events.

Table 10 summarizes the rainfall and runoff volume estimates at the City Hall Complex locations. The events are described in more detail in **Appendix C** and **Appendix D** event memoranda. The list of constituents shown in **Table 11** was monitored for most samples outside of specific evaluations for methylmercury surrogate relationships and concentration changes over time.

Table 9. Summary of Events and Samples Collected

Year No.	Event No.	Date	Sample Timeframe	Sampling Locations
1	CH01	January 30, 2014	1:50 - 2:30	PL-2
	CH02	February 9, 2014	13:00 - 16:45	PL-1, PL-3, SV-0
	CH03	February 26, 2014	19:30 - 23:00	PL-2, PL-3
	CH04	February 28, 2014	15:55 - 18:10	PL-1, PL-3
2	CH05	November 29, 2014	10:50 - 11:45	PL-2, PL-3
	CH06	December 3, 2014	4:22 - 11:20	PL-1, PL-2, PL-3
	CH07	December 11, 2014	12:26 - 23:50	PL-1, PL-2, PL-3, SV-LID
	CH08	February 6, 2015	13:50 - 22:37	PL-1, PL-2, PL-3
	CH09	February 8, 2015	12:50 - 15:10	PL-1

Table 10. Precipitation (in) and Discharge (L) Per Event at the City Hall Complex

Event	Precipitation (in)	Discharge (L)		
		PL-1	PL-2	PL-3
CH01	0.19	--	12,825	--
CH02	2.7	5,059	395,760	---
CH03	0.44	0	50,736	34,999
CH04	1.31	1,539	170,294	128,224
CH05	0.71	0	73,752	54,195
CH06	2.18	100,510	315,395	296,814
CH07	3.12	173,494	385,820	355,137
CH08	1.12	15,412	128,000	77,859
CH09	1.04	30,089	127,465	123,895

Table 11. Constituents Analyzed by the Laboratories

Constituent	Units	Pesticide	Units
Methyl Mercury	ng/L	Allethrin	ng/L
Mercury - Total	ng/L	Bifenthrin	ng/L
Mercury - Reactive	ng/L	Chlorpyrifos	ng/L
Copper - Dissolved	µg/L	Cyfluthrin	ng/L
Copper - Total	µg/L	Lambda-Cyhalothrin	ng/L
Lead - Dissolved	µg/L	Cypermethrin	ng/L
Lead - Total	µg/L	Diazinon	ng/L
Nickel - Dissolved	µg/L	Deltamethrin:Tralomethrin	ng/L
Nickel - Total	µg/L	Esfenvalerate:Fenvalerate	ng/L
Zinc- Dissolved	µg/L	Fenpropathrin	ng/L
Zinc - Total	µg/L	Tau-Fluvalinate	ng/L
Chloride	µmol/L	Permethrin	ng/L
Sulfate	µmol/L	Tetramethrin	ng/L
Nitrogen, Total Kjeldahl	mg/L		
Nitrogen, Nitrate-Nitrite	mg/L		
Nitrogen, Ammonia (as N)	mg/L		
Phosphorus - Total	mg/L		
Turbidity	NTU		
Dissolved Organic Carbon	mg/L		
Total Organic Carbon	mg/L		
Total Dissolved Solids	mg/L		
Total Suspended Solids	mg/L		
Suspended Sediment Concentration	mg/L		

4.2 QUALITY CONTROL REVIEW

This section presents the results of the quality assurance/quality control (QA/QC) analyses conducted during the study period (provided in **Appendix H**) and an evaluation of the effects of the QA/QC results on the data collected at the LID monitoring sites.

The procedures used in the QA/QC analysis performed for the study are detailed in the QAPP. The QAPP (**Appendix A**) includes a discussion of each type of QA/QC parameter examined. In addition, the document contains tables of data acceptability or data quality objectives (DQOs) for spike recovery, relative percent difference (RPD) between duplicate samples, and holding times. The review process considers both field sampling and laboratory analytical issues.

4.2.1 Contamination Checks

Potential sources of contamination are evaluated by analyzing field and method blanks. Field blanks must be collected by the same process as the environmental sample and can confirm whether the collection process has a potential to contaminate the sample. Method blanks are run in the laboratory and check for any possible contamination during the analysis.
The QAPP requires qualification of any blank sample if its concentration is greater than that of its reporting limit (RL). If the blank sample is qualified as having potential contamination and the environmental sample is less than five times the concentration of the blank, then the environmental is also qualified.

The results of the field and method blank analyses are listed in **Table 12**. There were 22 blank samples that required qualification, but of those qualified only six resulted in an environmental sample being labeled as having potential contamination. Trace metals had the highest prevalence of potential contamination, but most of the environmental results were much higher than the blank concentrations. Metals are common contaminants, since they can be found in the environment and atmosphere; therefore, the occurrence of contaminated samples should not impact the overall results.

Table 12. Contamination Checks in Field and Method Blanks

Event	Site	Collection Date	Analyte	Units	Result: Blank	Result: ENV	QA Code
CH01	PL-1	1/30/2014	Mercury – Total	ng/L	0.0014	0.011	[a]
CH01	PL-1	1/30/2014	Zinc – Dissolved	µg/L	1.60	180	[a]
CH08	PL-2	2/6/2015	Chloride	µmol/L	16.39	30	IP
CH02	PL-3	2/9/2014	Sulfate	µmol/L	1.35	13.5	[a]
CH03	PL-2	2/26/2014	Sulfate	µmol/L	1.44	6.9	IP
CH05	PL-3	11/29/2014	Sulfate	µmol/L	0.53	186.2	[a]
CH08	PL-2	2/6/2015	Sulfate	µmol/L	2.16	12.9	[a]
CH08	PL-2	2/6/2015	Nickel – Total	µg/L	0.97	5.11	[a]
CH02	PL-3	2/9/2014	Copper – Total	µg/L	1.84	12.78	[a]
CH08	PL-2	2/6/2015	Copper – Total	µg/L	2.04	15	[a]
CH05	PL-3	11/29/2014	Zinc – Total	µg/L	1.11	152.76	[a]
CH08	PL-2	2/6/2015	Zinc – Total	µg/L	2.19	78.3	[a]
CH02	PL-3	2/9/2014	Lead – Total	µg/L	0.24	4.42	[a]
CH05	PL-3	11/29/2014	Lead – Total	µg/L	0.26	4.64	[a]
CH08	PL-2	2/6/2015	Lead – Total	µg/L	0.39	2.78	[a]
CH08	PL-2	2/6/2015	Nickel – Dissolved	µg/L	1.14	1.25	IP
CH08	PL-2	2/6/2015	Copper – Dissolved	µg/L	1.68	7.49	IP
CH05	PL-3	11/29/2014	Zinc – Dissolved	µg/L	1.66	32.35	[a]
CH08	PL-2	2/6/2015	Zinc – Dissolved	µg/L	4.21	40.66	[a]
CH02	PL-3	2/9/2014	Lead – Dissolved	µg/L	0.22	0.21	IP
CH08	PL-2	2/6/2015	Lead – Dissolved	µg/L	0.47	<0.10	IP
CH08	Caltest	2/7/2015	SSC	mg/L	3.2	38	[a]

[a] Blank result was qualified, since it was reported as >RL, but environmental result did not necessitate qualification because its concentration was 5x greater than the blank concentration.
[b] This analysis was a method blank analysis and was performed on blank water within the Caltest laboratory.
IP = SWAMP qualification for analyte detected in method, trip, or field blank.

4.2.2 Accuracy Checks

Matrix spikes and laboratory control spikes (LCS) are used to check the accuracy of a result. Matrix spikes are run by spiking the environmental sample with a known quantity of analyte. The spike is then analyzed and the result is compared to the expected result. From that the percent recovery is calculated. Any percent recovery that is outside of the laboratory specified control limits are then qualified.

Table 13 contains the results for any matrix spike that was outside of the control limit and its respective environmental result. There were nine matrix spikes that had percent recoveries that were below the lower control limits and were qualified as being biased low. All of these resulted in qualification of the environmental samples. There was also one matrix spike that had a recovery that was higher than the upper control limit. This also resulted in a qualification of the environmental sample. There were no issues with any of the LCS results. Therefore, no environmental results needed qualification.

Table 13. Accuracy Checks in Matrix Spikes

Event	Site	Collection Date	Analyte	Units	Percent Recovery	Control Limits		ENV Result	QA Code
						Lower	Upper		
CH02	PL-1	2/9/2014	Diazinon	ng/L	12	50	150	9	GB
CH02	PL-1	2/9/2014	Lambda-Cyhalothrin	ng/L	33	40	120	<0.2	GB
CH02	PL-1	2/9/2014	Esfenvalerate: Fenvalerate	ng/L	34	40	140	<0.2	GB
CH02	PL-1	2/9/2014	Bifenthrin	ng/L	40	70	165	<0.1	GB
CH02	PL-1	2/9/2014	Cyfluthrin	ng/L	41	55	140	<0.2	GB
CH02	PL-1	2/9/2014	Cypermethrin	ng/L	40	50	130	<0.2	GB
CH02	PL-1	2/9/2014	Permethrin	ng/L	46	50	160	<2	GB
CH03	PL-3	2/26/2014	Diazinon	ng/L	47	50	150	<0.2	GB
CH07	PL-3	12/11/2014	Nitrogen, Nitrate-Nitrite	mg/L	89	90	110	0.098[DNQ]	GB
CH06	PL-1	12/3/2014	Total Phosphorus as P	mg/L	125	90	110	0.1	GB

GB = Matrix spike recovery is outside of the control limits
DNQ = Detected but not quantified

4.2.3 Precision Checks

Precision evaluates the reproducibility of a given result by running two samples concurrently and comparing the results. Precision checks are divided between samples that are collected in the field and duplicates that are run in the laboratory. Any precision check is qualified if its relative percent difference (RPD) to the primary result is greater than 25 and the difference between the two results is greater than the RL.

Field precision checks were evaluated by collecting field duplicates at the same time as the environmental samples. **Table 14** contains any field duplicates and their respective environmental results that required qualification. There were nine results that required qualification during the study period.

Table 14. Precision Checks in Field Duplicates

Event	Site	Collection Date	Analyte	Units	Result		RPD	QA Code
					ENV	DUP		
CH03	PL-3	2/26/2014	Chloride	µmol/L	6.77	12.32	58.2	FDP
CH03	PL-3	2/26/2014	Sulfate	µmol/L	7.16	12.25	52.5	FDP
CH03	PL-3	2/26/2014	Zinc – Total	µg/L	46.35	87	61.0	FDP
CH03	PL-3	2/26/2014	Lead – Total	µg/L	0.77	0.28	93.3	FDP
CH03	PL-3	2/26/2014	Copper – Dissolved	µg/L	2.37	3.49	38.2	FDP
CH03	PL-3	2/26/2014	Zinc – Dissolved	µg/L	23.61	68.73	97.7	FDP
CH02	PL-1	2/9/2014	Methyl Mercury	ng/L	0.010	0.15	41.5	FDP

CH02	PL-1	2/9/2014	Mercury – Reactive	ng/L	1.38	3.06	75.7	FDP
CH02	PL-1	2/9/2014	Lead – Total	µg/L	2.03	0.99	68.9	FDP

FDP = Field duplicate RPD was greater than the acceptability criteria of 25.

Laboratory precision checks were evaluated by comparing multiple pairs of matrix spikes and LCSs called matrix spike duplicates (MSDs) and laboratory control spike duplicates (LCSD), respectively. The results of the MSD and LCSDs are in **Table 15**. There were two MSDs that had RPDs greater than the acceptability criteria. Both of these resulted in qualification of the environmental sample. There were four LCSDs that were qualified, which resulted in 16 environmental samples being qualified. These qualified data are not rejected and can still be used with the understanding that laboratory quality assurance indicates the results were less reproducible. All of the samples were non-detect, but still necessitated qualification, though the issue is not considered significant. There is currently no EPA promulgated method specified for pyrethroids that laboratories can perform to adequately low reporting limits.

Table 15. Precision Checks in Matrix Spike Duplicates and Laboratory Control Spike Duplicates

QA Type	Event	Site	Collection Date	Analyte	Percent Recovery		RPD	QA Code
					Primary	Duplicate		
MSD	CH03	PL-3	2/26/2014	Deltamethrin: Tralomethrin	99	64	43	IL
MSD	CH03	PL-3	2/26/2014	Chlorpyrifos	46	75	45	IL
LCSD	CH06	Caltest	12/16/2014	Lambda-Cyhalothrin	58	76	27	IL
LCSD	CH05	Caltest	12/15/2014	Chlorpyrifos	62	85	31	IL
LCSD	CH05	Caltest	12/15/2014	Diazinon	64	89	33	IL
LCSD	CH08	Caltest	2/27/2015	Lambda-Cyhalothrin	74	97	27	IL

IL = MSD or LCSD had a RPD greater than the acceptability criteria of 25.

4.3 ANALYSIS RESULTS

Water quality analyses were performed by the United States Geological Survey (USGS) laboratory in Menlo Park, California and Caltest Analytical Laboratory in Napa, California for the constituents listed in **Table 11**. Field measurement results recorded on log sheets for the entire study period are show in **Table 16**. Water quality sample results reported by the laboratories, including data qualifications, are provided in **Table 17** through **Table 28**. All environmental water quality data is provided in **Appendix G**. Results are provided as a reference and are summarized and discussed in subsequent sections.

Table 16. Field Probe Data, All Events

Event	Site	Water Temp (°C)	Air Temp. (°C)	pH	EC (µS/cm)	Turbidity (NTU)	DO (mg/L)	ORP (mV)
CH01	PL-2	12.8	10.3	7.46	169.8	[a]	9.6	[a]
CH02	PL-1	13.4	13.4	[c]	195.7	43.4	4.7	[a]
CH02	PL-3	14.2	14.1	5.51	44.7	[a]	10.9	[a]
CH02	SV-0	13.1	13.7	4.9	188.5	33.4	6.3	[a]
CH03	PL-2	12.8	12.0	6.48	[a]	49.5	10.8	[a]
CH03	PL-3	13.3	11.8	6.57	175.7	25.4	10.4	[a]
CH03	PL-3[b]	13.6	12.4	5.24	633	25.1	10.4	[a]
CH04	PL-1	12.4	10.8	3.61	173.4	98.4	9.9	[a]
CH04	PL-1[b]	12.2	11.2	3.32	372	102	9.2	[a]
CH04	PL-3	12.3	10.6	4.16	83.6	27.8	10.7	[a]
CH05	PL-2	13.6	12.2	8.46	25.2/26.1	[a]	10.5	[a]
CH05	PL-3	13.7	[a]	8.19	85.4	[a]	10.8	[a]
CH06	PL-1	[a]	[a]	8.08	141	[a]	9.0	[a]
CH06	PL-2	[a]	[a]	7.91	302	[a]	9.9	[a]
CH06	PL-3	[a]	[a]	8.07	421	[a]	10.5	[a]
CH07	PL-1	13.06	[a]	7.76	75.4	[a]	10.07	108.6
CH07	PL-2	12.38	[a]	8.33	13.6	[a]	10.81	104.9
CH07	PL-3	14.88	[a]	8.54	101.4	[a]	10.17	77.8
CH07	SV-LID	14.7	[a]	7.49	121.8	[a]	9.41	85.5
CH08	PL-2	12.8	[a]	6.4	18.37	[a]	11.8	[a]
CH08	PL-3	14.3	[a]	6.42	194.2	[a]	11.6	[a]

[a] Not sampled
[b] The sample was collected at the same location at a later time
[c] The field meter did not appear to be functioning properly. The pH was reported to be 3.65.

Table 17. Water Quality Data, Event CH01 (January 30, 2014)

Constituent	Units	PL-2	PL-2 Field Blank
Methyl Mercury	ng/L	0.17	< 0.02
Mercury – Total	ng/L	11	1.4
Mercury – Reactive	ng/L	[a]	[a]
Copper – Dissolved	µg/L	28	0.21 DNQ
Copper – Total	µg/L	28	0.11 DNQ
Lead - Dissolved	µg/L	1.1	< 0.03
Lead - Total	µg/L	1.5	< 0.03
Nickel - Dissolved	µg/L	5.9	< 0.06
Nickel - Total	µg/L	6.3	< 0.06
Zinc- Dissolved	µg/L	180	1.6
Zinc - Total	µg/L	190	< 0.7
Chloride	µmol/L	[a]	[a]
Sulfate	µmol/L	31.2 [b]	[a]
Nitrogen, Total Kjeldahl	mg/L	1.6	[a]
Nitrogen, Nitrate-Nitrite	mg/L	0.38	[a]
Nitrogen, Ammonia (as N)	mg/L	[a]	[a]
Phosphorus - Total	mg/L	1.3	[a]
Turbidity	NTU	7.9	[a]
Dissolved Organic Carbon	mg/L	110	[a]
Total Organic Carbon	mg/L	110	[a]
Total Dissolved Solids	mg/L	240	[a]
Total Suspended Solids	mg/L	< 4	[a]
Suspended Sediment Concentration	mg/L	17	[a]
Allethrin	ng/L	[a]	[a]
Bifenthrin	ng/L	[a]	[a]
Chlorpyrifos	ng/L	[a]	[a]
Cyfluthrin	ng/L	[a]	[a]
Lambda-Cyhalothrin	ng/L	[a]	[a]
Cypermethrin	ng/L	[a]	[a]
Diazinon	ng/L	[a]	[a]
Deltamethrin:Tralomethrin	ng/L	[a]	[a]
Esfenvalerate:Fenvalerate	ng/L	[a]	[a]
Fenpropathrin	ng/L	[a]	[a]
Tau-Fluvalinate	ng/L	[a]	[a]
Permethrin	ng/L	[a]	[a]
Tetramethrin	ng/L	[a]	[a]
pH	Std. units	[a]	[a]
Electrical Conductivity	µS/cm	[a]	[a]

DNQ = Detected but not quantified
[a] Constituent not analyzed
[b] This result was initially reported as 3 mg/L.

Table 18. Water Quality Data, Event CH02 (February 9, 2014)

Constituent	Units	PL-1A	PL-1A Field Duplicate	PL-1B	PL-3	PL-3 Field Blank	SV-0
Methyl Mercury	ng/L	0.099[FDP]	0.151	0.072	0.074	< 0.007	0.213
Mercury - Total	ng/L	8.56	8.00	6.35	2.23	< 0.11	15.98
Mercury - Reactive	ng/L	1.38[FDP]	3.06	2.04	0.72	< 0.30	3.73
Copper - Dissolved	µg/L	7.83	7.12	6.38	1.50	0.45[DNQ]	9.50
Copper - Total	µg/L	11.07	8.70	5.72	2.22	1.84	12.78
Lead - Dissolved	µg/L	0.28	0.28	0.30	0.21[IP]	0.22	0.69
Lead - Total	µg/L	2.03[FDP]	0.99	0.22	< 0.04	0.24	4.42
Nickel - Dissolved	µg/L	2.80	2.83	2.68	0.40[DNQ]	< 0.04	2.71
Nickel - Total	µg/L	4.10	4.10	2.77	0.20[DNQ]	< 0.01	2.85
Zinc- Dissolved	µg/L	23.71	23.60	19.03	15.51	0.80[DNQ]	31.39
Zinc - Total	µg/L	34.01	36.80	22.20	23.74	< 0.27	43.23
Chloride	µmol/L	160.8	155.6	125.7	17.0	0.4[DNQ]	477.0
Sulfate	µmol/L	83.2	82.3	80.9	13.5	1.4	87.7
Nitrogen, Total Kjeldahl	mg/L	0.83	0.75	2.9	0.22	[a]	1.6
Nitrogen, Nitrate-Nitrite	mg/L	< 0.02	< 0.02	0.021[DNQ]	0.24	[a]	3.2
Nitrogen, Ammonia (as N)	mg/L	0.24	0.32	0.25	0.23	[a]	0.29
Phosphorus - Total	mg/L	4.7	4.6	4.9	0.085[DNQ]	[a]	0.27
Turbidity	NTU	27	27	17	4.7	[a]	17
Dissolved Organic Carbon	mg/L	64	61	62	4.7	0.56[DNQ]	12
Total Organic Carbon	mg/L	67	64	70	5.4	< 0.3	12
Total Dissolved Solids	mg/L	260	280	290	24	[a]	160
Total Suspended Solids	mg/L	40.3	44.0	20.0	5.0[DNQ]	< 5.0	14.0
Suspended Sediment Concentration	mg/L	28	128	41	3.4	[a]	21
Allethrin	ng/L	< 0.1	< 0.1	< 0.1	< 0.2	< 0.1	< 0.1
Bifenthrin	ng/L	< 0.1[GB]	< 0.1	< 0.1	2.2	< 0.1	1.1[DNQ]
Chlorpyrifos	ng/L	< 0.5	< 0.5	< 0.5	0.8[DNQ]	< 0.5	< 0.5
Cyfluthrin	ng/L	< 0.2[GB]	< 0.2	< 0.2	< 0.3	< 0.2	1.0[DNQ]
Lambda-Cyhalothrin	ng/L	< 0.2[GB]	< 0.2	< 0.2	< 0.3	< 0.2	< 0.2
Cypermethrin	ng/L	< 0.2[GB]	< 0.2	< 0.2	< 0.3	< 0.2	< 0.2
Diazinon	ng/L	9.0[GB]	5.2	< 0.1	< 0.2	< 0.1	< 0.1
Deltamethrin:Tralomethrin	ng/L	< 0.2	< 0.2	< 0.2	< 0.3	< 0.2	< 0.2
Esfenvalerate:Fenvalerate	ng/L	< 0.2[GB]	< 0.2	< 0.2	< 0.3	< 0.2	< 0.2
Fenpropathrin	ng/L	< 0.2	< 0.2	< 0.2	< 0.3	< 0.2	< 0.2
Tau-Fluvalinate	ng/L	< 0.2	< 0.2	< 0.2	< 0.3	< 0.2	< 0.2
Permethrin	ng/L	< 2[GB]	< 2	< 2	< 3	< 2	15
Tetramethrin	ng/L	< 0.2	< 0.2	< 0.2	< 0.3	< 0.2	< 0.2
pH	Std. units	6.65	6.47	6.50	6.35	6.08	6.13
Electrical Conductivity	µS/cm	170.5	171.1	191.6	28.1	5.1	168.9

DNQ = Detected but not quantified
IP = Analyte detected in method, trip, or equipment blank GB = Matrix spike recovery is outside of the control limits
FDP = Field duplicate RPD was greater than the acceptability criteria of 25.
[a] Constituent not analyzed

Table 19. Water Quality Data, Event CH03 (February 26, 2014)

Constituent	Units	PL-2 Field Blank	PL-2	PL-3	PL-3 Field Duplicate	PL-3B
Methyl Mercury	ng/L	< 0.007	0.161	0.079	0.073	0.120
Mercury - Total	ng/L	< 0.11	11.17	4.82	4.50	5.99
Mercury - Reactive	ng/L	< 0.30	0.91	0.88	1.00	0.53
Copper - Dissolved	µg/L	0.36[DNQ]	2.82	2.37[FDP]	3.49	2.07
Copper - Total	µg/L	0.23[DNQ]	14.68	4.60	4.82	3.77
Lead - Dissolved	µg/L	< 0.16	< 0.16	0.19[DNQ]	0.29	0.25
Lead - Total	µg/L	< 0.04	4.44	0.77[FDP]	0.28	0.35
Nickel - Dissolved	µg/L	< 0.04	< 0.04	0.36[DNQ]	0.68	0.42[DNQ]
Nickel - Total	µg/L	< 0.01	2.29	0.23[DNQ]	< 0.01	0.19[DNQ]
Zinc- Dissolved	µg/L	0.55[DNQ]	22.71	23.61[FDP]	68.73	21.52
Zinc - Total	µg/L	< 0.27	118.19	46.35[FDP]	87.00	42.69
Chloride	µmol/L	0.5[DNQ]	3.7	6.8[FDP]	12.3	8.1
Sulfate	µmol/L	1.4	6.9[IP]	7.2[FDP]	12.2	7.4
Nitrogen, Total Kjeldahl	mg/L	[a]	0.70	0.48	0.88	0.087[DNQ]
Nitrogen, Nitrate-Nitrite	mg/L	[a]	0.12	0.19	0.29	0.15
Nitrogen, Ammonia (as N)	mg/L	[a]	[a]	[a]	[a]	[a]
Phosphorus - Total	mg/L	[a]	0.19	0.13	0.52	0.12
Turbidity	NTU	[a]	[a]	[a]	[a]	[a]
Dissolved Organic Carbon	mg/L	< 0.3	3.8	4.8	7.6	4.5
Total Organic Carbon	mg/L	< 0.3	2.9	4.8	8.1	4.5
Total Dissolved Solids	mg/L	[a]	4.0[DNQ]	6.0[DNQ]	23	14
Total Suspended Solids	mg/L	< 5.0	80.0	25.0	19.0	26.5
Suspended Sediment Concentration	mg/L	[a]	109	19	428	57
Allethrin	ng/L	< 0.1	< 0.2	< 0.2	< 0.1	< 0.1
Bifenthrin	ng/L	< 0.1	16	2.9	2.2	4.3
Chlorpyrifos	ng/L	< 0.5	1.2[DNQ,IL]	< 1	0.9[DNQ]	1[DNQ]
Cyfluthrin	ng/L	< 0.2	3.7	0.7[DNQ]	0.5[DNQ]	0.7[DNQ]
Lambda-Cyhalothrin	ng/L	< 0.2	0.5[DNQ]	< 0.4	< 0.2	< 0.2
Cypermethrin	ng/L	< 0.2	< 0.4	< 0.4	< 0.2	< 0.2
Diazinon	ng/L	< 0.1	< 0.2	< 0.2[GB]	< 0.1	< 0.1
Deltamethrin:Tralomethrin	ng/L	< 0.2	51	2.9[DNQ,IL]	3.2	11
Esfenvalerate:Fenvalerate	ng/L	< 0.2	< 0.4	< 0.4	< 0.2	< 0.2
Fenpropathrin	ng/L	< 0.2	< 0.4	< 0.4	< 0.2	< 0.2
Tau-Fluvalinate	ng/L	< 0.2	< 0.4	< 0.4	< 0.2	< 0.2
Permethrin	ng/L	< 2	< 4	< 4	< 2	< 2
Tetramethrin	ng/L	< 0.2	< 0.4	< 0.4	< 0.2	< 0.2
pH	Std. units	6.56	6.20	6.05	6.01	6.13
Electrical Conductivity	µS/cm	5.55	12.36	13.46	21.3	14.69

DNQ = Detected but not quantified
IP = Analyte detected in method, trip, or equipment blank
GB = Matrix spike recovery is outside of the control limits
FDP = Field duplicate RPD was greater than the acceptability criteria of 25.
IL = MSD or LCSD had a RPD greater than the acceptability criteria of 25.
[a] Constituent not analyzed

Table 20. Water Quality Data, Event CH04 (February 24, 2014)

Constituent	Units	PL-1	PL-1B	PL-3
Methyl Mercury	ng/L	0.271	0.227	0.169
Mercury – Total	ng/L	16.13	12.18	16.82
Mercury – Reactive	ng/L	2.77	1.63	0.64
Copper – Dissolved	µg/L	17.15	13.81	1.08
Copper – Total	µg/L	21.91	15.61	8.48
Lead – Dissolved	µg/L	0.33	0.24	< 0.16
Lead – Total	µg/L	2.33	0.99	1.93
Nickel – Dissolved	µg/L	5.66	4.97	0.18 DNQ
Nickel – Total	µg/L	8.38	5.70	1.94
Zinc- Dissolved	µg/L	32.92	22.31	9.14
Zinc – Total	µg/L	58.91	28.53	69.18
Chloride	µmol/L	102.1	92.3	7.7
Sulfate	µmol/L	38.5	56.3	4.2
Nitrogen, Total Kjeldahl	mg/L	5.2	3.7	< 0.07
Nitrogen, Nitrate-Nitrite	mg/L	0.061 DNQ	0.093 DNQ	0.079 DNQ
Nitrogen, Ammonia (as N)	mg/L	[a]	[a]	[a]
Phosphorus - Total	mg/L	3.1	3.0	0.083
Turbidity	NTU	[a]	[a]	[a]
Dissolved Organic Carbon	mg/L	170	130	2.6
Total Organic Carbon	mg/L	160	110	3.2
Total Dissolved Solids	mg/L	500	390	15
Total Suspended Solids	mg/L	178.0	50.0	110.7
Suspended Sediment Concentration	mg/L	50	103	30
Allethrin	ng/L	< 0.1	< 0.1	< 0.1
Bifenthrin	ng/L	< 0.1	< 0.1	4.4
Chlorpyrifos	ng/L	0.6 DNQ	< 0.5	4.5
Cyfluthrin	ng/L	< 0.2	< 0.2	1.2 DNQ
Lambda-Cyhalothrin	ng/L	< 0.2	< 0.2	< 0.2
Cypermethrin	ng/L	< 0.2	< 0.2	< 0.2
Diazinon	ng/L	< 0.1	< 0.1	< 0.1
Deltamethrin:Tralomethrin	ng/L	< 0.2	< 0.2	6.3
Esfenvalerate:Fenvalerate	ng/L	< 0.2	< 0.2	< 0.2
Fenpropathrin	ng/L	< 0.2	< 0.2	< 0.2
Tau-Fluvalinate	ng/L	< 0.2	< 0.2	< 0.2
Permethrin	ng/L	< 2	< 2	< 2
Tetramethrin	ng/L	< 0.2	< 0.2	< 0.2
pH	Std. units	6.54	6.97	6.74
Electrical Conductivity	µS/cm	165.6	178.5	13.96

DNQ = Detected but not quantified
[a] Constituent not analyzed

Table 21. Water Quality Data, Event CH05 (November 29, 2014)

Constituent	Units	PL-2	PL-3	PL-3 Field Blank	Equipment Blank
Methyl Mercury	ng/L	0.047	0.044	< 0.007	< 0.007
Mercury - Total	ng/L	2.51	6.16	< 0.10	< 0.10
Mercury - Reactive	ng/L	0.70	0.97	< 0.20	< 0.20
Copper - Dissolved	µg/L	3.22	2.68	0.25[DNQ]	0.92
Copper - Total	µg/L	8.18	14.21	0.57[DNQ]	0.76[DNQ]
Lead - Dissolved	µg/L	0.73	0.61	< 0.10	0.27
Lead - Total	µg/L	3.05	4.64	0.26	0.37
Nickel - Dissolved	µg/L	2.03	1.94	< 0.36	0.59
Nickel - Total	µg/L	6.88	8.87	0.50[DNQ]	0.77
Zinc- Dissolved	µg/L	19.80	32.35	1.66	3.44
Zinc - Total	µg/L	37.39	152.76	1.11	1.56
Chloride	µmol/L	4.2	55.6	0.1[DNQ]	0.1[DNQ]
Sulfate	µmol/L	9.1	186.2	0.5[DNQ]	0.7
Nitrogen, Total Kjeldahl	mg/L	0.35	0.62	[a]	[a]
Nitrogen, Nitrate-Nitrite	mg/L	0.21	0.39	[a]	[a]
Nitrogen, Ammonia (as N)	mg/L	[a]	[a]	[a]	[a]
Phosphorus - Total	mg/L	0.089	0.053	[a]	[a]
Turbidity	NTU	9.8	10	[a]	[a]
Dissolved Organic Carbon	mg/L	2.6	2.5	< 0.30	[a]
Total Organic Carbon	mg/L	2.9	2.4	< 0.30	0.60
Total Dissolved Solids	mg/L	10	82	[a]	[a]
Total Suspended Solids	mg/L	12.8	83.0	[a]	[a]
Suspended Sediment Concentration	mg/L	9.1	92	[a]	[a]
Allethrin	ng/L	< 0.1	< 0.1	< 0.1	[a]
Bifenthrin	ng/L	3.4	6.8	< 0.1	[a]
Chlorpyrifos	ng/L	< 0.5	< 0.5	< 0.5	[a]
Cyfluthrin	ng/L	< 0.2	< 0.2	< 0.2	[a]
Lambda-Cyhalothrin	ng/L	< 0.2	< 0.2	< 0.2	[a]
Cypermethrin	ng/L	< 0.2	< 0.2	< 0.2	[a]
Diazinon	ng/L	< 0.1	< 0.1	< 0.1	[a]
Deltamethrin:Tralomethrin	ng/L	0.98[DNQ]	3.8	< 0.2	[a]
Esfenvalerate:Fenvalerate	ng/L	< 0.2	< 0.2	< 0.2	[a]
Fenpropathrin	ng/L	< 0.2	< 0.2	< 0.2	[a]
Tau-Fluvalinate	ng/L	< 0.2	< 0.2	< 0.2	[a]
Permethrin	ng/L	< 2	< 2	< 2	[a]
Tetramethrin	ng/L	< 0.2	< 0.2	< 0.2	[a]
pH	Std. units	5.78	6.23	5.83	5.93
Electrical Conductivity	µS/cm	20.1	92.7	11.4	4.1

DNQ = Detected but not quantified
[a] Constituent not analyzed

Table 22. Water Quality Data, Automated Microsamples, Event CH06 (December 3, 2014)

Constituent	Units	PL-1 Auto #1	PL-1 Auto #2	PL-1 Auto #3	PL-1 Auto #4
Methyl Mercury	ng/L	0.016[DNQ]	0.025	0.020	0.018[DNQ]

DNQ = Detected but not quantified

Table 23. Water Quality Data, Grab and Composite Samples, Event CH06 (December 3, 2014)

Constituent	Units	PL-1 Sample #5	PL-1 Field Duplicate	PL-1 Sample #6	PL-1 Composite #1 - #6	PL-2	PL-3
Methyl Mercury	ng/L	0.015[DNQ]	[a]	0.021	0.024	0.047	0.032
Mercury - Total	ng/L	[a]	[a]	[a]	3.35	4.48	3.38
Mercury - Reactive	ng/L	[a]	[a]	[a]	0.56	0.65	0.42[DNQ]
Copper - Dissolved	µg/L	[a]	[a]	[a]	2.22	1.92	0.35[DNQ]
Copper - Total	µg/L	[a]	[a]	[a]	4.73	9.33	6.82
Lead - Dissolved	µg/L	[a]	[a]	[a]	0.62	< 0.10	< 0.10
Lead - Total	µg/L	[a]	[a]	[a]	1.79	2.03	1.74
Nickel - Dissolved	µg/L	[a]	[a]	[a]	2.14	< 0.36	< 0.36
Nickel - Total	µg/L	[a]	[a]	[a]	5.20	3.64	5.04
Zinc- Dissolved	µg/L	[a]	[a]	[a]	3.52	19.30	5.37
Zinc - Total	µg/L	[a]	[a]	[a]	11.40	44.46	36.58
Chloride	µmol/L	[a]	[a]	[a]	70.8	23.8	101.1
Sulfate	µmol/L	[a]	[a]	[a]	156.4	29.31	255.7
Nitrogen, Total Kjeldahl	mg/L	0.48	< 0.07	[a]	[a]	0.79	0.088[DNQ]
Nitrogen, Nitrate-Nitrite	mg/L	0.1	0.1	[a]	[a]	0.11	0.12
Nitrogen, Ammonia (as N)	mg/L	[a]	[a]	[a]	[a]	[a]	[a]
Phosphorus - Total	mg/L	0.1[GB]	0.1	[a]	[a]	0.3	0.06
Turbidity	NTU	13	10	[a]	[a]	8.8	8.1
Dissolved Organic Carbon	mg/L	2.1	2.3	[a]	[a]	7.9	3.6
Total Organic Carbon	mg/L	2.3	1.7	[a]	[a]	7.9	3.6
Total Dissolved Solids	mg/L	91	86	[a]	[a]	19	130
Total Suspended Solids	mg/L	[a]	[a]	[a]	15.2	14.25	37.8
Suspended Sediment Concentration	mg/L	14	17	[a]	[a]	12	35
Allethrin	ng/L	< 0.1	< 0.1	[a]	[a]	< 0.1	< 0.1
Bifenthrin	ng/L	< 0.1	< 0.1	[a]	[a]	1.9	1.9
Chlorpyrifos	ng/L	< 0.5	< 0.5	[a]	[a]	< 0.5	< 0.5
Cyfluthrin	ng/L	< 0.2	< 0.2	[a]	[a]	< 0.2	< 0.2
Lambda-Cyhalothrin	ng/L	< 0.2	< 0.2	[a]	[a]	< 0.2	< 0.2
Cypermethrin	ng/L	< 0.2	< 0.2	[a]	[a]	< 0.2	< 0.2
Diazinon	ng/L	< 0.1	< 0.1	[a]	[a]	< 0.1	< 0.1
Deltamethrin:Tralomethrin	ng/L	< 0.2	< 0.2	[a]	[a]	1.5	< 0.2
Esfenvalerate:Fenvalerate	ng/L	< 0.2	< 0.2	[a]	[a]	< 0.2	< 0.2
Fenpropathrin	ng/L	< 0.2	< 0.2	[a]	[a]	< 0.2	< 0.2
Tau-Fluvalinate	ng/L	< 0.2	< 0.2	[a]	[a]	< 0.2	< 0.2
Permethrin	ng/L	< 2	< 2	[a]	[a]	< 2	< 2
Tetramethrin	ng/L	< 0.2	< 0.2	[a]	[a]	< 0.2	< 0.2
pH	std. units	[a]	[a]	[a]	[a]	[a]	[a]
Electrical Conductivity	µS/cm	[a]	[a]	[a]	[a]	[a]	[a]

DNQ = Detected but not quantified GB = Matrix spike recovery is outside of the control limits [a] Constituent not analyzed

Table 24. Water Quality Data, Automated Microsamples, Event CH07 (December 11, 2014)

Constituent	Units	PL-1 Auto #1	PL-1 Auto #2	PL-1 Auto #3	PL-1 Auto #4
Methyl Mercury	ng/L	0.016[DNQ]	0.012[DNQ]	0.018[DNQ]	0.016[DNQ]

DNQ = Detected but not quantified
[a] Constituent not analyzed

Table 25. Water Quality Data, Grab Samples, Event CH07 (December 11, 2014)

Constituent	Units	PL-1 Sample #5	PL-2 Field Blank	PL-2	PL-3	SV-LID
Methyl Mercury	ng/L	0.012[DNQ]	<0.007	0.024	0.017[DNQ]	0.066
Mercury - Total	ng/L	[a]	[a]	[a]	[a]	[a]
Mercury - Reactive	ng/L	[a]	[a]	[a]	[a]	[a]
Copper - Dissolved	µg/L	[a]	[a]	[a]	[a]	[a]
Copper - Total	µg/L	[a]	[a]	[a]	[a]	[a]
Lead - Dissolved	µg/L	[a]	[a]	[a]	[a]	[a]
Lead - Total	µg/L	[a]	[a]	[a]	[a]	[a]
Nickel - Dissolved	µg/L	[a]	[a]	[a]	[a]	[a]
Nickel - Total	µg/L	[a]	[a]	[a]	[a]	[a]
Zinc- Dissolved	µg/L	[a]	[a]	[a]	[a]	[a]
Zinc - Total	µg/L	[a]	[a]	[a]	[a]	[a]
Chloride	µmol/L	[a]	[a]	[a]	[a]	[a]
Sulfate	µmol/L	[a]	[a]	[a]	[a]	[a]
Nitrogen, Total Kjeldahl	mg/L	0.26	[a]	< 0.07	< 0.07	0.4
Nitrogen, Nitrate-Nitrite	mg/L	0.081[DNQ]	[a]	0.11	0.098[DNQ, GB]	0.73
Nitrogen, Ammonia (as N)	mg/L	[a]	[a]	[a]	[a]	[a]
Phosphorus - Total	mg/L	0.15	[a]	0.053	0.07	0.24
Turbidity	NTU	4.8	[a]	2.7	7.5	11
Dissolved Organic Carbon	mg/L	3.2	[a]	1.7	1.8	6.1
Total Organic Carbon	mg/L	2.6	[a]	1.6	1.7	6.8
Total Dissolved Solids	mg/L	75	[a]	24	57	110
Total Suspended Solids	mg/L	[a]	[a]	[a]	[a]	[a]
Suspended Sediment Concentration	mg/L	2.0[DNQ]	[a]	3.9	32	5.7
Allethrin	ng/L	< 0.1	[a]	< 0.1	< 0.1	< 0.1
Bifenthrin	ng/L	< 0.1	[a]	1.9	1.1	0.7
Chlorpyrifos	ng/L	< 0.5	[a]	< 0.6	< 0.5	< 0.6
Cyfluthrin	ng/L	< 0.2	[a]	< 0.2	< 0.2	0.5[DNQ]
Lambda-Cyhalothrin	ng/L	< 0.2	[a]	< 0.2	< 0.2	< 0.2
Cypermethrin	ng/L	< 0.2	[a]	< 0.2	< 0.2	< 0.2
Diazinon	ng/L	< 0.1	[a]	< 0.1	< 0.1	< 0.1
Deltamethrin:Tralomethrin	ng/L	< 0.2	[a]	6.0	< 0.2	< 0.2
Esfenvalerate:Fenvalerate	ng/L	< 0.2	[a]	< 0.2	< 0.2	< 0.2
Fenpropathrin	ng/L	< 0.2	[a]	< 0.2	< 0.2	< 0.2
Tau-Fluvalinate	ng/L	< 0.2	[a]	< 0.2	< 0.2	< 0.2
Permethrin	ng/L	< 2	[a]	< 2	< 2	< 2
Tetramethrin	ng/L	< 0.2	[a]	< 0.2	< 0.2	< 0.2
pH	Std. units	[a]	[a]	[a]	[a]	[a]
Electrical Conductivity	µS/cm	[a]	[a]	[a]	[a]	[a]

DNQ = Detected but not quantified GB = Matrix spike recovery is outside of the control limits [a] Constituent not analyzed

Table 26. Water Quality Data, Automated and Composite Samples, Event CH08 (February 6, 2015)

Constituent	Units	PL-1 Auto #1	PL-1 Auto #2	PL-1 Composite #1 and #2	PL-1 Auto #1[(b)]	PL-1 Auto #2[(b)]	PL-1 Composite[(b)] #1 and #2
Methyl Mercury	ng/L	[a]	[a]	0.015[DNQ]	0.050	0.032	0.045
Mercury - Total	ng/L	[a]	[a]	3.52	4.59	1.45	4.28
Mercury - Reactive	ng/L	[a]	[a]	0.87	[a]	[a]	[a]
Copper - Dissolved	µg/L	[a]	[a]	2.71	[a]	[a]	[a]
Copper - Total	µg/L	[a]	[a]	6.49	[a]	[a]	[a]
Lead - Dissolved	µg/L	[a]	[a]	< 0.10	[a]	[a]	[a]
Lead - Total	µg/L	[a]	[a]	1.94	[a]	[a]	[a]
Nickel - Dissolved	µg/L	[a]	[a]	0.87	[a]	[a]	[a]
Nickel - Total	µg/L	[a]	[a]	5.59	[a]	[a]	[a]
Zinc- Dissolved	µg/L	[a]	[a]	5.87	[a]	[a]	[a]
Zinc - Total	µg/L	[a]	[a]	11.31	[a]	[a]	[a]
Chloride	µmol/L	[a]	[a]	92.3	[a]	[a]	[a]
Sulfate	µmol/L	[a]	[a]	334.1	[a]	[a]	[a]
Nitrogen, Total Kjeldahl	mg/L	[a]	[a]	[a]	[a]	0.31	[a]
Nitrogen, Nitrate-Nitrite	mg/L	[a]	[a]	[a]	[a]	0.56	[a]
Nitrogen, Ammonia (as N)	mg/L	[a]	[a]	[a]	[a]	[a]	[a]
Phosphorus - Total	mg/L	[a]	[a]	[a]	[a]	0.13	[a]
Turbidity	NTU	[a]	[a]	[a]	[a]	6.5	[a]
Dissolved Organic Carbon	mg/L	[a]	[a]	[a]	[a]	10	[a]
Total Organic Carbon	mg/L	[a]	[a]	[a]	[a]	10	[a]
Total Dissolved Solids	mg/L	[a]	[a]	[a]	[a]	130	[a]
Total Suspended Solids	mg/L	[a]	[a]	7.5[DNQ]	[a]	[a]	[a]
Suspended Sediment Concentration	mg/L	[a]	[a]	[a]	[a]	[a]	[a]
Allethrin	ng/L	[a]	[a]	[a]	[a]	< 0.1	[a]
Bifenthrin	ng/L	[a]	[a]	[a]	[a]	< 0.1	[a]
Chlorpyrifos	ng/L	[a]	[a]	[a]	[a]	< 0.5	[a]
Cyfluthrin	ng/L	[a]	[a]	[a]	[a]	< 0.2	[a]
Lambda-Cyhalothrin	ng/L	[a]	[a]	[a]	[a]	< 0.2	[a]
Cypermethrin	ng/L	[a]	[a]	[a]	[a]	< 0.2	[a]
Diazinon	ng/L	[a]	[a]	[a]	[a]	< 0.1	[a]
Deltamethrin:Tralomethrin	ng/L	[a]	[a]	[a]	[a]	< 0.2	[a]
Esfenvalerate:Fenvalerate	ng/L	[a]	[a]	[a]	[a]	< 0.2	[a]
Fenpropathrin	ng/L	[a]	[a]	[a]	[a]	< 0.2	[a]
Tau-Fluvalinate	ng/L	[a]	[a]	[a]	[a]	< 0.2	[a]
Permethrin	ng/L	[a]	[a]	[a]	[a]	< 2	[a]
Tetramethrin	ng/L	[a]	[a]	[a]	[a]	< 0.2	[a]
pH	Std. units	[a]	[a]	[a]	[a]	[a]	[a]
Electrical Conductivity	µS/cm	[a]	[a]	[a]	[a]	[a]	[a]

DNQ = Detected but not quantified
[a] Constituent not analyzed [b] Sample preserved with HCl

Table 27. Water Quality Data, Grab Samples, Event CH08 (February 6, 2015)

Constituent	Units	PL-2 Field Blank	PL-2 Field Blank[b]	PL-2	PL-2[b]	PL-3	PL-3[b]
Methyl Mercury	ng/L	[a]	<0.007	[a]	0.017[DNQ]	[a]	0.010[DNQ]
Mercury - Total	ng/L	[a]	0.21[DNQ]	[a]	7.62	[a]	7.05
Mercury - Reactive	ng/L	0.46[DNQ]	[a]	0.99	[a]	0.84	[a]
Copper - Dissolved	µg/L	1.68	[a]	7.49[IP]	[a]	3.36	[a]
Copper - Total	µg/L	2.04	[a]	15.00	[a]	9.52	[a]
Lead - Dissolved	µg/L	0.47	[a]	< 0.1[IP]	[a]	< 0.1	[a]
Lead - Total	µg/L	0.39	[a]	2.78	[a]	2.13	[a]
Nickel - Dissolved	µg/L	1.14	[a]	1.25[IP]	[a]	0.37[DNQ]	[a]
Nickel - Total	µg/L	0.97	[a]	5.11	[a]	5.66	[a]
Zinc- Dissolved	µg/L	4.21	[a]	40.66	[a]	73.40	[a]
Zinc - Total	µg/L	2.19	[a]	78.30	[a]	111.66	[a]
Chloride	µmol/L	16.4	[a]	30.0[IP]	[a]	80.8	[a]
Sulfate	µmol/L	2.2	[a]	12.9	[a]	275.4	[a]
Nitrogen, Total Kjeldahl	mg/L	[a]	[a]	1.4	[a]	0.70	[a]
Nitrogen, Nitrate-Nitrite	mg/L	[a]	[a]	0.36	[a]	0.55	[a]
Nitrogen, Ammonia (as N)	mg/L	[a]	[a]	[a]	[a]	[a]	[a]
Phosphorus - Total	mg/L	[a]	[a]	0.20	[a]	0.091	[a]
Turbidity	NTU	[a]	[a]	15	[a]	11	[a]
Dissolved Organic Carbon	mg/L	< 0.30	[a]	5.4	[a]	12	[a]
Total Organic Carbon	mg/L	< 0.30	[a]	5.7	[a]	12	[a]
Total Dissolved Solids	mg/L	[a]	[a]	34	[a]	94	[a]
Total Suspended Solids	mg/L	< 5.0	[a]	25.8	[a]	39.3	[a]
Suspended Sediment Concentration	mg/L	[a]	[a]	38	[a]	75	[a]
Allethrin	ng/L	< 0.1	[a]	< 0.5	[a]	< 0.5	[a]
Bifenthrin	ng/L	< 0.1	[a]	35	[a]	19	[a]
Chlorpyrifos	ng/L	< 0.5	[a]	4.0[DNQ]	[a]	< 2	[a]
Cyfluthrin	ng/L	< 0.2	[a]	< 1	[a]	< 1	[a]
Lambda-Cyhalothrin	ng/L	< 0.2	[a]	< 1	[a]	< 1	[a]
Cypermethrin	ng/L	< 0.2	[a]	< 1	[a]	< 1	[a]
Diazinon	ng/L	< 0.1	[a]	< 0.5	[a]	< 0.5	[a]
Deltamethrin:Tralomethrin	ng/L	< 0.2	[a]	13	[a]	5.4	[a]
Esfenvalerate:Fenvalerate	ng/L	< 0.2	[a]	1.3[DNQ]	[a]	< 1	[a]
Fenpropathrin	ng/L	< 0.2	[a]	< 1	[a]	< 1	[a]
Tau-Fluvalinate	ng/L	< 0.2	[a]	< 1	[a]	< 1	[a]
Permethrin	ng/L	< 2	[a]	< 10	[a]	< 10	[a]
Tetramethrin	ng/L	< 0.2	[a]	< 1	[a]	< 1	[a]
pH	Std. units	[a]	[a]	[a]	[a]	[a]	[a]
Electrical Conductivity	µS/cm	[a]	[a]	[a]	[a]	[a]	[a]

DNQ = Detected but not quantified
IP = Analyte detected in method, trip, or equipment blank
[a] Constituent not analyzed [b] Sample preserved with HCl

Table 28. Water Quality Data, Automated Microsamples, Event CH09 (February 8, 2015)

Constituent	Units	PL-1 Auto #1	PL-1 Auto #2	PL-1 Auto #3	PL-1 Auto #4
Methyl Mercury	ng/L	0.040	0.040	0.022	0.023

4.4 MERCURY AND SOLIDS CHARACTERIZATION AT CITY HALL COMPLEX

Figure 10 through **Figure 13** display the representative measured concentrations of methylmercury, total mercury, bifenthrin and SSC for Year No. 1 and Year No. 2 sampling events at each City Hall Complex monitoring location. The graphs display a general trend such that all concentrations decrease at all locations over the study period. This is with the exception of SSC and bifenthrin at location PL-3, which exhibit higher concentrations on average during Year No. 2 sampling events. The average and median concentrations of the results from the three City Hall Complex monitoring locations are shown in **Table 29**.

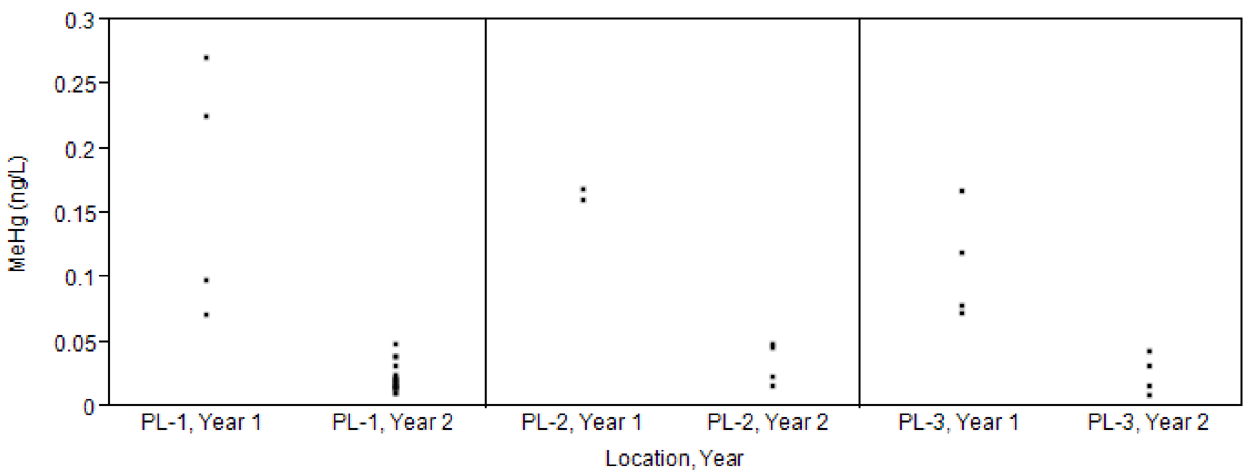


Figure 10. Methylmercury (ng/L) Year No. 1 vs. Year No. 2, City Hall Complex Monitoring Sites

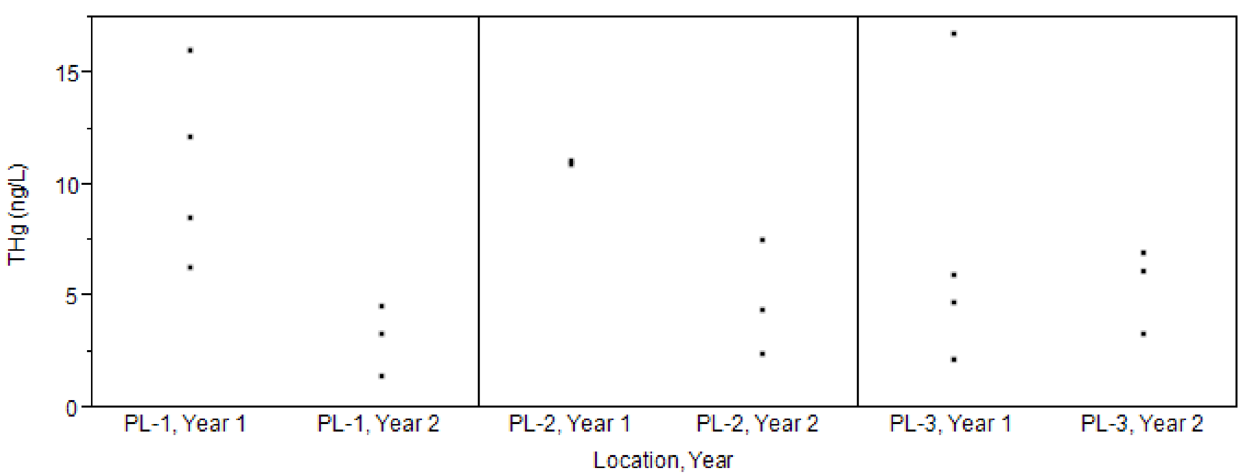
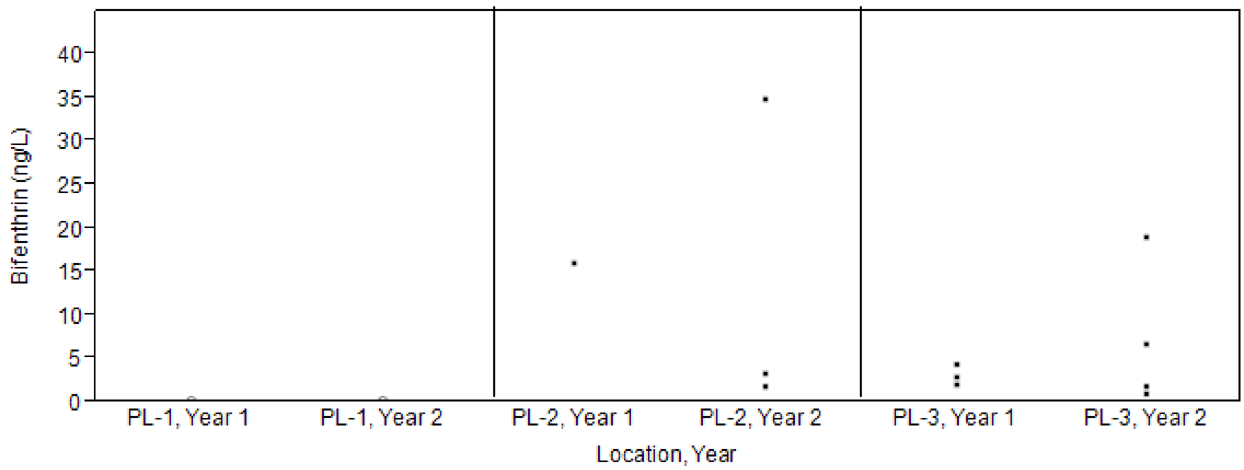


Figure 11. Total Mercury (ng/L) Year No. 1 vs. Year No. 2, City Hall Complex Monitoring Sites



Note: For PL-1, non-detected results (four during Year No. 1 and three during Year No. 2) are indicated by a hollow circle equal to the method detection limit of 0.1ng/L.

Figure 12. Bifenthrin (ng/L) Year No. 1 vs. Year No. 2, City Hall Complex Monitoring Sites

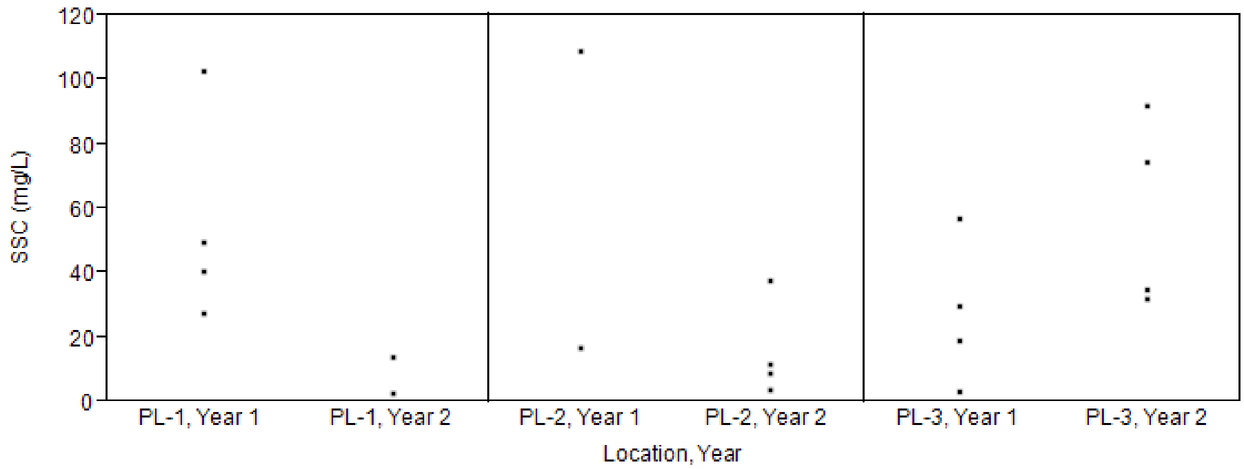


Figure 13. SSC (ng/L) Year No. 1 vs. Year No. 2, City Hall Complex Monitoring Sites

Table 29. Average and Median Concentrations, City Hall Complex Monitoring Sites

			PL-1			PL-2			PL-3		
Constituent	**Year**	**Units**	**n**	**Avg.**	**Median**	**n**	**Avg.**	**Median**	**n**	**Avg.**	**Median**
Methylmercury	1	ng/L	4	0.17	0.16	2	0.17	0.17	4	0.11	0.10
	2		17	0.02	0.02	4	0.03	0.04	4	0.03	0.02
Total Mercury	1	ng/L	4	10.81	10.37	2	11.08	11.08	4	7.46	5.41
	2		3	3.13	3.35	3	4.87	4.48	3	5.53	6.16
Suspended Sediment Concentration	1	mg/L	4	55.50	45.50	2	63.00	63.00	4	27.35	24.50
	2		2	[a]	<8.50	4	15.75	10.55	4	58.5	55.00
Bifenthrin	1	ng/L	4	[a]	<0.10	1	[a]	16.00	4	3.45	3.60
	2		3	[a]	<0.10	4	10.55	2.65	4	7.2	4.35

Note = Average summary statistic based on a regression on order statistics (ROS).
[a] Insufficient detected data to run ROS.

4.5 LOADING RATE CALCULATIONS

Estimation of the mass or load of a constituent in runoff leaving the sites can be used to evaluate the relative impact of the source and source area to others in downstream drainages and watersheds. The Delta Methylmercury TMDL assigns a mass-based wasteload allocation to the SSQP area within the "legal" Delta area. Thus, a measure of Project effectiveness is the reduction in loads of constituents of interest. "Loading rate" was calculated (see Equation 1) for both the pre- and post-Project conditions to "normalize" for the purpose of comparing the mass of constituents leaving the sites to the drainage area and depth of rainfall. The calculated runoff coefficient is multiplied by the median observed concentration for this estimate shown in **Table 30** through **Table 33**. Calculation worksheets are included as Appendix

$$Loading\_Rate = runoff\_coefficient * median\_concentration$$

$$\left[\frac{mass_{constituent}}{area * depth_{precipitation}}\right] = \left[\frac{volume_{runoff}}{area * depth_{precipitation}}\right] * \frac{mass_{constituent}}{volume_{sample}}$$

Equation 1. Loading Rate

These loading rate estimates are intended as general characteristics of the pre- and post-Project conditions to confirm effectiveness. A more detailed assessment should consider other factors influencing loading rates (rainfall rate, days since last rainfall, etc.) as well as a quantification of error. Analysis of error was not included in this assessment, and a more detailed assessment should be performed for incorporation into future larger watershed scale models.

Table 30. Loading Rate Calculations for Methylmercury

Drainage Area	Runoff Coefficient (cu. ft./sq. ft.*ft.)	Median Concentration (ng/L)	Area (acre)	Effective Loading Rate (g/in)
		Year 1 Methylmercury		
PL-1	0.0077	0.16	1.7	0.0000026
PL-2	1	0.17	1.5	0.00032
PL-3	1	0.10	2.1	0.00025
Total			**5.3**	**0.00057**
		Year 2 Methylmercury		
PL-1	0.16	0.020	1.7	0.0000066
PL-2	0.71	0.04	1.5	0.000048
PL-3	0.50	0.02	2.1	0.000031
Total			**5.3**	**0.000086**
Methylmercury Percent Change				**-85%**

Table 31. Loading Rate Calculations for Total Mercury

Drainage Area	Runoff Coefficient (cu. ft./sq. ft.*ft)	Median Concentration (ng/L)	Area (acre)	Effective Loading Rate (g/in)
		Year 1 Total Mercury		
PL-1	0.0077	10.37	1.7	0.00017
PL-2	1	11.08	1.5	0.021
PL-3	1	5.41	2.1	0.014
Total			**5.3**	**0.035**
		Year 2 Total Mercury		
PL-1	0.16	3.35	1.7	0.0011
PL-2	0.71	4.48	1.5	0.0061
PL-3	0.50	6.16	2.1	0.0078
Total			**5.3**	**0.015**
Total Mercury Percent Change				**-57%**

Table 32. Loading Rate Calculations for Suspended Sediment Concentration

Drainage Area	Runoff Coefficient (cu. ft./sq. ft.*ft)	Median Concentration (mg/L)	Area (acre)	Effective Loading Rate (g/in)
		Year 1 Suspended Sediment Concentration		
PL-1	0.0077	45.5	1.7	738
PL-2	1	63.0	1.5	120,047
PL-3	1	24.5	2.1	62,037
Total			**5.3**	**182,822**
		Year 2 SSC		
PL-1	0.16	<8.5	1.7	<2,770
PL-2	0.71	10.6	1.5	14,346
PL-3	0.50	55.0	2.1	69,766
Total			**5.3**	**<86,882**
SSC Percent Change				**-52%**

Table 33. Loading Rate Calculations for Bifenthrin

Drainage Area	Runoff Coefficient (cu. ft./sq. ft*ft)	Median Concentration (ng/L)	Area (acre)	Effective Loading Rate (g/in)
		Year 1 Bifenthrin		
PL-1	0.0077	<0.10	1.7	<0.0000016
PL-2	1	16.00	1.5	0.030
PL-3	1	3.60	2.1	0.009
Total			**5.3**	**<0.040**
		Year 2 Bifenthrin		
PL-1	0.16	<0.10	1.7	<0.000033
PL-2	0.71	2.65	1.5	0.004
PL-3	0.50	4.35	2.1	0.006
Total			**5.3**	**<0.0092**
Bifenthrin Percent Change				**-77%**

4.6 SURROGATE MEASUREMENT OF METHYLMERCURY USING FDOM

A fluorescence-based optical sensor was used to measure dissolved organic matter (FDOM) as part of the study. This study evaluated the relationship between FDOM and methylmercury concentration at all three locations at the City Hall Complex. It was expected that the extensive bioswale in PL-1 would provide the best opportunity to characterize ranges of FDOM and methylmercury and was the focus of the effort to better characterize methylmercury outflow from a LID feature. With the high resolution sensor data collection and a surrogate relationship, calculation of methylmercury loads and evaluation of changes over time are much more powerful than more limited grab sample collection and even event composite collection.

Figure 14 shows the apparent linear relationship between methylmercury and FDOM and **Table 34** summarizes the linear model parameters. The FDOM sensor output can also be processed to account better for water properties (e.g., temperature) that could improve regression relationships.

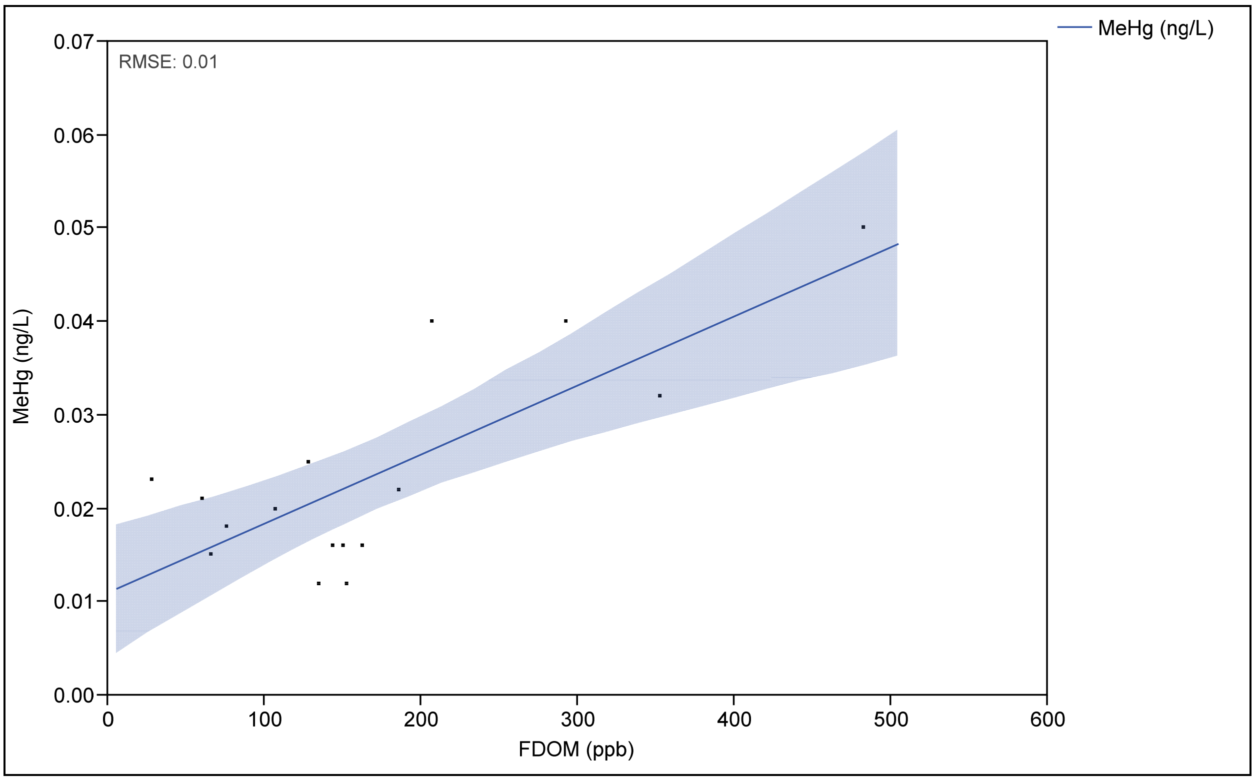


Figure 14. PL-1 Methylmercury Correlation with FDOM

Table 34. Methylmercury vs. FDOM Model Parameter Estimates

Term	Estimate	Std. Error	t Ratio	Prob>|t|
Intercept	0.0110322	0.003272	3.37	0.0046*
FDOM	7.3967e-5	0.000016	4.63	0.0004*

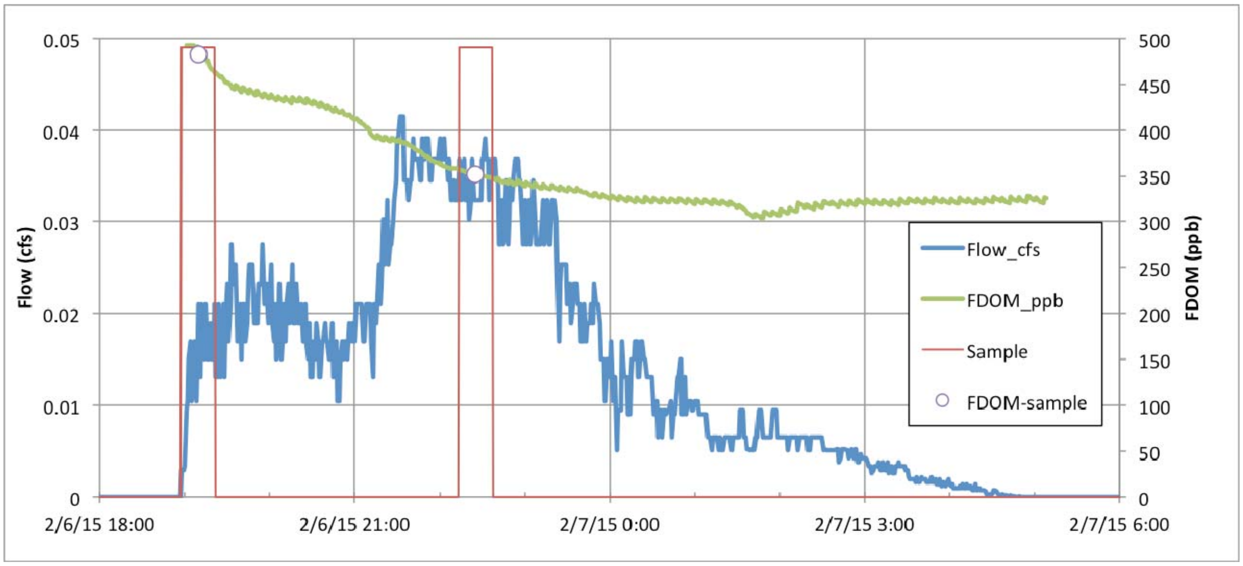


Figure 15. PL-1 Event CH08 Flow and FDOM Measurement

Table 35. Event CH08 PL-1 Methylmercury Load Calculation Methodology Comparison

Load Calculation Basis (544 L event outflow)	Load Outflow (ng)	Percent Difference From FDOM Sensor Based Load
FDOM Sensor Based Load – surrogate relationship using one minute FDOM data (n = 595)	20.9	NA
Median All Year No. 2 Concentration – all samples combined (n=17, median = 0.02 ng/L)	11.1	-47%
Early Outflow Concentration (0.05 ng/L)	27.2	30%
Mid-Outflow Concentration (0.032 ng/L)	17.4	-17%
Two Sample Composite Concentration (0.045 ng/L)	24.5	17%

These mass loading estimates were prepared to evaluate the range of possible calculation outcomes. A more detailed assessment of the errors associated with the estimates and more robust calculation methodologies could be useful in developing appropriate loading models.

5 Conclusions

The evaluation of pre- and post-Project runoff volume and concentrations from the City of Citrus Heights City Hall Complex quantified pollutant reduction performance and assessed a number of monitoring and analysis techniques to better conduct these performance evaluations for LID installations and low-level constituents. The Sylvan Community Center evaluation confirmed the expected performance for that site and only a small volume of water (<1,000 gallons) left the site during the study period. The major conclusions are as follows:

- The Project reduced run off coefficient (volume per area drainage, per depth rainfall) from 0.71 (modeled) to 0.45 (measured).
- The Project reduced the median methylmercury, total mercury, and bifenthrin concentrations at every location with pre- and post-Project sample collection occurred.
- The Project reduced the loading rates for methylmercury (85%), total mercury (57%), suspended sediment concentration (52%) and bifenthrin (77%). The loading rate or flux (net constituent mass export rate) of constituents leaving the Project site to the MS4 system decreased significantly after completion of the Project. Even though the concentrations of suspended solids increased slightly at one location, the flow reductions were significant enough to reduce the load of solids. This decrease in pollutant loading occurred despite the increase in pavement area.
- The bioswales and combination of pervious and impervious pavement at PL-1 decreased methylmercury concentrations compared to pre-Project conditions. The maximum methylmercury concentration was observed before the Project construction at the PL-1 location. The second highest maximum value was observed from the off-site runoff adjacent to the Sylvan Community Center (SV-0). Though runoff volume increased at PL-1 with the addition of permeable and impermeable pavement, loading rate decreased.
- The rain garden in the PL-2 drainage decreased the flow and load of constituents leaving the site. This feature provided significant benefit in reducing runoff leaving the site, despite the inclusion of permeable pavement in this drainage.
- Multiple methods for performing constituent loading rate calculations were performed and resulted in estimates ranging by approximately 50%. Microsampling, whereby a number of samples are collected over longer durations or based on specific conditions and the use of surrogate relationships was useful in developing methods to cost effectively quantify loadings of constituents for the purpose of TMDL and wasteload allocation compliance.
- Reductions in flow volume observed in the study were close to, but slightly less than, the modeled projections. The differences in the observed and modeled conditions were within expected accuracy of model projections and flow measurement. The model results represent an average over a longer continuous simulation period than was monitored.

6 Recommendations

Based on the experimental process, outcomes, and needs of the City and the SSQP during the Study, several recommendations were developed to assist in future LID monitoring for the SSQP and other agencies. These recommendations were considered in development of templates for QAPP and sampling plan documents that are included as **Appendix B**. The major recommendations are as follows:

- Low flow measurement required the appropriate type of depth sensor for each site-specific condition. Future studies should develop hydrologic models to estimate the range of expected flow rates and hydraulic conditions to best identify the appropriate flow-measurement equipment, especially for lower flow conditions. Opportunities for sample collection are less frequent for lower flow LID locations, and remote triggering of sample collection is recommended.
- LID monitoring studies should consider standardized measures of performance that can be used to characterize facilities for the purpose of watershed models. Unique and non-standard mixes of LID features are typical for urban retrofit. It is recommended that an approach to characterize performance be standardized for incorporation into larger watershed models. These input parameters and watershed model outputs can then be used to better develop and specify design criteria. For example, the performance of multiple study locations could be evaluated to determine the important factors (e.g., length of bioswales, water volume fraction infiltrated, water volume fraction treated, percent pervious pavement, rain garden design volume, etc.) that can be quantified to estimate overall performance indicators (e.g., loading per acre-inch of rain). While these probabilistic watershed modeling approaches are already used for individual LID features, a more robust treatment of "feature mix" is needed.
- Assessment of performance over time, especially as it relates to hydrologic performance as well as build of conditions (i.e., organic matter accumulation). Appropriate use and maintenance practices may be necessary to maintain the level-of-performance.
- Development of surrogate relationships and monitoring approaches should be further evaluated as a cost-effective approach to characterize the timing and cumulative loading of constituents.
- The use of continuous sensors to collect flow measurements and water quality data should be considered, when feasible. Adjustments to the sensor processing equation and use of multiple types of sensors should be considered to develop more robust site specific surrogate relationships. Continuous sensors allow for collection of data even when field crews are not on-site and can be useful in understanding system dynamics and adjusting the sample collection approach.
- FDOM performance would improve if the flow-through flow is either filtered or screened of heavier debris that can interfere with the measurement.
- A more robust assessment of error in the loading rate calculations would provide better information to potential watershed modeling efforts as well as provide better context to summary results. Sensor readings, flow monitoring and analytical chemistry all introduce some error rates that may be relevant when considering compliance with TMDL wasteload allocations, especially when wasteload allocations are small.
- Flow monitoring should account for the expected range of flows and measurement locations should provide laminar hydraulics to more accurately collect data.

- Remote triggering of sample collection as well as "conditional" sample collection is useful to characterize specific conditions (turbidity, DOM, etc.) that can be critical to surrogate relationships.