

Watershed Monitoring and Assessment Program



Pilot Urban Runoff Diversion Evaluation *Palo Alto, California*

*Prepared in compliance with provisions C.11f and C.12f of NPDES
Permit # CAS612008*

September 15, 2015

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Executive Summary

Provisions C.11.f and C.12.f of the Municipal Regional Stormwater National Pollutant Discharge Elimination System (NPDES) Permit, more commonly referred to as the Municipal Regional Permit (MRP), require Permittees to pilot test a variety of control measures to reduce polychlorinated biphenyls (PCBs) and mercury in urban runoff. The overall goal of these pilot projects was to make progress towards achieving stormwater load reductions called for in mercury and PCB load reduction strategies (i.e., Total Maximum Daily Loads). The Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP) in cooperation with the City of Palo Alto conducted a pilot evaluation of an existing urban runoff diversion structure located in the City of Palo Alto, CA, in compliance with MRP provisions. The purpose of this pilot project was to better understand the challenges, costs and load reduction benefits associated with diversion of dry weather and storm flows to publicly owned treatment works (POTWs) as a control measure for reducing mercury and PCBs loads to San Francisco Bay. The knowledge gained from this pilot project will be used to inform planning for focused implementation of urban runoff control measures during subsequent Permit terms.

Monitoring was conducted at the influent to the diversion structure and from the diverted flow over two wet seasons to characterize the quantity and quality of diverted flows, and estimate the loads of PCBs and mercury to the Bay that are reduced due to current operation and functioning of the diversion structure. Continuous flow and turbidity measurements were made from January to May, 2013, and from October 2013 to March 2014. During this same time period, additional water quality samples were collected during three storm events and two dry weather events and analyzed for suspended sediment concentrations (SSC), particle size distributions (PSDs) and concentrations of pollutants of concern (POC), including PCBs, mercury, and other metals. These monitoring data were used to understand flow characteristics at the site, to calculate the volume and percent of flow diverted, and to establish relationships between turbidity, suspended sediment, particle size distributions and/or POCs in order to calculate total loads diverted and identify conditions which maximized diverted loads of SSC and POCs.

The estimated total annual flow volumes diverted during Water Year (WY) 13 and WY14, which run from October 1 – September 30 each year, were 2.0 million gallons (MG) and 1.2 MG, respectively, representing 65% - 66% of the total annual flow at the site. Of those volumes, 97% during WY13 and 95% during WY14 were from storm flows. Based on the estimated diverted flows during all of WY13 and WY14, the largest volume of flow diverted on a single day was 323,000 gallons, which is below the maximum diversion design limit of 0.5 million gallons per day (MGD). Annual diverted loads of suspended sediment ranged from 150 Kg to 270 Kg, while diverted loads of PCBs and mercury were both less than one gram per year. Storm flows accounted for 98% of the total suspended sediment, PCBs and mercury loads diverted. Although stormwater POC concentrations and particle ratios at this site were not as low as expected based on the lack of PCB sources in this area, because the total suspended sediment load and flow volumes diverted were relatively small, the total annual loads of PCBs and mercury diverted were low.

Next, the municipal costs and operational challenges, and any associated impacts of the diversion on the Palo Alto Regional Water Quality Control Plant (RWQCP) were documented. Annual costs, including design and construction costs prorated over the approximately 20-year time period that the structure has been in operation, summed with the annual operation and maintenance costs for the Palo Alto diversion structure ranged from \$12,000 to \$19,000 per year. Because the RWQCP did not charge connection or treatment fees, the normal rates for industrial dischargers were

applied to the flow volumes and sediment loads diverted at the site, in order to generate more representative annual cost. Total estimated POTW fees ranged from \$4,400 to \$7,300 per year, indicating these fees can represent a substantial portion of the total cost for diversion projects. In addition, a number of POTW concerns were identified which would need to be addressed before POTWs would be willing to accept stormwater diversion, including regulatory and legal issues associated with acceptance of stormwater diversions, potential impacts on POTW operations and effluent concentrations and loading, capacity limitations, especially during wet weather, and added costs due to additional connections, treatment and/or plant maintenance.

Finally, the results from the hydraulic analysis, water quality characterization and pollutant load data were combined with the cost information to evaluate the cost effectiveness in terms of the annual cost per gram of pollutant removed for a range of potential diversion scenarios. By far, the most cost-effective scenario was diversion of storm flows in a large catchment with elevated POC concentrations (\$16,000 per gram of PCBs diverted), while the least cost-effective scenario was diversion of dry weather flows in a small catchment with a baseline level of POCs (\$16 M per gram of PCBs diverted). With diversion of both storm and dry weather flows, both the small and large catchment scenarios with elevated POC concentrations were significantly more cost-effective (\$18,000 - \$28,000 per gram of PCBs diverted) than the scenarios with baseline POC concentrations (\$180,000 - \$250,000 per gram of PCBs diverted). The results of this pilot project will be used to compare the costs and benefits of urban runoff diversions to other types of mercury and PCBs pollutant control measures as required by MRP provisions, and to inform planning and implementation of urban runoff diversions in other Bay Area watersheds in the future.

1.0 INTRODUCTION

The Municipal Regional Stormwater National Pollutant Discharge Elimination System (NPDES) Permit, more commonly referred to as the Municipal Regional Permit (MRP), requires Permittees to evaluate the effectiveness of a variety of actions to reduce polychlorinated biphenyls (PCBs) and mercury from urban runoff. The general strategy outlined in the MRP requires pilot projects of control measures during the initial permit term, and as confidence associated with the water quality benefits of these measures was gained, to implement control measures with a greater scope during subsequent permit terms. Provisions C.11.f and C.12.f of the MRP are nearly identical provisions for assessing the effectiveness of pilot diversions of dry weather urban runoff and/or first flush events to publicly owned treatment works (POTWs) for controlling mercury and PCBs. The MRP required a total of five pilot diversion projects, with one project located in each county covered by the MRP (Contra Costa, Solano, Alameda, Santa Clara, and San Mateo). Pilot diversion projects were implemented and evaluated in parallel with other types of urban runoff control measures, including stormwater treatment retrofits, sediment management pilot projects, and source investigations to identify contaminated sites. This report presents the results of the stormwater diversion evaluation pilot project in Santa Clara County, conducted by the Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP).

1.1. Project Location

The location selected for the Santa Clara County diversion pilot project was at an existing low-flow diversion structure installed by the City of Palo Alto (City) in 1993 at the intersection of Bryant Street and Channing Avenue in Palo Alto, CA (Figure 1.1). The structure was installed to divert urban runoff from the stormwater conveyance system to the Palo Alto Regional Water Quality Control Plant (RWQCP) in order to remove sediments from an approximately 35-acre commercial area bound by Hamilton Avenue, Bryant Street, Channing Avenue and Alma Street. The site was originally selected by the City because of the land use in the drainage area (commercial, light industrial, multi-family residential), proximity of the 27" sewer trunk line to the storm drain line, and because the sewer trunk line had excess capacity. The structure was designed to divert urban runoff flows into the sanitary sewer at a rate of no more than 0.5 million gallons per day (MGD). At the present time, the catchment is predominantly impervious, with the following land uses: commercial (50%), retail (24%) light industrial (4%), high density residential (19%) and low density residential (2%).

Business activities within the commercial area of the catchment at the time of construction (early 1990's) consisted primarily of automotive repair shops, restaurants, and a dairy product manufacturing plant. Automotive repair shops had been identified as potential sources of pollutants to stormwater, including heavy metals, oil/grease, and sediment. Approval, design, and construction of the diversion structure required cooperation between different divisions within the City of Palo Alto Public Works Department, including Environmental Compliance Division and the Regional Water Quality Control Plant, as well as the Utilities Department, including Utilities Engineering Division and Water-Gas-Wastewater Operations. Furthermore, waivers of Section 1102(b) of the Uniform Plumbing Code and Section 16.09.110(1) of the Palo Alto Municipal Code, which prohibited stormwater discharge to the sanitary sewer, were obtained.

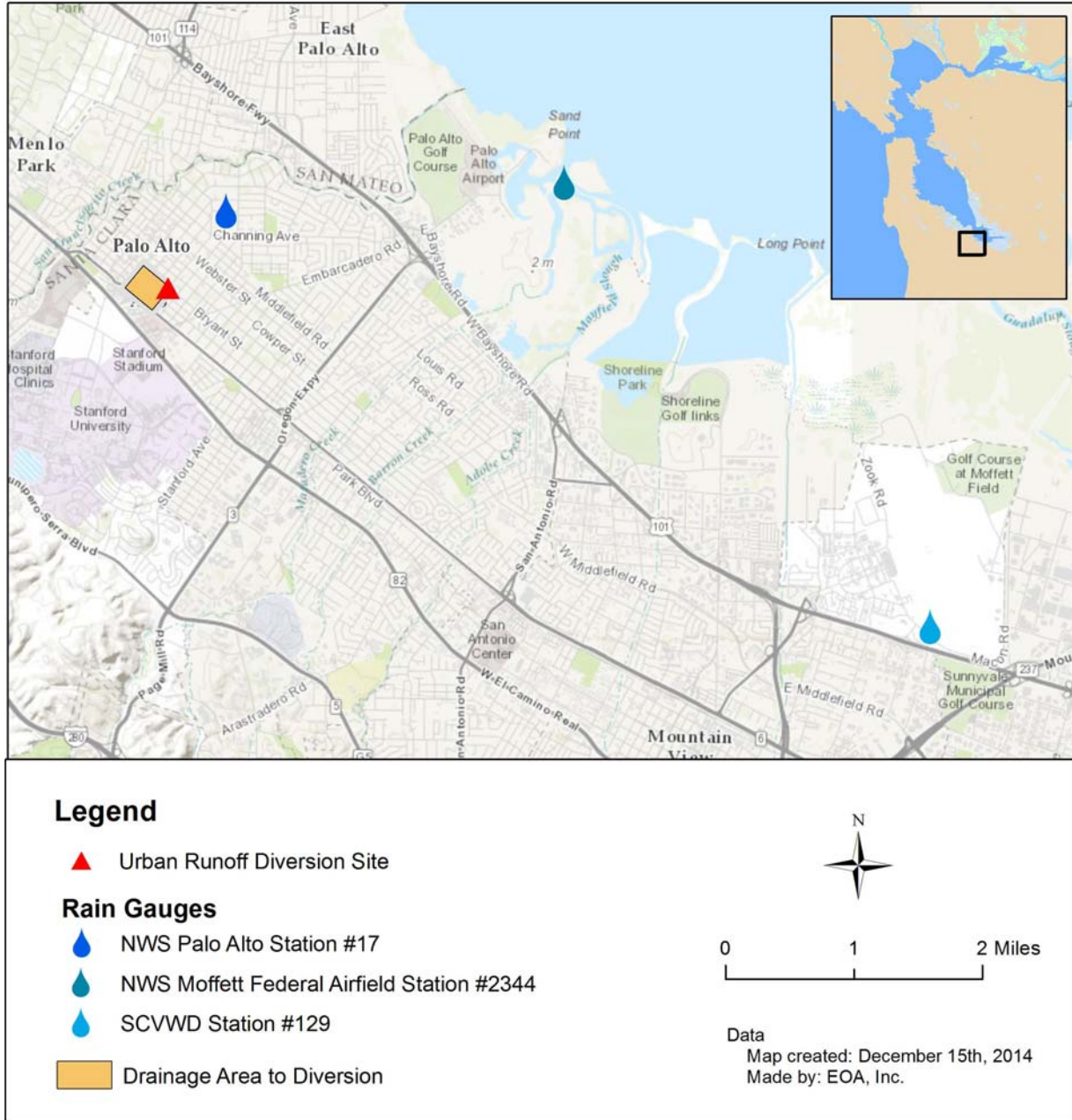


Figure 1.1. Location of the City of Palo Alto Urban Runoff Diversion Structure, Santa Clara County, CA.

1.2. Description of the Diversion Structure

The Palo Alto diversion was designed to increase interception of highly polluted first flush flows from the storm drain to the sanitary sewer through a low-flow gravity-controlled structure, with no moving parts and no external power requirements. The diversion structure consists of a concrete vault, installed around the stormdrain line. The bottom of the vault is at a slightly lower elevation than the upstream side of the 15 inch diameter stormdrain line to facilitate gravity flow through the vault. The vault is divided into two sections by a weir which separates the diversion side of the vault (e.g., the diversion box) from the stormdrain line. Runoff from the storm drain flows into the vault and small openings at the bottom of the weir allow runoff to flow into the diversion box. A bar screen was installed upstream of the weir to block trash/large debris from entering the diversion box. The diversion box contains two valves (a vortex valve and a float-actuated plug valve) which are connected to the sanitary sewer outflow pipe. The vortex valve is always open, and was sized such that the maximum flow through the valve is 350 gallons per minute (gpm). The float-actuated plug valve automatically opens or closes depending on the liquid level in the box. When the liquid level is below the float set-point elevation, the plug valve is fully open, essentially allowing all flow into the vault to be diverted to the sanitary sewer. However, when the liquid level is at or above the float set-point elevation, the plug valve is fully closed. When the plug valve is closed, flow through the vortex valve is limited to < 350 gpm, and the excess runoff overflows the weir, bypassing the diversion box and continuing downstream through the stormdrain line. The valves in the diversion box are connected to an 8" diameter sanitary sewer outflow pipe, which carries the runoff approximately 30 feet to the 27" sanitary sewer trunk line. A gate valve was installed in the 8" sanitary sewer outflow pipe to provide a way to block all flows to the sanitary sewer, if needed (e.g., during periods of high flow in the sanitary sewer which may occur during very large rainfall events). The gate valve, which is manually opened/closed by use of a valve operating wrench, is the only part of the diversion structure that must be manually activated.

Previous water quality monitoring of runoff into the diversion structure was conducted periodically within the first few years after the structure was installed. However, the value of these previous monitoring efforts to the present study was limited, because no flow monitoring was conducted, and water quality samples were analyzed for metals, but no other stormwater pollutants. Thus, the data available on flow characteristics and concentrations of pollutants in the diverted urban runoff were inadequate to fully assess the current effectiveness of the structure.

1.3. Objectives

The overall goal of this pilot project was to make progress towards achieving stormwater load reductions called for in mercury and PCB load reduction strategies (i.e., Total Maximum Daily Loads) by evaluating the existing Palo Alto diversion structure to better understand the challenges, costs and load reduction benefits associated with current operation of the structure.

The following three tasks were defined to achieve these goals:

1. Quantify runoff flows and pollutant loads to the Bay that are reduced due to current operation of the existing diversion structure,¹ and identify conditions which maximize diverted loads.

¹ Based on preliminary estimates presented in BASMAA (2010) and the absence of sources in the project watershed, load reductions of PCB and mercury from the diversion structure are expected to be minimal.

2. Document the challenges, constraints, and costs of constructing and operating the diversion structure.
3. Evaluate the cost effectiveness of implementing diversions in other watersheds (e.g., larger drainage area and/or elevated runoff concentrations of POCs).

The knowledge gained from this pilot project will be used to inform planning for focused implementation of urban runoff control measures during subsequent Permit terms.

2.0 EVALUATION OF RUNOFF QUANTITY AND QUALITY DIVERTED

The purpose of this task was to quantify both the quantity and quality of urban runoff loads diverted under current functioning and operation of the Palo Alto Diversion Structure, and to identify conditions which maximize diverted loads. Continuous flow and turbidity were monitored at the project site, and additional water quality samples were collected during two dry weather and three storm events to further characterize water quality. These data were used to estimate the total annual volume of flow and POCs that were diverted over a two year period.

2.1. Monitoring Methods

2.1.1. Sampling Sites

Monitoring was conducted at two sites during this project. An influent sampling site, located in the 15 inch storm drain pipe approximately 3 feet upstream of the diversion vault, provided data on flow volume and water quality of the runoff entering the vault. This sampling site was accessible through manhole A (Figure 2.1). A diverted flow sampling site, located in the 8 " sanitary sewer outflow pipe, approximately ten feet upstream of the connection to the sanitary sewer trunk line, provided data on the flow volume and water quality of the diverted stream. This diverted flow sampling site was accessible through manhole B (Figure 2.1).

2.1.2. Instrumentation and Field Data Collection

Flow was monitored continuously at both the influent and the diverted flow sites with ISCO 2150 area-velocity flow meters, which measure stage and velocity and convert these readings to a volumetric flow rate (e.g., cubic feet per second) based on the pipe diameter. The flow sensors were mounted on expansion rings and installed within the drainage pipes at both sampling sites (Figure 2.1). The instruments were set to record measurements every 15 minutes, increasing to a one-minute recording interval when the flow exceeded 0.05 gallons per second (gps).

Turbidity was monitored continuously at the influent site only, using a Forest Technology Systems (FTS) DTS-12 turbidity sensor attached to an FTS data logger. Turbidity data were set to record at one minute intervals throughout the monitoring period. Turbidity was not monitored at the diverted flow site.

Manhole entry was required to install/uninstall all sensors into the pipes, and proper confined space entry gear and procedures were followed. At each sampling site, the flow meter, data logger and battery unit were hung at the top of the manhole near the opening and connected by cables to the sensors that were mounted inside the pipes.

Discrete water quality samples were collected manually at each site using clean sample containers attached to a hand-held pole. For dry weather events, a single grab sample per analyte was collected at each site to characterize runoff water quality during dry weather. During storm events, four grab samples were collected at each site over the duration of a storm. The timing and frequency of water quality sampling during storms was based on best professional judgment, with the goal of capturing the rise, peak and fall of a given runoff event, in order to fully characterize concentrations throughout the storm. The sites were visited periodically between storm events to perform equipment maintenance (e.g., clear debris from the sensors or inlets), download continuous data, and check battery power to ensure continued operation of the instruments throughout the project. A summary report of all field monitoring is located in Appendix 1.

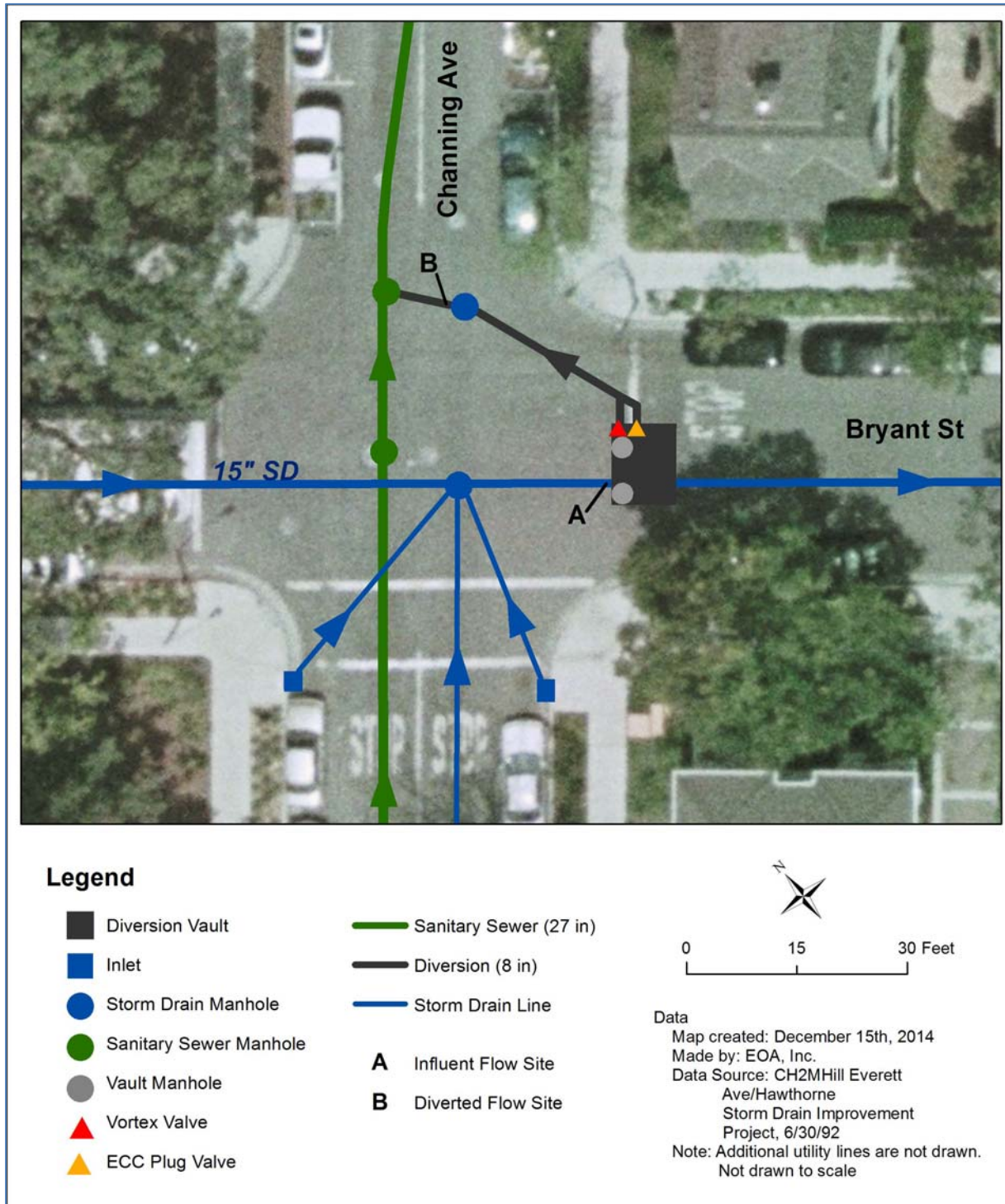


Figure 2.1. Location and configuration of the diversion structure and location of the project monitoring sites.

Rainfall data during the monitoring period was obtained from three nearby weather stations, including a Santa Clara Valley Water District rainfall gauge (Station 129) in Palo Alto, CA, located approximately 3 miles north east of the diversion structure, at the confluence of Matadero Creek and Adobe Creek, National Weather Service (NWS) station ID GHCND:US1CASC0017 in Palo Alto, CA, located approximately 0.75 miles north east of the diversion structure, and NWS station ID GHCND:USW00023244, located at Moffett Federal Airfield, Mountain View, CA, approximately 6 miles south east of the site (Figure 1.1). The daily average rainfall from these three sites was calculated and used to represent rainfall at the diversion structure.

2.1.3. Analytical Methods

All discrete water quality samples were analyzed for suspended sediment concentrations (SSC), total organic carbon (TOC), sediment particle size distributions (PSDs), total mercury and total PCBs. Roughly half of the samples were also analyzed for metals, including aluminum, arsenic, cadmium, chromium, copper, lead, manganese, nickel, selenium, silver and zinc. Monitoring parameters, laboratories, target reporting limits and analytical methods used are listed in Table 2.1. These methods are consistent with MRP requirements and Method Quality Objectives (MQOs) developed by the Surface Water Ambient Monitoring Program (SWAMP). Analytical laboratories were selected to perform these analyses based on their ability to meet MQOs.

Table 2.1. Laboratory Analytical Methods for Analytes in Water

Analyte	Target Reporting Limit	Reporting Units	Analytical Method	Laboratory
Suspended Sediment Concentration (SSC)	0.5	mg/L	ASTM D3977-97 (Method C)	Calscience
Total Organic Carbon (TOC)	0.6	mg/L	SM5310D	Calscience
Mercury (total)	0.0005	µg/L	EPA 1631	Calscience
Total PCBs ^a	0.000005 (per congener)	µg/L	EPA 1668A	Axys Analytical
Total Recoverable Metals	< 1.0	µg/L	EPA 1640	Calscience
Particle Size Distribution	0.01%	%	ASTM D4464(M)	Calscience

^a Project laboratories quantified the 40 individual PCB congeners routinely quantified by the San Francisco Bay Regional Monitoring Program for Water Quality (RMP), listed in Table 27-2 of the BASMAA Clean Watersheds for a Clean Bay QAPP (BASMAA 2011).

2.1.4. Data Quality Assurance and Control

Quality Assurance/Quality Control (QA/QC) activities associated with the field monitoring and laboratory analysis followed the procedures and practices documented in the Bay Area Stormwater Management Agencies Association (BASMAA) Clean Watersheds for a Clean Bay Quality Assurance Project Plan (BASMAA 2011). Activities included the following:

- Employed certified analytical laboratories trained in the applicable procedures;
- Adhered to documented procedures, USEPA methods and written SOPs;

- Calibration of analytical instruments;
- Use of quality control samples, internal standards, surrogates, and SRMs; and
- Complete documentation of sample tracking and analysis.

The laboratory data were reviewed for quality and were generally found to have sufficient quality for project purposes. A summary report of the QA/QC review of the laboratory data is located in Appendix B.

2.1.5. Data Analysis

Data analysis focused on characterizing suspended sediment and pollutant loads in urban runoff diverted to the sanitary sewer system under varying flow conditions, including both dry weather flows (e.g., flow through the structure in the absence of precipitation such as from landscape irrigation and other urban runoff drainage, groundwater infiltration, etc.) and wet weather flows (e.g., storm flow), and to identify conditions which maximized diverted loads. This was accomplished through three steps: hydraulic analysis, characterization of influent and diverted flow water quality, and calculation of suspended sediment and POC loads diverted. The measurement data were then used to extrapolate flows and loads diverted for all of WY13 and WY14 and to identify conditions which maximized diverted loads.

Hydraulic Analysis

Hydraulic analysis consisted of characterizing the urban runoff flows at the influent and diverted flow sites and evaluating the relationship between rainfall and runoff at the site. Time series plots of the measured flows were reviewed to document the functioning and response of the diversion structure under variable flow regimes, and estimate the percent of flow diverted over time. From a review of rainfall data, all flows were stratified as either storm flow or dry weather flow regimes. Storm flow was defined as flow occurring on any day with measurable rainfall of at least 0.01 inches. All other flows were defined as dry weather flow (e.g., flow in the absence of rainfall). Flows were summed to provide the daily dry weather, storm influent and diverted flow volumes. The percent of flow diverted each day during both storm and dry weather flow regimes was calculated from the difference between the measured influent and diverted flows, and the average daily percent of flow diverted was calculated for each month of monitoring. To extrapolate the measured flow data to all unmonitored portions of WY13 and WY14, rainfall data were first reviewed to categorize all days during each year as either storm days (≥ 0.01 in of rainfall) or dry weather days. For all storm days, flows were estimated from a linear regression of daily rainfall and influent flow from days when monitoring was conducted. For all dry weather days, the percent of dry weather days during monitoring that had zero flow was assumed to be the same during all portions of each year that were not monitored. For the remaining dry days, the daily average dry flow calculated from the monitoring data was applied, and the results were summed to provide monthly and annual total dry weather flows. The average percent of flows diverted during storm flows or dry weather flows that were observed during monitoring was used to calculate the total monthly and annual flows diverted each year.

Characterization of Influent and Diverted Flow Water Quality

Statistical tests were used to compare paired concentrations from the influent and diverted flow sites to better understand if diverted flow water quality differed from the influent water quality in SSC, POC concentrations, and/or PSDs. Because flow characteristics, antecedent dry period, and other conditions which affect stormwater concentrations can be highly variable over time, a parameter that can be monitored continuously using instrumentation that does not require labor-

intensive collection and laboratory analysis of water quality samples can be a cost-effective method to characterize the variability in sediment and/or pollutant concentrations and loads in stormwater over time. Previous studies have identified turbidity as a reasonable surrogate for suspended sediment and particle-bound POC concentrations in stormwater runoff with the development of a site-specific turbidity-SSC/POC relationship (Gilbreath et al., 2012). Linear regression was used to establish the relationship between paired turbidity and SSC and POC concentrations in water quality samples collected at the same time during targeted storm events. For parameters which were adequately predicted by turbidity, the continuous turbidity data were used in the regression equation(s) to estimate continuous SSC and/or POC concentrations in the influent throughout the entire period of turbidity monitoring for all storm flows.

Calculation of Annual Suspended Sediment and POC Loads Diverted

In order to account for variability over time, continuous data (either measured or estimated from turbidity-regression equations) were used whenever possible to estimate concentrations and/or loads. Suspended sediment loads were calculated by multiplying the fifteen-minute average SSC by the paired 15-minute average flow volume, and summing to estimate total daily loads. Linear regression of the daily suspended sediment load with daily rainfall was used to estimate the daily suspended sediment load during storms that were not monitored. Because this project focused on POCs which are predominantly particle-bound, the continuous suspended sediment loads were multiplied by the continuous POCs particle ratio (the water concentration normalized to suspended sediment) to estimate POC loads. For dry weather load calculations, and for storm load calculations for POC concentrations that were not well predicted by turbidity, the concentrations measured during selected dry weather and storm events were assumed to represent the range of concentrations at the site over time, and these data were used in load calculations. To estimate the total loads diverted, the total daily suspended sediment and POC influent loads were multiplied by the average daily percent of flow diverted during storm or dry weather (as appropriate), and then summed to provide the total monthly and annual loads diverted for all parameters during WY13 and WY14.

All of the measured and estimated data on runoff flows, and suspended sediment and POC loads diverted were reviewed to better understand how loads diverted varied under different flow conditions, and to identify conditions which resulted in maximum suspended sediment and/or POC loads diverted.

2.2. Results

2.2.1. Hydraulic Analysis – Rainfall and Urban Runoff Flow Characterization

Annual rainfall totals ranged from 10.10” – 14.18” (mean = 11.7”) during WY13, and from 6.19” to 7.15” (mean = 6.57”) during WY14 (NCDC, 2014; SCVWD, 2014). Based on the thirty-year average annual rainfall for Palo Alto of 16.15” (NCDC, 2010), rainfall was below normal in both WY13 (72% of normal) and WY14 (41% of normal). Thus, monitoring results presented here are representative of drier than normal conditions at the site.

During WY13, influent and diverted flow were continuously monitored for a total of 125 days between January 2013 and May 2014, including 23 days with rainfall, 92 days with dry weather flow, and 10 days with zero flow (Figure 2.2). During WY14, influent and diverted flow were continuously monitored for a total of 154 days between October 2013 and March 2014, including 35 days with rainfall, 28 days with dry weather flow, and 91 days with zero flow (Figure 2.3). Due to equipment issues (the flow sensor in the influent pipe was dislodged by a large storm event at

the end of November 2013, which pushed the sensor further up the side of the pipe and out of the flow during all but the highest flow volumes), valid influent flow data during WY14 were only obtained during October and November 2013. However, turbidity was successfully monitored at the influent site through March 2014.

Flows were typically higher during storm events than during dry weather (Figures 2.2 – 2.3). Instantaneous peak flows ranged from 0.05 to 0.35 cubic feet per second (cfs) in dry weather and 3.07 to 6.68 cfs during storm events. Peak flows during WY13 were observed with the largest two storm events monitored that year, which occurred on February 19, 2013 (0.25" rain) and March 7-8, 2013 (0.42" rain). Peak flows during WY14 were observed during the largest storm event monitored that year, which occurred on November 19-20, 2013 (1.0" rain). Figure 2.4 demonstrates the typical pattern that was observed wherein diverted flows tracked influent flows with a short time lag. Further inspection of the flow data identified a number of time periods in which there was measurable flow at the inlet, but no measureable flow at the diversion sensor, and it was assumed during these circumstances that the flow into the diversion structure was temporarily blocked by debris (e.g., sediment, trash, leaves, etc.) covering the inlet to the diversion vault. This assumption was informed by City of Palo Alto Stormwater crews reporting that they periodically inspect and remove debris from the inlet to the diversion vault after rainfall events, usually between 3 and 10 times per year. Further review of the flow data indicated low flow conditions were not reliably measured at the influent site, with a number of time periods during low flow conditions (stage height in pipe < 1 inch), where flow was measured at the diverted flow site but not the influent site. Because the flow sensors required a minimum of 1 inch of depth to measure velocity, low flows were more accurately measured in the smaller 8" diversion pipe than in the larger 15" influent pipe. Given that the influent was the only source of flow to the diversion pipe, it was assumed under these low flow conditions that the influent flow over time, at a minimum, must be equal to the diverted flow, and the flow data were adjusted accordingly. These corrections were applied only to the daily total flow volumes, rather than the instantaneous data, to account for the observed time-lag between flow measured at the influent sensor and flow measured at the diverted flow sensor.

Storm flows were by far the largest contributor to flow volume at the site, contributing approximately 96% of the total measured runoff at the site (Table 2.2). Dry weather flows remained low throughout monitoring, and contributed less than 4% to the total measured flows. The highest flows were observed during the largest storm events and the lowest flows during extended dry periods, as would be expected. Over the entire monitoring period, 46% of dry weather days had zero flow, while there were no days with rainfall > 0.01" that did not have observable flow. The average daily dry weather flows (on days with flow) ranged from 200 to 1,000 gallons/day (mean=540 gallons/day), while the average daily storm flows ranged from 9,000 to 150,000 gallons/day (Table 2.2). The average daily flow rate throughout monitoring never exceeded the maximum diversion design limit of 0.5 MGD.

Based on the daily averages, approximately 73% of dry weather flows and 66% of storm flows were diverted during the monitoring period (Table 2.2). The maximum volume of runoff that was diverted to the sanitary sewer on a single day during the monitoring period was 2,500 gallons during dry weather, and 180,000 gallons during the largest storm monitored, which occurred on November 20, 2013 (0.70" of rainfall). These volumes are well below the diversion structure's upper design limit of 0.5 MGD. However, there were relatively few storm events during the monitoring period, and no large events > 1 inch rainfall per day, so these data do not represent the upper range of potential flow scenarios at the site.

A strong linear relationship was observed between average daily rainfall and runoff volume measured at the influent site during storm flow ($R^2=0.94$, $p < 0.0001$), and daily storm flows for all periods that were not monitored were estimated from the regression equation ($y = 272,113x - 2,810$). The estimated total annual runoff volumes diverted during WY13 and WY14 were 2.0 MG and 1.2 MG, respectively, representing 65% - 66% of the total annual flow at the project site (Table 2.2). Of those volumes, 97% during WY13 and 95% during WY14 were from storm flows. Based on the estimated diverted flows during all of WY13 and WY14, the largest volume of flow diverted on a single day during WY13 and WY14 was 323,000 gallons on December 23, 2012, following 1.78 inches of rain within 24 hours. Again, this estimate is below the maximum diversion design limit of 0.5 MGD.

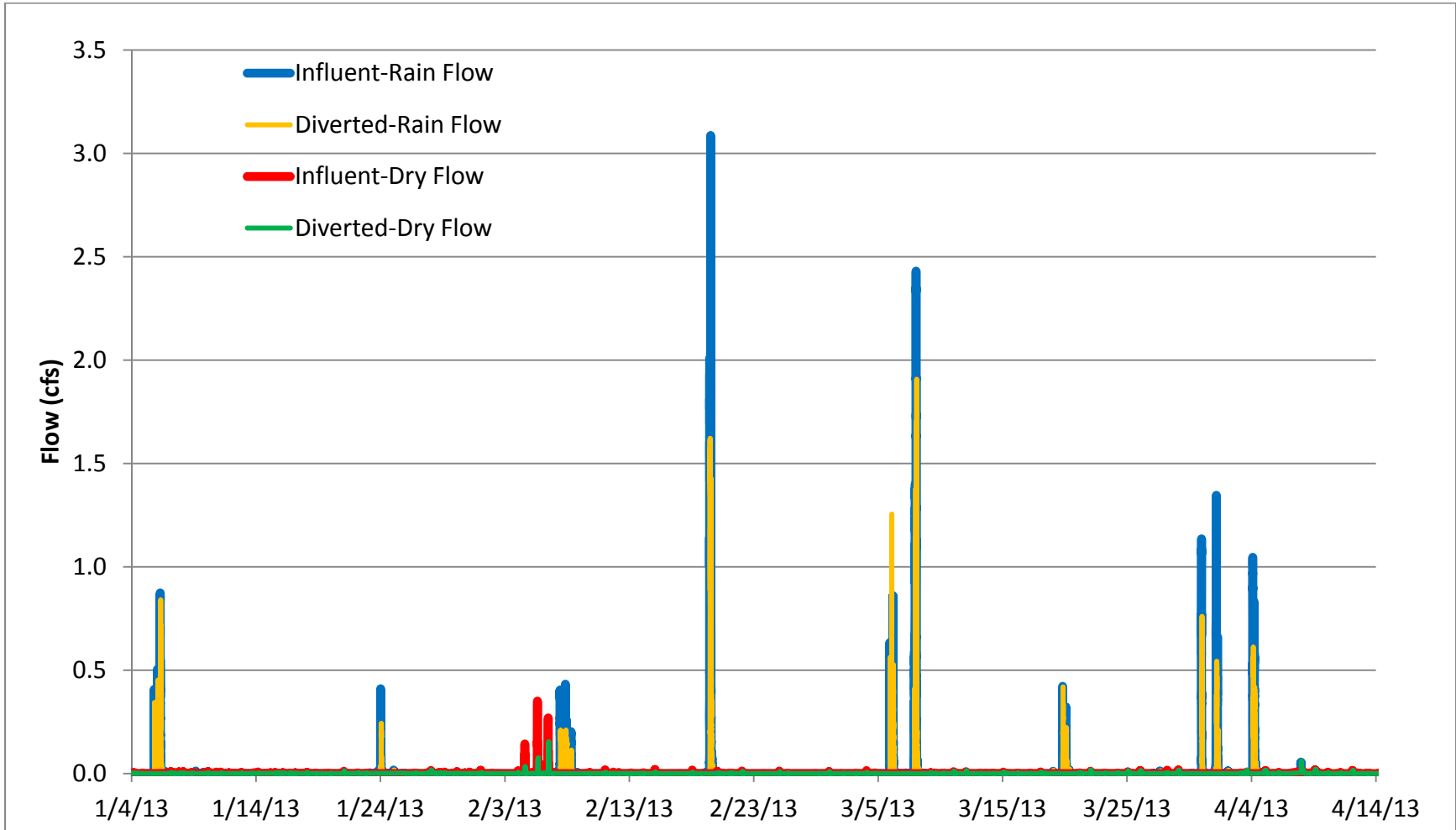


Figure 2.2. Runoff influent and diverted flow rates at the Palo Alto diversion structure measured during both rainfall and dry weather conditions in Water Year 13.

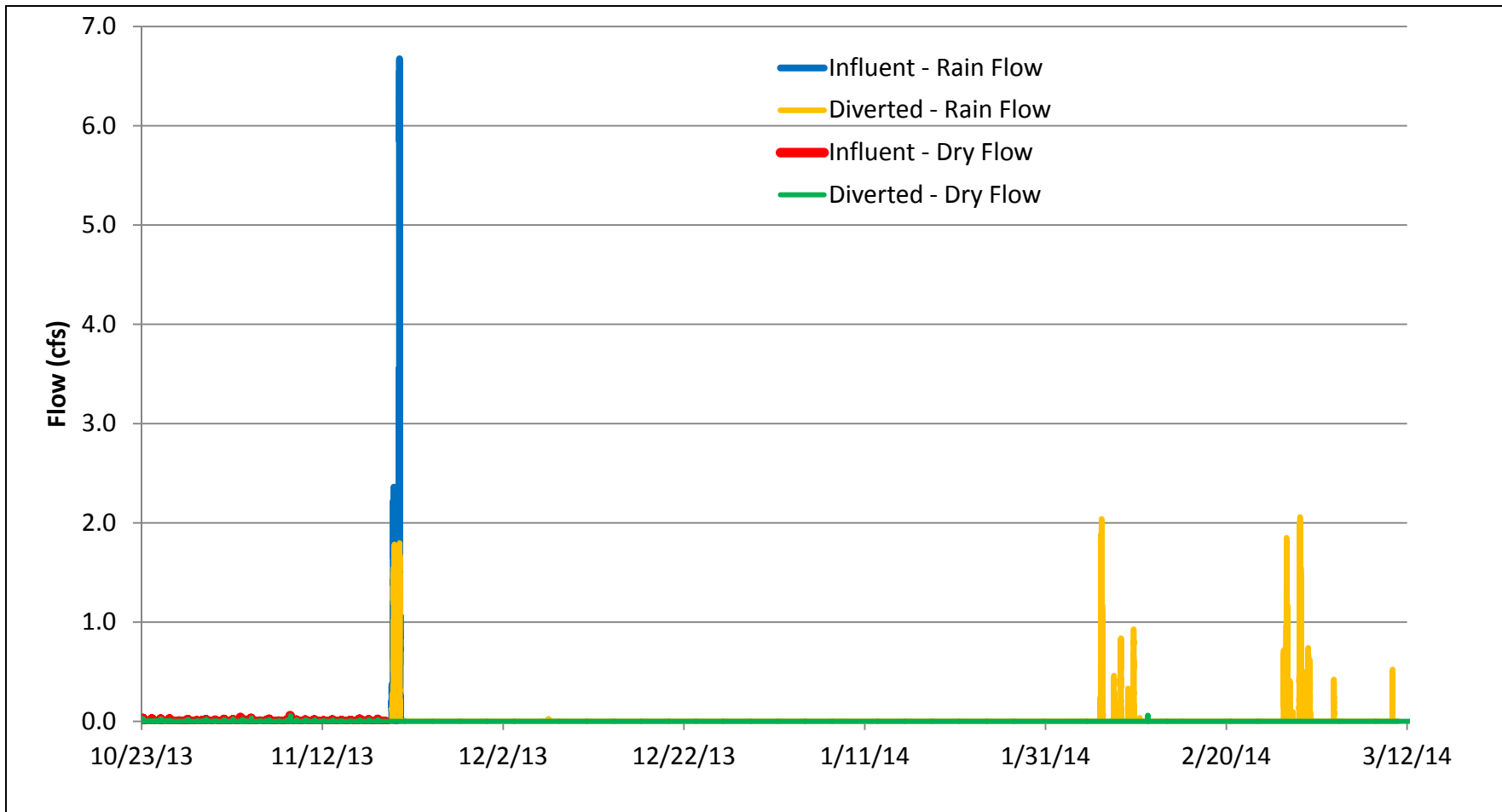


Figure 2.3. Runoff influent and diverted flow rates at the Palo Alto diversion structure measured during both rainfall and dry weather conditions in Water Year 14. Influent flow was only measured through November 20, 2013.

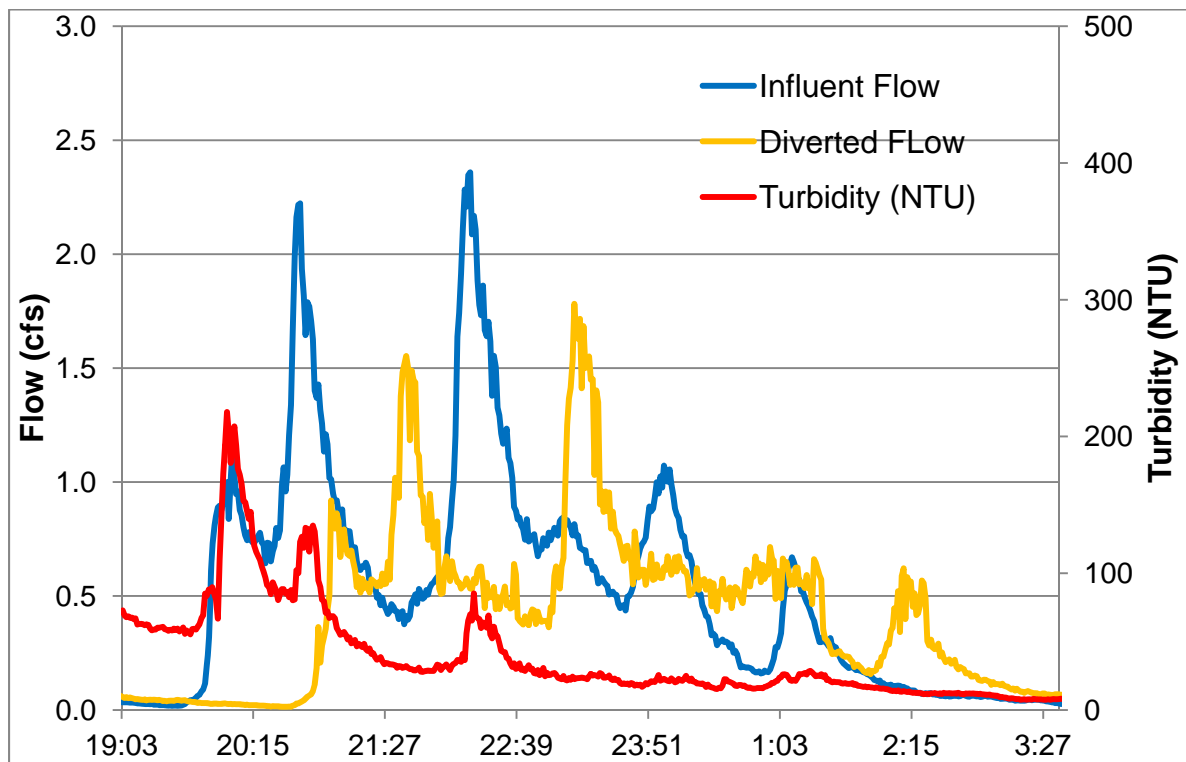
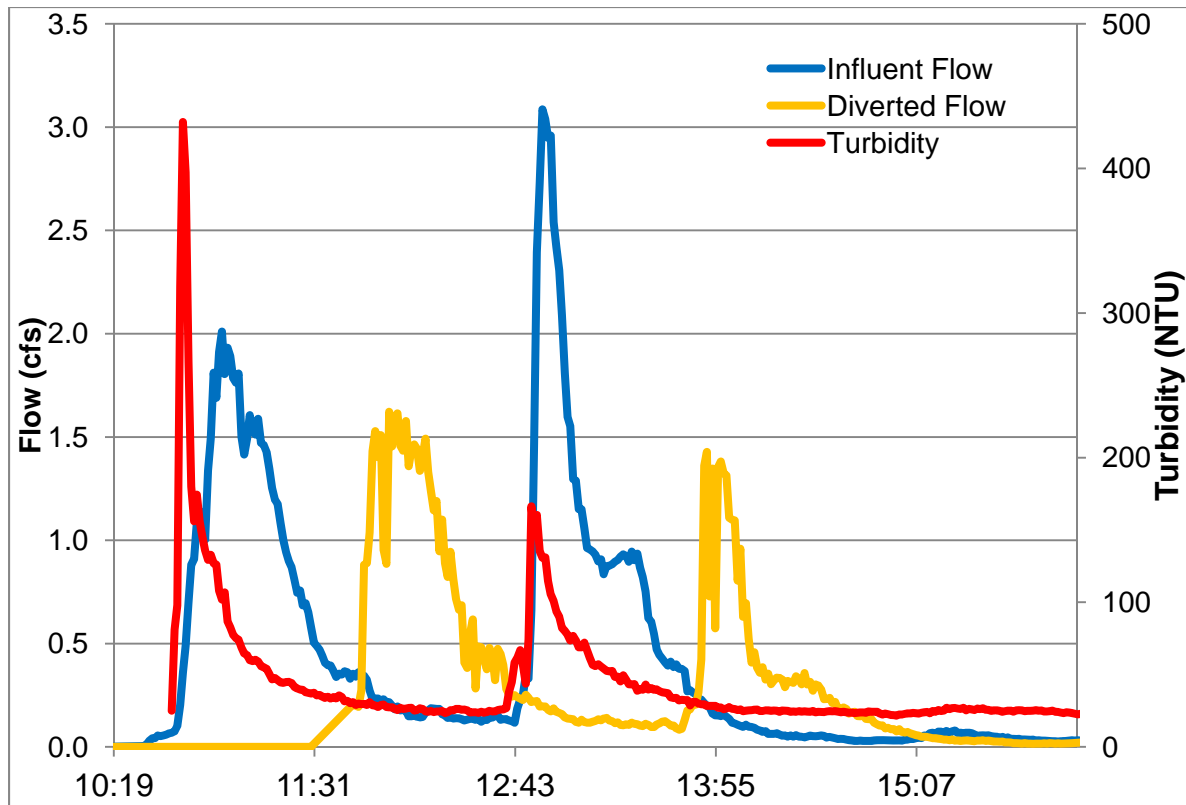


Figure 2.4. Influent and diverted flow rates and Influent turbidity measured at the Palo Alto diversion structure during the two largest storm events monitored each water year: (a) February 19, 2013; and (b) November 19-20, 2013.

Table 2.2. Flow Data for the Influent and Diverted Flow Sites at the Diversion Structure in Palo Alto, CA.¹

Flow Data Source ²	Month	STORM FLOW						DRY WEATHER FLOW				
		Number of Days with Rain	Rainfall (inches)	Flow Volume (gallons)			% Diverted	Number of Dry Days with Flow	Flow Volume (gallons)			% Diverted
				Daily Average Influent	Total Influent	Total Diverted			Daily Average Influent	Total Influent	Total Diverted	
Water Year 13	E Oct	7	0.81		201,000	133,000		13		7,000	5,110	
	E Nov	11	3.86		1,020,000	673,000		10		5,500	4,015	
	E Dec	15	4.66		1,230,000	812,000		9		4,700	3,431	
	M Jan	6	0.32	9,000	54,000	48,000	89%	23	530	12,000	8,500	71%
	M Feb	3	0.40	32,000	95,000	59,000	62%	19	950	18,000	4,100	23%
	M Mar	9	0.78	20,000	178,000	123,000	69%	22	200	4,500	3,900	87%
	M Apr	4	0.34	21,000	84,000	47,000	56%	24	417	10,000	7,900	79%
	E/M May	1	0.01	0	0	0		4	83	330	230	70%
	E Jun	2	0.03		3,700	2,400		15		8,200	5,986	
	E Jul	0	0		0	0		17		9,000	6,570	
E Aug	0	0		0	0		17		9,000	6,570		
E Sep	2	0.48		128,000	85,000		15		8,200	5,986		
WY13 Total		60	12	16,400	2,990,000	1,980,000	69%	188	436	96,000	62,000	66%
Water Year 14	E/M Oct	1	0.01	800	800	590	74%	16	1,000	9,000	9,000	100%
	M Nov	2	1.00	146,000	293,000	140,000	48%	15	560	10,000	8,000	80%
	E/M Dec	2	0.17		40,000	26,000		0		0	0	
	E/M Jan	5	0.05		3,600	24,000		0		0	0	
	E/M Feb	15	2.53		659,000	435,000		1		490	358	
	E/M Mar	10	1.43		365,000	241,000		0		0	0	
	E Apr	6	0.97		250,000	165,000		13		7,000	5,100	
	E May	0	0.00		0	0		17		9,000	6,600	
	E Jun	1	0.01		0	0		16		8,500	6,200	
	E Jul	0	0		0	0		17		9,000	6,600	
E Aug	1	0		0	0		16		8,700	6,400		
E Sep	2	0.41		105,000	69,000		15		8,200	6,000		
WY14 Total		45	7	73,400	1,700,000	1,100,000	61%	126	780	70,000	54,000	90%
TOTAL		105	18	33,000	4,690,000	3,080,000	66%	314	540	166,000	116,000	73%

¹Daily average influent volumes and % diverted were calculated for monitoring data only.

²E=estimated: flow data were calculated from daily rainfall-runoff regression equation; M=measured=flow data were obtained from monitoring.

2.2.2. Water Quality Characterization

Water quality samples were collected from 3 storm events and 2 dry weather events, as described in detail in the Field Data Report (Appendix A). The water quality data from these events, including PSDs, SSC and POC concentrations at both the influent and diverted flow sites, are summarized in Table 2.3. The ranges of total PCB and mercury concentrations observed were within the ranges of concentrations reported elsewhere for urban catchments in the Bay Area (McKee et al., 2012). Figure 2.5 demonstrates the hydrograph for the storm event that was monitored on March 5-6th, 2013, including influent flow, influent turbidity and diverted flow, which were monitored continuously at 1 to 15 minute intervals throughout the storm. SSC, mercury, and total PCBs concentrations from four discrete water samples that were collected at the influent and diverted flow sites over the course of the storm are also shown (Figure 2.5). The flow time series demonstrates the rapid response of the catchment to rainfall resulting from the small size and high imperviousness of the catchment.

No significant differences were found between measured influent and diverted flow concentrations of paired SSC, mercury concentrations or percent fines, which were normally distributed (paired t-test; $p > 0.52$), nor for total-PCBs and TOC concentrations, which were not normally distributed (Wilcoxon Signed Rank Test, $p > 0.14$). For other metals, which were not collected as influent and diverted flow paired samples, no significant differences were found between influent and diverted flow concentrations for Al, Cr, Mn, Ni, Se and Zn, which were normally distributed (t-test, $p > 0.60$), nor for As, Cd, Cu, Pb or Ag which were not normally distributed (Mann-Whitney Rank Sum test, $p > 0.35$).

Comparison between PSD in the influent and diverted flows were further investigated to better understand if particles of a certain size were preferentially diverted. Review of the particle size distributions indicated that although distributions were similar between influent and diverted flows, there was large variability between samples collected from the same location during different storm events (Figure 2.6 and Figure 2.7). For example, at the influent site, samples from the first storm were 100% composed of the smallest clay fraction ($d_p < 4 \mu\text{m}$), while samples collected during the second and third storm were dominated by silt and sand size fractions (Figure 2.6). Differences in PSDs between and within storms are likely related to the rainfall and flow characteristics of a given storm over time, as well as other variable factors such as the antecedent dry period, the timing of street sweeping prior to a rain event, and other activities in the watershed such as construction. Runoff from larger and/or more intense storms is likely to remove different particle sizes from urban catchments than smaller, and/or less intense storms. However, the results provided here demonstrate that the smallest particle sizes (e.g., the fine fraction $< 0.63 \mu\text{m}$), which are likely responsible for the majority of the pollutant load in urban runoff, were successfully diverted in all three monitored storm events, comprising 40% to 100% of the total suspended sediment concentrations in the diverted flow.

Turbidity data collected continuously during monitoring at the influent site and SSC and POC concentrations estimated from the regression relationship with turbidity are summarized in Table 2.4. Turbidity was generally highest during storm flow, although there were periodic elevated turbidity readings during dry weather flow as well. Daily average turbidity ranged from 1.6 to 92 NTU during storm flow and from 0.8 to 83 NTU during dry weather. One-minute maximum turbidity readings were 1,200 and 1,300 NTU during dry weather and storm flows, respectively. One-minute median turbidity was a moderate predictor of SSC during storm flow ($R^2 = 0.60$,

$p=0.001$; $y = 0.47x + 8.4$). The average daily SSC during storm flow estimated from the regression equation ranged from 9.1 to 52 mg/L, while the 1-minute maximum SSC ranged from

Table 2.3. Water Quality Concentrations Measured During Dry Weather and Storm Flows at the Influent and Diverted Flow Sites at the Diversion Structure in Palo Alto, CA.

Parameter	STORM FLOW						DRY WEATHER FLOW					
	Influent Flow			Diverted Flow			Influent Flow			Diverted Flow		
	Mean	Range	n	Mean	Range	n	Mean	Range	n	Mean	Range	n
SSC (mg/L)	28	4 - 88	14	25	7 - 68	12	20	1.8 - 39	2	13	6.7 - 20	2
Total PCBs (ng/L)	43	9.8 - 180	14	32	8.1 - 64	12	2.7	1.5 - 4.0	2	8.9	4.2 - 14	2
Mercury (ng/L)	16	8 - 23	14	16	10 - 33	12	6.2	5.6 - 6.7	2	4.9	4.1 - 5.7	2
TOC (mg/L)	28	14 - 60	14	28	16 - 56	12	12	6 - 18	2	18	na	1
% Fines	71	17 - 100	14	73	41 - 100	12	96	94 - 99	2	90	80 - 100	2
Aluminum (µg/L)	400	200 - 580	7	390	250 - 600	7	310	75 - 540	2			
Arsenic (µg/L)	1.0	0.83 - 1.3	7	1.4	0.87 - 3.5	7	0.94	0.92 - 0.96	2			
Cadmium (µg/L)	0.19	0.08 - 0.52	7	0.14	0.08 - 0.19	7	0.06	0.04 - 0.07	2			
Chromium (µg/L)	2.3	1.3 - 4.2	7	2.2	1.5 - 2.7	7	1.7	0.68 - 2.8	2			
Copper (µg/L)	41	24 - 51	7	40	24 - 56	7	89	23 - 154	2			
Lead (µg/L)	5.8	1.9 - 12	7	4.7	1.9 - 11	7	1.4	0.8 - 2.0	2		not measured	
Manganese (µg/L)	28	16 - 50	7	26	17 - 39	7	24	15 - 33	2			
Nickel (µg/L)	3.5	2 - 5.1	7	3.2	2.2 - 4.5	7	1.9	1.3 - 2.4	2			
Selenium (µg/L)	0.07	0.03 - 0.11	7	0.06	0.04 - 0.11	7	0.07	0.04 - 0.10	2			
Silver (µg/L)	0.02	nd - 0.23	7	0.01	nd - 0.11	7	0.02	0.01 - 0.03	2			
Zinc (µg/L)	230	150 - 400	7	210	150 - 270	7	110	93 - 130	2			

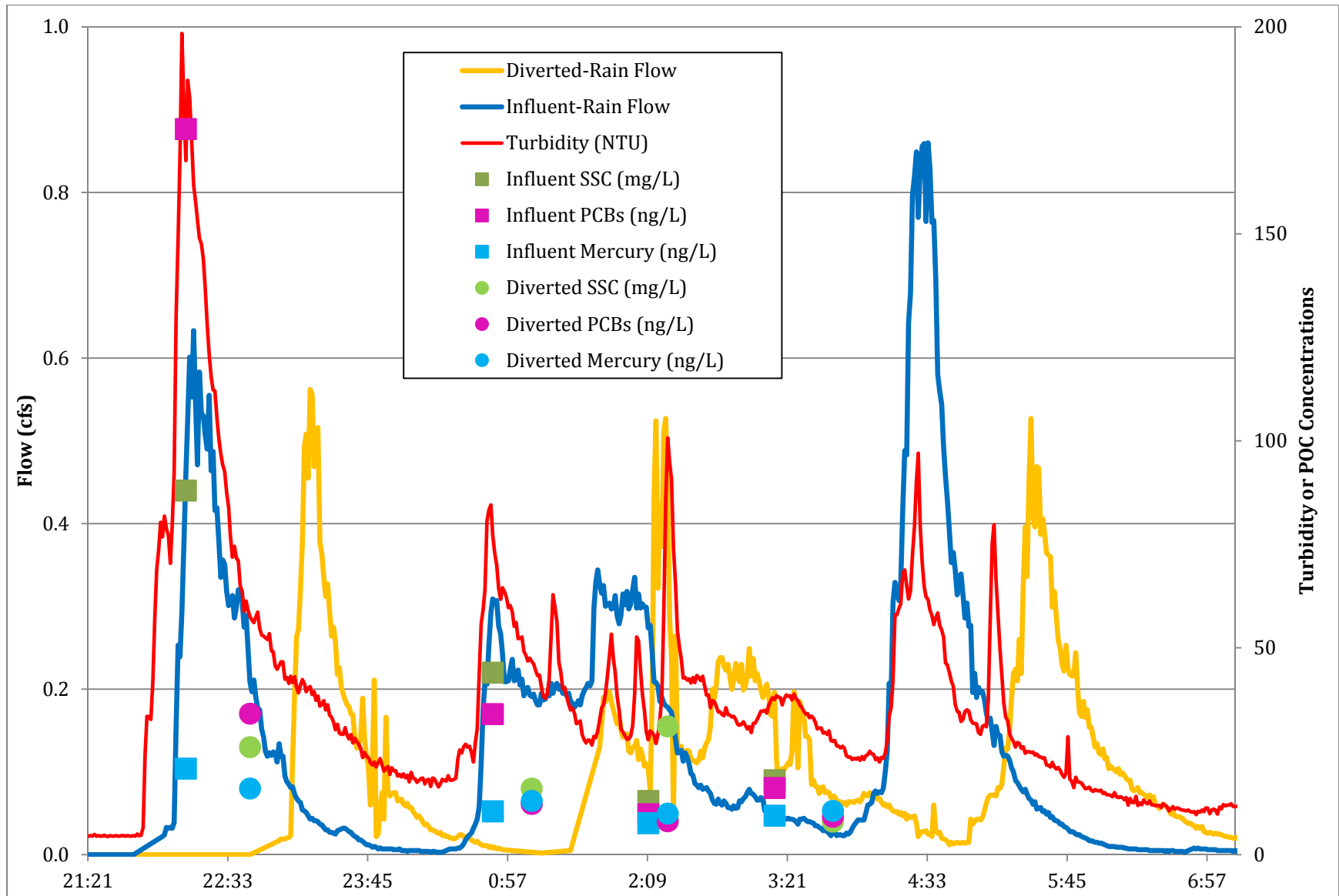


Figure 2.5. Measurements of continuous turbidity (influent) and flow (both influent and diverted), and discrete measurements of suspended sediment concentrations, mercury, and total PCBs on March 5-6, 2013 at the Palo Alto Diversion Structure.

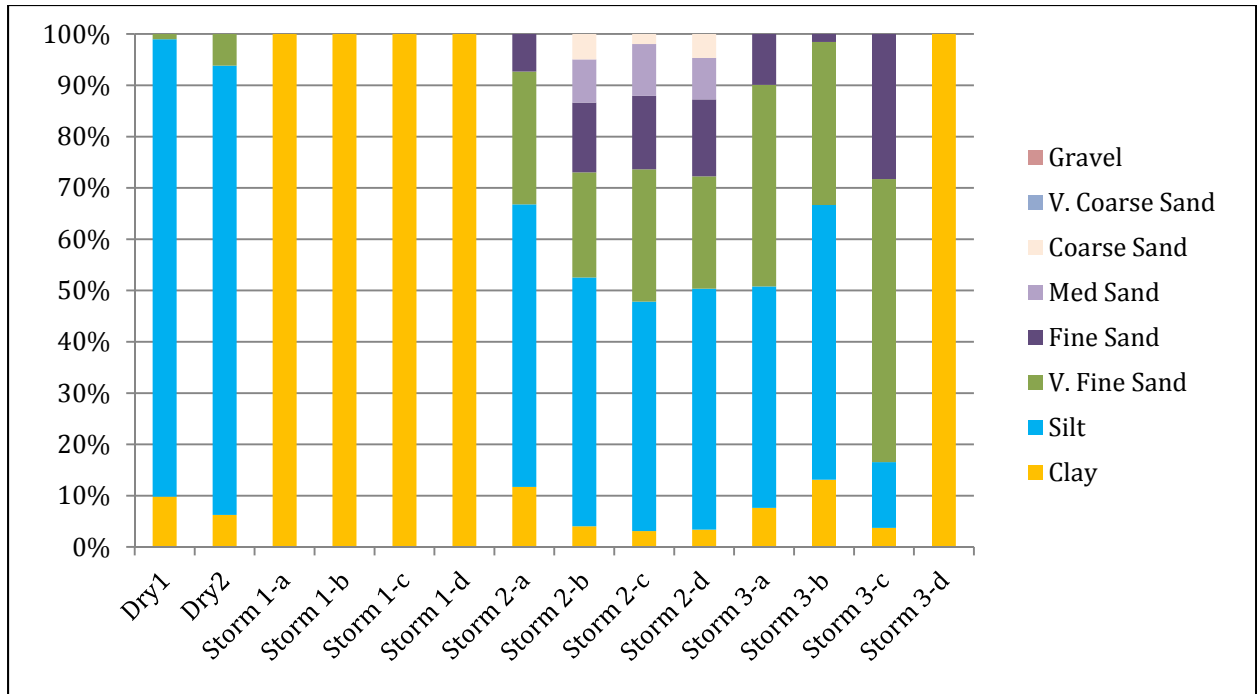


Figure 2.6. Particle Size Distributions Measured at the Influent Flow Site, Palo Alto, CA.

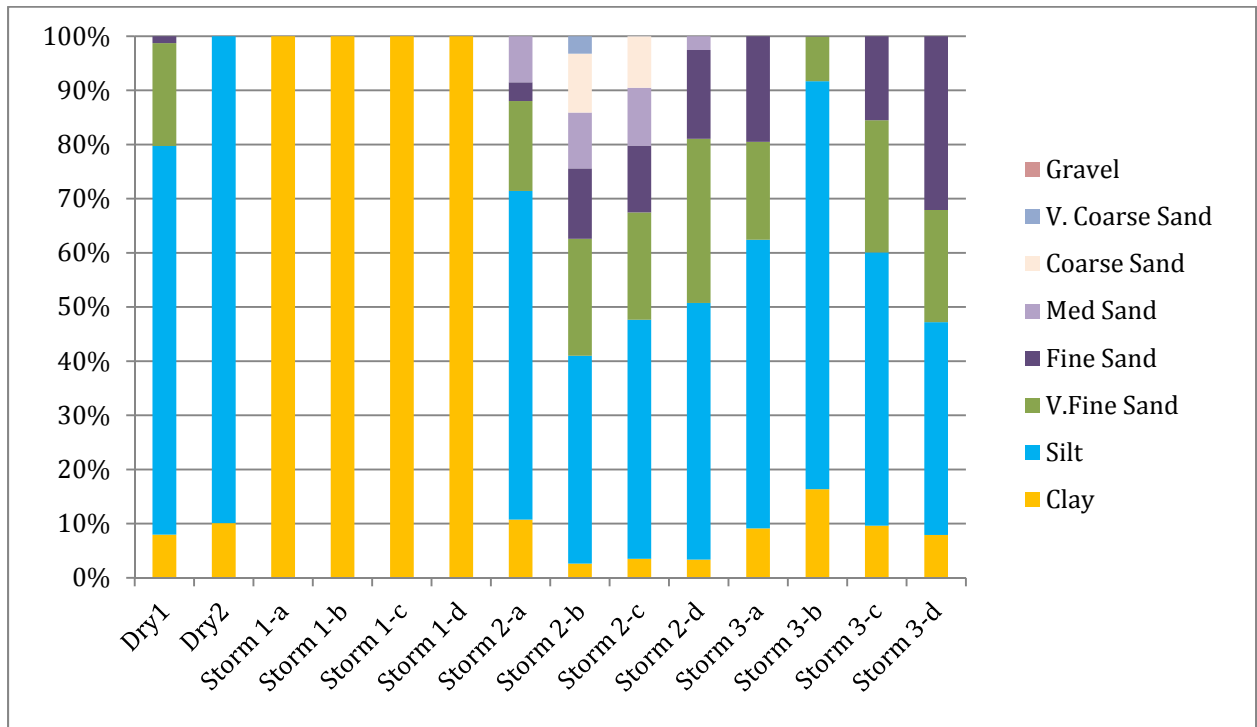


Figure 2.7. Particle Size Distributions Measured at the Diverted Flow Site, Palo Alto, CA

13 to 560 mg/L. With inclusion of only those samples composed of >50% fines ($d_p < 63 \mu\text{m}$; $n=9$), turbidity was a modestly better predictor of SSC ($R^2=0.71$, $p<0.001$), while inclusion of only samples that were 100% clay ($d_p < 4 \mu\text{m}$, $n=5$) indicated turbidity was a strong predictor of SSC ($R^2=0.99$, $p=0.002$). These results demonstrate turbidity is most closely associated with the smallest particle sizes, and thus the turbidity-SSC regression produces more accurate SSC estimates when suspended sediment in the runoff is dominated by fine particles. These results are based on a limited number of storm samples, and additional samples would be needed to fully characterize the PSD of runoff at the diversion structure and establish a robust turbidity-SSC relationship. However, the results presented here provide a reasonable first order estimate of SSC variability and magnitude at the site over time.

Regression of paired one-minute median turbidity and PCB concentrations during storm flow at the influent site demonstrated turbidity was a good predictor of PCB concentrations during storm flow ($R^2=0.70$, $p<0.001$), allowing prediction of continuous PCB concentrations during storm flow over the monitoring period. Average daily PCB concentrations estimated from the regression equation ranged from 7.9 to 88 ng/L.

However, neither turbidity nor SSC were found to be good predictors of mercury concentrations during storm flow ($R^2=0.03$, $p=0.54$; and $R^2=0.38$, $p=0.02$, respectively). For the subset of samples collected during storms that were analyzed for additional metals, cadmium, chromium, manganese and zinc concentrations were well predicted by turbidity, ($R^2=0.83 - 0.98$, $p<0.04$); aluminum, arsenic, copper, lead, nickel, and selenium were not well predicted by turbidity or SSC ($R^2<0.5$, $p>0.14$). These results are limited by the small sample size ($n=5$).

2.2.3. SSC and POC Loads and Conditions Which Maximize Loads Diverted

Rainfall was found to be a strong predictor of suspended sediment loads during storm flow ($R^2=0.93$, $p<0.001$), allowing suspended sediment loads during periods that were not monitored to be calculated from the regression equation ($y=21,734,933x+561,279$) and daily rainfall. The total annual loads of suspended sediment diverted were 270 kg and 150 kg for WY13 and WY14, respectively (Tables 2.5 and 2.6). The total annual loads of PCBs diverted each year were 350 mg and 210 mg for WY13 and WY14, respectively. The total annual loads of mercury diverted each year were 160 and 93 mg for WY13 and WY14, respectively. Storm flows accounted for 98% of the total loads of suspended sediment, total PCBs and mercury. Although stormwater POC concentrations and particle ratios at this site were not as low as expected, because the total suspended sediment load and flow volumes diverted were relatively small, the total annual loads of POCs diverted were also small (e.g., < 1 g per year, Tables 2.5 and 2.6). Other diverted metal loads varied, with Aluminum and Zinc ranging from 1.5-4.5 Kg per year at the high end, and Selenium and Silver at the lower end with < 1 g per year (Tables 2.7 and 2.8). Copper and Manganese both ranged between 180 g – 500 g per year. Arsenic, cadmium, chromium, lead and nickel loads ranged between 2 g and 63 g per year. Stormwater loads comprised 94% to 99% of the total annual loads for these metals. Gilbreath et al., (2012) reported stormwater loads calculated from similar field, laboratory and load calculation techniques, and estimated the error in the load data were 14% to 72% for regression estimators, and 55% to 170% for loads estimated from measured mean concentrations.

Table 2.4. Summary of 1-minute Median Turbidity Data Measured at the Influent Flow Site and the SSC and PCBs Concentrations Estimated from Linear Regression with Turbidity.

Water Year	Month	# Storm Days	<u>1-Minute Turbidity (NTU)</u>		<u>1-Minute SSC (mg/L)</u>		<u>1-Minute PCBs (ng/L)</u>	
			Daily Average	Range	Daily Average	Range	Daily Average	Range
WY13	Jan	6	10	2 - 170	13	9.3 - 88	16	8.3 - 160
	Feb	3	58	2.2 - 430	36	9.4 - 210	58	8.5 - 390
	Mar	9	11	1.5 - 320	14	9.1 - 160	17	7.8 - 290
	Apr	4	24	1.3 - 310	20	9.0 - 160	28	7.7 - 280
	May	0	na		na		na	
WY14	Oct	1	2.1	1.4 - 78	9.4	9.0 - 45	8.4	7.7 - 76
	Nov	2	27	1.2 - 800	21	8.9 - 380	30	7.6 - 710
	Dec	2	6.4	0.9 - 370	11	8.8 - 180	12	7.3 - 340
	Jan	5	2.5	0.9 - 170	10	8.8 - 90	8.7	7.3 - 160
	Feb	15	23	1.1 - 1,200	19	9.3 - 560	27	8.2 - 1,000
	Mar	5	7.5	2.7 - 330	12	10 - 160	13	8.9 - 300

Review of rainfall, flow and suspended sediment load time series for both influent and diverted flow sites, clearly demonstrates flow and suspended sediment loads track well with the daily rainfall amounts (Figure 2.8). Larger storms produced higher flows and higher suspended sediment loads, while smaller storms and dry weather produced smaller flows and smaller suspended sediment loads (Figure 2.8). For the time period studied, this appears to be the case regardless of antecedent dry days. First flush effects were not observed during monitoring, although this may in part be due to the drier than normal weather conditions with infrequent and relatively small storms that occurred during the monitoring period. Had there been much larger and/or more frequent storms, it is possible a first flush effect may have been observed.

By far, the largest factors contributing to increased suspended sediment and POC loads at the site were rainfall amounts and the type of flow. Suspended sediment loads in storm flow were 45 to 55 times greater than dry weather flow, and storm flow diverted 40 to 60 times more SS each year than dry flow. Dry flow was limited at the project site, accounting for only 3% to 4% of the total annual flow, and 2% each of the total SS and PCB loads at this site, for WY13 and WY14, respectively. The dry weather flow and load estimates presented here have greater uncertainty associated with them because there were fewer dry weather measurements, and low flows that are more common during dry weather than during storms were less accurately measured. Flows during summer months were not monitored during this study, and it is likely the estimates presented here overestimate dry weather flows during the summer because of the long antecedent dry conditions and the limited sources of flow to the site during dry summer months. However, despite the greater uncertainty associated with the dry weather estimates presented here, the contribution of dry weather loads is expected to remain low compared with storm loads, given the small magnitude of dry weather flow volume compared with storm flows, even during the drier than normal conditions experienced during WY13 and WY14. In addition, because there are few sources of flow to the diversion structure other than rainfall, other factors which may contribute to increased flows and subsequent loads would likely be minor compared with rainfall amounts.

Table 2.5. Water Year 13 Estimated and Measured Flows, and Loads of Suspended Sediment, Mercury, and Total PCBs.

	Data Source ¹	Month	Days with Flow	Rainfall (inches)	Suspended Sediment (Kg)		Total PCBs (mg)		Mercury (mg)	
					Influent	Diverted	Influent	Diverted	Influent	Diverted
DRY WEATHER FLOW	E	Oct	13		0.54	0.39	0.60	0.44	0.17	0.12
	E	Nov	10		0.43	0.31	0.47	0.35	0.13	0.10
	E	Dec	9		0.36	0.26	0.40	0.29	0.11	0.08
	M	Jan	14		0.93	0.43	1.0	0.48	0.29	0.21
	M	Feb	14		1.4	0.21	1.6	0.23	0.43	0.32
	M	Mar	12		0.35	0.20	0.39	0.22	0.11	0.08
	M	Apr	14		0.78	0.40	0.87	0.45	0.24	0.18
	E	May	16		0.03	0.02	0.03	0.02	0.01	0.01
	E	Jun	15		0.63	0.46	0.70	0.51	0.20	0.14
	E	Jul	17		0.70	0.51	0.77	0.57	0.22	0.16
	E	Aug	17		0.70	0.51	0.77	0.57	0.22	0.16
E	Sep	15		0.63	0.46	0.70	0.51	0.20	0.14	
Total Dry			166	0	7.5	4.2	8.3	4.6	2.3	1.7
STORM FLOW	E	Oct	7	0.81	26	17	33	22	15	10
	E	Nov	11	3.86	150	99	190	130	86	56
	E	Dec	15	4.66	180	120	230	150	103	68
	M	Jan	6	0.32	4.2	3.3	5.9	4.7	2.4	1.6
	M	Feb	3	0.40	15	4.9	25	7.3	8.5	5.6
	M	Mar	9	0.78	19	9.1	29	13	11	7
	M	Apr	4	0.34	7.0	2.8	10	3.6	4.0	2.6
	E	May	1	0.01	0	0	0	0	0	0
	E	Jun	2	0.03	0	0	0	0	0	0
	E	Jul	0	0	0	0	0	0	0	0
	E	Aug	0	0	0	0	0	0	0	0
E	Sep	2	0.48	19	12	24	16	11	7	
Total Storm			60	11.70	419	268	546	346	239	158
Total Storm + Dry			226	11.70	427	273	555	351	241	159

¹E=estimated: data were calculated from regression equations; M=measured=flow data were obtained from monitoring.

Table 2.6. Water Year 14 Estimated and Measured Flows, and Loads of Suspended Sediment, Mercury, and Total PCBs.

	Data Source ¹	Month	Days with Flow	Rainfall (inches)	Suspended Sediment (Kg)		Total PCBs (mg)		Mercury (mg)	
					Influent	Diverted	Influent	Diverted	Influent	Diverted
DRY WEATHER FLOW	M	Oct	16		0.70	0.45	0.78	0.51	0.22	0.16
	M	Nov	15		0.78	0.40	0.87	0.45	0.24	0.18
	E	Dec	16		0.00	0.00	0.00	0.00	0.00	0.00
	E	Jan	14		0.00	0.00	0.00	0.00	0.00	0.00
	E	Feb	7		0.0	0.03	0.04	0.03	0.01	0.01
	E	Mar	11		0.00	0.00	0.00	0.00	0.00	0.00
	E	Apr	13		0.54	0.39	0.60	0.44	0.17	0.12
	E	May	17		0.70	0.51	0.77	0.57	0.22	0.16
	E	Jun	16		0.65	0.48	0.72	0.53	0.20	0.15
	E	Jul	17		0.70	0.51	0.77	0.57	0.22	0.16
	E	Aug	16		0.68	0.49	0.75	0.55	0.21	0.15
	E	Sep	15		0.63	0.46	0.70	0.51	0.20	0.14
Total Dry			173	0	5.4	3.7	6.0	4.1	1.7	1.2
STORM FLOW	M	Oct	1	0.00	0	0	0	0	0	0
	M	Nov	2	1.00	46	16	76	24	26	17
	E	Dec	2	0.17	5	3	0	0	3	2
	E	Jan	5	0.05	0	0	0	0	0	0
	E	Feb	15	2.53	94	62	140	92	53	35
	E	Mar	10	1.43	50	33	63	42	29	19
	E	Apr	6	0.97	35	23	45	30	20	13
	E	May	0	0.00	0	0	0	0	0	0
	E	Jun	1	0.01	0	0	0	0	0	0
	E	Jul	0	0	0	0	0	0	0	0
	E	Aug	1	0	0	0	0	0	0	0
	E	Sep	2	0.41	15	10	19	13	9	6
Total Storm			45	6.57	245	147	343	201	140	92
Total Storm + Dry			218	6.57	250	151	349	205	141	93

¹E=estimated: data were calculated from regression equations; M=measured=flow data were obtained from monitoring.

Table 2.7. Water Year 13 Estimated Dry Weather and Storm Flow Metal Loads.

	Data Source ¹	Month	Days with Flow	Rainfall (inches)	Estimated Metal Loads (g)										
					Al	As	Cd	Cr	Cu	Pb	Mn	Ni	Se	Ag	Zn
DRY WEATHER FLOW	E	Oct	13		6.1	0.02	0.001	0.03	1.7	0.03	0.48	0.04	0.001	0.0004	2.2
	E	Nov	10		4.8	0.01	0.001	0.03	1.4	0.02	0.38	0.03	0.001	0.0003	1.7
	E	Dec	9		4.1	0.01	0.001	0.02	1.2	0.02	0.32	0.02	0.0009	0.0003	1.4
	M	Jan	14		11	0.03	0.002	0.06	3.0	0.05	0.83	0.06	0.002	0.0007	3.8
	M	Feb	14		16	0.05	0.003	0.09	4.5	0.07	1.2	0.09	0.004	0.001	5.6
	M	Mar	12		4.0	0.01	0.001	0.02	1.1	0.02	0.31	0.02	0.0009	0.0003	1.4
	M	Apr	14		8.8	0.03	0.002	0.05	2.5	0.04	0.69	0.05	0.002	0.0006	3.1
	E	May	16		0.29	0.001	0.0001	0.002	0.08	0.001	0.02	0.002	0.0001	0.00002	0.1
	E	Jun	15		7.1	0.02	0.001	0.04	2.0	0.03	0.56	0.04	0.002	0.0005	2.5
	E	Jul	17		7.9	0.02	0.001	0.04	2.3	0.04	0.62	0.05	0.002	0.0006	2.8
	E	Aug	17		7.9	0.02	0.001	0.04	2.3	0.04	0.62	0.05	0.002	0.0006	2.8
	E	Sep	15		7.1	0.02	0.001	0.04	2.0	0.03	0.56	0.04	0.002	0.0005	2.5
Total Dry			166	0	85	0.26	0.02	0.47	24	0.39	6.6	0.50	0.02	0.01	30
STORM FLOW	E	Oct	7	0.81	268.44	0.68	0.12	1.6	28	3.9	19	2.3	0.05	0.02	154
	E	Nov	11	3.9	1,564	3.95	0.73	9	162	23	110	14	0.27	0.09	899
	E	Dec	15	4.7	1,877	4.74	0.87	11	195	27	132	16	0.33	0.11	1,079
	M	Jan	6	0.32	43	0.11	0.02	0.25	4.5	0.63	3.1	0.38	0.01	0.002	25
	M	Feb	3	0.40	156	0.39	0.07	0.90	16	2.3	11	1.4	0.03	0.01	90
	M	Mar	9	0.78	193	0.49	0.09	1.12	20	2.8	14	1.7	0.03	0.01	111
	M	Apr	4	0.34	73	0.18	0.03	0.42	7.5	1.0	5.12	0.63	0.01	0.004	42
	E	May	1	0.01	0	0	0	0	0	0	0	0	0	0	0
	E	Jun	2	0.03	0	0	0	0	0	0	0	0	0	0	0
	E	Jul	0	0	0	0	0	0	0	0	0	0	0	0	0
	E	Aug	0	0	0	0	0	0	0	0	0	0	0	0	0
E	Sep	2	0.48	194.71	0.49	0.09	1.13	20.19	2.81	13.73	1.70	0.03	0.01	112	
Total Storm			60	11.70	4,370	11	2.0	25	453	63	308	38	0.76	0.25	2,513
Total Storm + Dry			226	11.70	4,454	11	2.0	26	477	63	315	39	0.78	0.25	2,543

¹E=estimated: data were calculated from regression equations; M=measured=flow data were obtained from monitoring.

Table 2.8. Water Year 14 Estimated Dry Weather and Storm Flow Metal Loads.

Data Type	Month	Days with Flow	Rainfall (inches)	Estimated Metal Loads (g)											
				Al	As	Cd	Cr	Cu	Pb	Mn	Ni	Se	Ag	Zn	
DRY WEATHER FLOW	M	Oct	16	7.9	0.02	0.001	0.04	2.3	0.04	0.62	0.05	0.0018	0.0006	2.8	
	M	Nov	15	8.8	0.03	0.002	0.05	2.5	0.04	0.69	0.05	0.0020	0.0006	3.1	
	E	Dec	16	0.00	0.00	0.000	0.00	0.00	0.00	0.00	0.00	0.0000	0.0000	0.00	
	E	Jan	14	0.00	0.00	0.000	0.00	0.00	0.00	0.00	0.00	0.0000	0.0000	0.00	
	E	Feb	7	0.42	0.00	0.000	0.00	0.12	0.00	0.03	0.00	0.0001	0.0000	0.15	
	E	Mar	11	0.00	0.00	0.000	0.00	0.00	0.00	0.00	0.00	0.0000	0.0000	0.00	
	E	Apr	13	6.1	0.02	0.001	0.03	1.7	0.03	0.48	0.04	0.0014	0.0004	2.2	
	E	May	17	7.9	0.02	0.001	0.04	2.3	0.04	0.62	0.05	0.0018	0.0006	2.8	
	E	Jun	16	7.4	0.02	0.001	0.04	2.1	0.03	0.58	0.04	0.0017	0.0005	2.6	
	E	Jul	17	7.9	0.02	0.001	0.04	2.3	0.04	0.62	0.05	0.0018	0.0006	2.8	
	E	Aug	16	7.6	0.02	0.001	0.04	2.2	0.04	0.60	0.05	0.0017	0.0005	2.7	
	E	Sep	15	7.1	0.02	0.00	0.04	2.0	0.03	0.56	0.04	0.00	0.00	2.5	
Total Dry		173	0	61	0	0	0	18	0	5	0	0	0	22	
STORM FLOW	M	Oct	1	0.00	0.31	0.00	0.00	0.03	0.00	0.02	0.00	0.00	0.00	0.18	
	M	Nov	2	1.00	479	1.2	0.22	2.8	50	6.9	34	4.2	0.08	0.03	275
	E	Dec	2	0.17	50	0.13	0.02	0.29	5.2	0.72	3.52	0.43	0.01	0.00	29
	E	Jan	5	0.05	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	E	Feb	15	2.53	978	2.5	0.45	5.7	101	14	69	8.5	0.17	0.06	562
	E	Mar	10	1.43	521	1.3	0.24	3.0	54	7.5	37	4.5	0.09	0.03	300
	E	Apr	6	0.97	368	0.93	0.17	2.1	38	5.3	26	3.2	0.06	0.02	211
	E	May	0	0.00	0	0	0	0	0	0	0	0	0	0	0
	E	Jun	1	0.01	0	0	0	0	0	0	0	0	0	0	0
	E	Jul	0	0	0	0	0	0	0	0	0	0	0	0	0
	E	Aug	1	0	0	0	0	0	0	0	0	0	0	0	0
E	Sep	2	0.41	156	0.40	0.07	0.91	16	2.3	11	1.4	0.03	0.01	90	
Total Storm		45	6.57	2,552	6.4	1.2	15	265	37	180	22	0.45	0.15	1,468	
Total Storm + Dry		218	6.57	2,614	6.6	1.2	15	282	37	185	23	0.46	0.15	1,489	

¹E=estimated: data were calculated from regression equations; M=measured=flow data were obtained from monitoring.

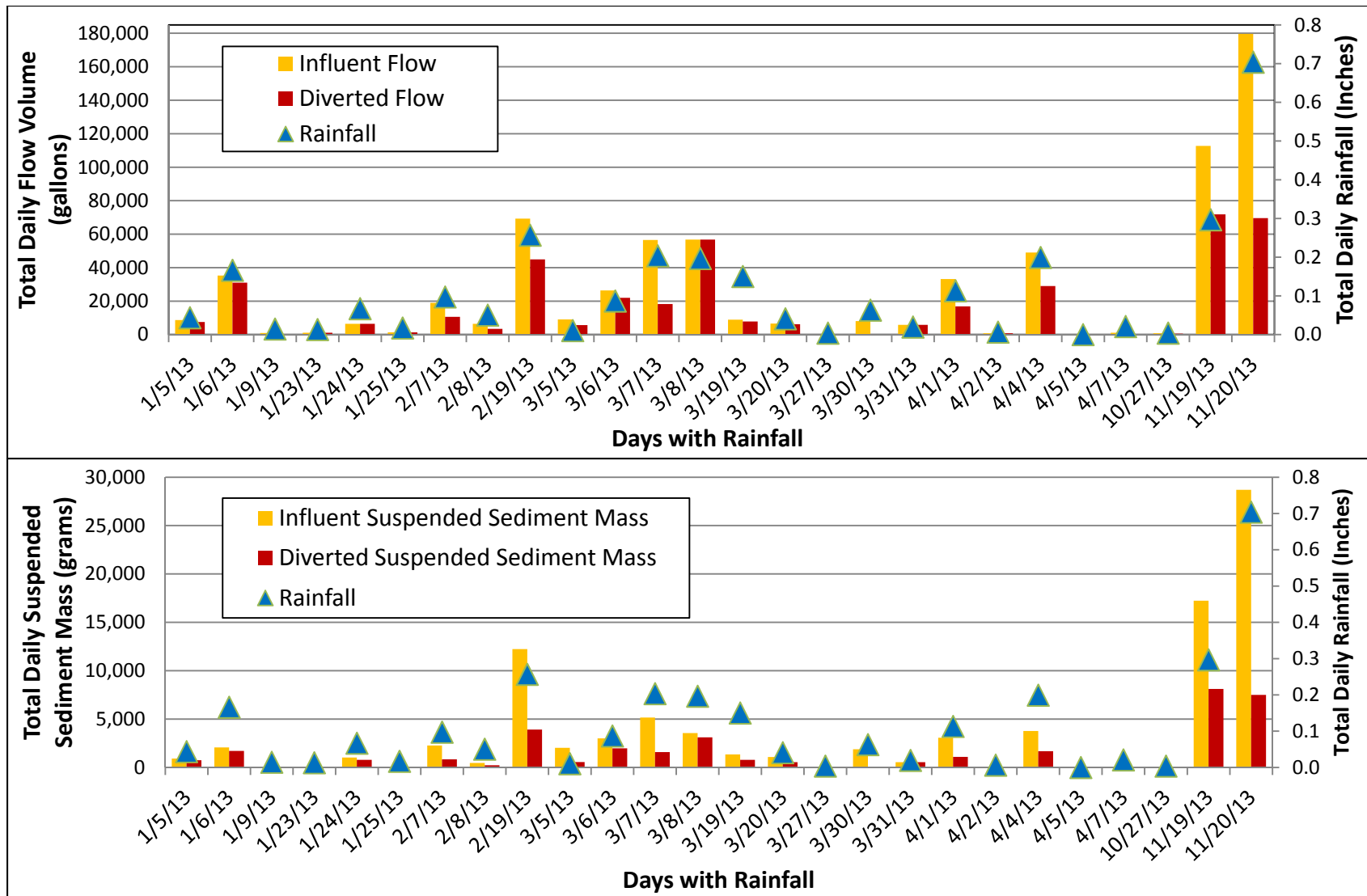


Figure 2.8. Daily Flow Volume, Suspended Sediment Load and Rainfall Measured at the Diversion Structure in Palo Alto, CA.

2.3. Limitations

The annual loads presented here are limited by the relatively small sample size and the drier than normal rainfall years during the two years of monitoring. Wetter years with more frequent rainfall and/or larger storm events are likely to have different load characteristics than drier years with less frequent rainfall events and/or smaller storms, as occurred during this study.

In addition, the relationship established between SSC and 1-minute median turbidity was only moderate, and a better relationship would provide more accurate SSC and suspended sediment load estimates. This is especially important given the large variability observed in PSDs within storm events, and the impact PSD may have on the SSC-turbidity relationship. In order to identify a stronger relationship, a number of other potential relationships between turbidity and SSC were explored, including log transformed data, SSC normalized to percent fines, 1-minute average turbidity, and 5-minute average turbidity. However, these relationships were all weaker than the relationship between 1-minute median turbidity and SSC, and additional measurement data would be needed to improve the strength of the relationship. Furthermore, the limited variability in the flows observed during the study due to the low rainfall during both monitoring years also limits confidence in the established SSC-turbidity relationship to relatively small storm flows. Data from larger, more frequent, and/or longer duration storms would provide better accuracy for the SSC-turbidity relationship at the higher end of the range, and thus higher confidence in estimated SS loads diverted.

3.0 EVALUATION OF COSTS AND OPERATIONAL CHALLENGES

This task documents the costs and operational challenges associated with construction, operation and maintenance of the Palo Alto diversion structure, as well as any associated impacts on the Palo Alto Regional Water Quality Control Plant (RWQCP). Program staff gathered all relevant construction, operation and maintenance, and cost information available with the assistance and cooperation of the City of Palo Alto and the RWQCP staff.

3.1. Construction – Challenges, Constraints and Costs

The City of Palo Alto Public Works Department proposed and implemented the capital improvement project to divert stormwater to the sanitary sewer system as a means of stormwater treatment for heavy metals, oil/grease, sediment, pesticides, and other pollutants that may be contained in urban runoff entering the municipal storm drain system, in an effort to reduce nonpoint source pollution to the San Francisco Bay.

The first step in implementing this project was to locate an appropriate site, consisting of close proximity between the storm drain system and a sanitary sewer line with excess capacity, within an area expected to benefit from treatment of urban runoff. The location at Bryant Avenue and Channing Avenue was selected because of proximity to the Channing Avenue sewer trunk line which had excess capacity, and because at the time this project was implemented, the catchment draining to this location consisted of a number of automobile facilities that were thought to contribute heavy metals and other pollutants to the storm drainage system. The next step was to obtain approval from the sanitary sewer system serving this location for the stormwater connection.

The City of Palo Alto Utilities Department, Water-Gas-Wastewater Division (WGW) (in consultation with staff at the Palo Alto Regional Water Quality Control Plant (RWQCP)) provided approval to the Stormwater Engineering Group in the Public Works Department for the stormwater connection to the sanitary sewer with the following conditions, which were applied to protect the existing sanitary sewer system and limit additional costs to RWQCP:

1. Waivers of the relevant sections of the Uniform Plumbing Code and Palo Alto Municipal Code, which prohibit stormwater discharges to the sanitary sewer, must be obtained.
2. All plans and specification for the stormwater connection must be reviewed and approved by the Utilities Department WGW engineering staff.
3. Written approval of the project must be provided by the Utilities Department WGW engineering staff.
4. Design must include the following: a rough bar screen to remove inert solids prior to discharge to the sanitary sewer; and a gate valve installed just prior to the connection to the sanitary sewer to allow the diversion flow to be reduced or shut off entirely at any time.
5. All ongoing maintenance of the structure (e.g., cleanout and disposal of solids and sediment accumulation in the vault) is the responsibility of the Public Works Department.
6. Any costs incurred by the Utilities Department associated with cleaning the Channing Avenue trunk sewer due to inadequate treatment of the stormwater are the responsibility of the Public Works Department.

The Public Works Department agreed to these conditions, and the diversion structure was built in 1992. The contractor costs for the design and construction, adjusted from 1992 to 2014 dollars (www.usinflationcalculator.com), were \$37,000 and \$107,000, respectively. It should be noted,

however, that these costs do not include any administrative and planning costs associated with City and RWQCP staff. These costs were roughly estimated at 25% of the total design and construction budgets, consistent with previous cost estimates developed for BMP implementation (SCVURPPP, 2014). Thus, the total cost to plan, design and construct the Palo Alto diversion structure is estimated at \$180,000. The RWQCP did not impose any fees associated with the connection to the sanitary sewer or for treatment of the diverted stormwater.

3.2. Operation and Maintenance – Challenges, Constraints and Costs to the Municipality

Because the diversion in Palo Alto is a passive system that has no moving parts and does not require an external power source, the maintenance requirements are relatively straightforward, and costs for ongoing maintenance were readily quantified. The structure maintenance involves regular inspections, to verify the diversion is operating properly, to check that the inlets to the diversion vault are not blocked by debris (trash or leaves) and to check for sediment accumulation inside the vault which may clog the valves and impede flow through the vault and into the sanitary sewer outfall. Parts are replaced and repaired as needed. If debris and/or sediment accumulation are present, the vault and the storm drain line are cleaned using a hydro-flusher/vacuum truck.

Discussions with City of Palo Alto Public Works Maintenance Personnel indicated the structure was initially inspected by current staff in 2006 and found to be non-operational due to missing components. It is not known how long prior to that inspection the diversion structure was non-operational. The structure was repaired, including the purchase and installation of new valves, and has been operational, with regular inspections and maintenance since that time. The structure is typically inspected between three and ten times per year during the rainy season. Staff typically inspect at the beginning of the wet season and after large rain events, and reported that blockages are more commonly observed during the fall leaf drop. Fewer inspections occur during years with relatively low rainfall and few large storms, while a higher number of inspections occur during very wet years (e.g., El Nino conditions). A two-member crew and a hydro-flusher/vacuum truck are required for inspection and maintenance of the structure, with a typical upper time limit of 6 hours per visit (including all inspection, cleaning, repairs, and travel time). The total cost per visit was estimated at \$1,000, and the total maintenance costs for the Palo Alto diversion structure ranges between \$3,000 and \$10,000 per year.

3.3. Operation and Maintenance – Challenges, Constraints and Costs to the Sanitary Sewer

Stormwater diversions present a number of challenges and constraints to any POTW which accepts the diversion. It is important to emphasize that the City of Palo Alto has a relatively unique situation in which the City owns and operates both the stormwater and sanitary sewer systems. Thus, the information reported here that is specific to the Palo Alto Diversion Structure may underestimate the full challenges, constraints and costs that would be expected when different entities own and operate the stormwater and sanitary sewer systems, as is the case in many other Bay Area locations. In addition, the sanitary sewer system in Palo Alto has excess capacity and relatively few issues with inflow/infiltration. These features allow for easier diversion implementation that may not be readily available in other locations. Discussions with RWQCP staff identified a number of potential issues with the Palo Alto diversion and stormwater diversions in general. The discussion below presents factors specific to the Palo Alto Diversion, as well as additional challenges, constraints and costs not applicable to the current situation in Palo Alto, but which would likely apply should stormwater

diversion be implemented at other locations. These additional factors provide a more realistic assessment of the potential challenges for future stormwater diversion projects in the Bay Area.

First, POTWs are concerned with the regulatory and legal issues associated with acceptance of stormwater diversions. The Palo Alto RWQCP requested and received waivers of their local ordinances that prohibit rainwater connections to the sanitary sewer in order to allow the existing diversion. If required to accept additional or larger diversions, Palo Alto indicated they would need to seek guidance from the EPA, the Water Board, and other local regulators on how diversions should be addressed. For example, if acceptance of stormwater diversions causes or could cause the POTW to fail to meet their pollutant loading limits, the POTW may need to request “adjustments” to effluent limits in their permit to account for this factor

Second, pollutant concentrations and loading in diverted stormwater, and any associated impacts on POTW operations are a primary concern to POTWs. Pollutants of Concern for POTWs include all pollutants for which they have current effluent limits, as well as any pollutants for which they may have limits in the future. POTWs set local limits for industrial dischargers that are designed to protect POTW processes and ensure the POTW can meet all effluent limits and other permit requirements. Table 3.1 provides a comparison between the current RWQCP local limits and stormwater concentrations measured at the Palo Alto diversion structure during the current study, the maximum concentrations measured in local POC hotspots areas in the Bay Area, as well as mean stormwater concentrations reported in the National Stormwater Quality Database (NSQD, 2008). This comparison demonstrates that for the majority of parameters reported, stormwater concentrations are typically well below current Palo Alto local limits. However, site-specific and ongoing monitoring would be required to document diverted stormwater concentrations remain below current local limits, as well as any limits that may be adopted in the future in response to additional effluent limits imposed on the POTW. Other impacts of concern to the POTW would be anything that creates a problem with POTW operations, such as process inhibition or recycled water and biosolids quality. (In theory these concerns are already incorporated into the POTWs local limits). A POTW that was experiencing problems with final effluent chronic toxicity might also have concerns that constituents in stormwater could exacerbate those problems. These types of impacts can be much more difficult to quantify than pollutant loadings, but some effort to account for these impacts would also need to be addressed.

In recognition of the concerns expressed in the previous two paragraphs, recent NPDES permits in the SF Bay Region include a reopener provision that states that the Water Board may modify or reopen the permit “If the Discharger requests adjustments in effluent limits due to the implementation of stormwater diversion pursuant to the Municipal Regional Stormwater Permit (CAS612008) for redirecting dry weather and first flush discharges from the storm drain system to the sanitary sewer system as a stormwater pollutant control strategy.”

Third, high wet weather flows can be a problem, particularly for POTWs that already have inflow/infiltration issues, and environmental harm may result if sewer overflows occur. Thus, capacity issues may present a major constraint to POTWs accepting stormwater diversions. If substantial load reduction benefits can still be achieved by focusing primarily on first flush and low flow diversions, capacity limitations could be dealt with by reducing or stopping diversions during high flow events. Although capacity issues have not typically been a problem in Palo Alto, two mechanisms were included in the design of the structure to address potential sanitary sewer capacity issues, should they arise in the future. First, the Palo Alto diversion was designed as a low flow device, which limits diversions to relatively low flow conditions (< 350 gpm), designed to capture the first flush of stormwater, and low flows during storms and dry weather, both of which may contain elevated pollutant loads. Second, at the request of the RWQCP, a gate valve was installed at the diversion

structure's discharge line to the sanitary sewer. This valve can be manually closed, if needed, to stop all diversion flow to the sanitary sewer. To date, it is not known if the valve has ever been closed. However, the RWQCP has requested development of criteria for when the valve should be closed, which would be implemented by the Public Works Department, Public Services Division storm drain maintenance crew. For example, if there have been a series of large storms in a row, it may be necessary to close the valve and stop any diversions temporarily to avoid capacity exceedances at the RWQCP.

Fourth, there are potential costs for additional connections, treatment and plant maintenance due to stormwater diversion. Because the Palo Alto diversion is on public property, and the City owns and operates both the stormwater system and the sanitary sewer system, the POTW has not charged any connection or treatment fees to date, and there have not been any additional permit requirements for the existing diversion. Given that stormwater diversions are treated to the same processes as all other sanitary sewer discharges, these types of fees would typically be charged if the stormwater and sanitary sewer systems were not owned and operated by the same entity, and in some cases, even if they were. Estimates for the connection and treatment fees based on the most current (2012) Utility Rate Schedule in Palo Alto for industrial dischargers are presented in Table 3.2. Palo Alto RWQCP staff also indicated that if they were required to treat stormwater diversion as an industrial discharge (with the associated Pretreatment permit and monitoring requirements) this would be burdensome, and would likely reduce their willingness to accept stormwater diversions.

Further, the RWQCP is not aware of any issues that have arisen at the treatment plant due to the existing Palo Alto diversion since it was installed in 1993. No additional maintenance at the plant or in the sewer trunk line has been required due to the diversion. Thus, the RWQCP to date has no known costs associated with maintenance issues resulting from the diversion. However, in the more general case, if there were additional POTW maintenance costs that exceeded "normal" maintenance provided for by the sewer rates, these would need to be funded through fees imposed by the POTW on the entity implementing the diversion.

All of the information gathered on the costs of the Palo Alto diversion structure is summarized in Table 3.3. The costs are based on actual incurred costs for the Palo Alto Diversion Structure plus the expected POTW fees for a structure of this capacity based on the RWQCP fees for industrial dischargers as described above. Both the total costs over twenty years are presented, as well as the annual cost each year, with design and construction costs pro-rated over 20 years.

Table 3.1. Comparison between Palo Alto Regional Water Quality Control Plant Local Limits and the Range of Pollutant Concentrations in Stormwater.

Pollutant	RWQCP Local Max Limits ¹ (mg/l)	Stormwater Concentrations (mg/L)		
		Palo Alto (Min-Max)	Bay Area Hotspots (Max)	National Stormwater Quality Database (Mean)
Arsenic	0.1	0.00083 - 0.0013	-	0.096
Barium	5	-	-	0.04
Beryllium	0.75	-	-	0.02
Boron	1	-	-	-
Cadmium	0.1	0.00008 - 0.0005	-	0.03
Chromium, Hexavalent	1	-	-	-
Chromium, total	2	0.0013 - 0.0042	-	0.01
Cobalt	1	-	-	-
Copper	0.252	0.024 - 0.051	0.03	0.04
Cyanide	0.5	-	-	0.06
Dissolved Sulfides	0.1	-	-	-
Fluoride	65	-	-	-
Formaldehyde	5	-	-	-
Lead	0.5	0.002 - 0.01	-	0.06
Manganese	1	0.02 - 0.05	-	-
Mercaptans	0.1	-	-	-
Mercury	0.01	0.00001 - 0.00002	0.002	0.03
Methyl Tertiary Butyl Ether	0.75	-	-	-
Nickel	0.5	0.002 - 0.005	-	0.02
Phenols	1	-	-	-
Selenium	1	0.00003 - 0.01	0.006	0.006
Silver	0.25	ND - 0.0002	-	0.1
Single Toxic Organic ³	0.75	-	-	-
Total Toxic Organics ³	1	-	-	-
Total PCB		0.00001 - 0.00017	0.0005	-
Total PAH		-	0.005	-
Zinc	2.04	0.15 - 0.14	-	0.2
Conventional Pollutants	Local Max Limit			
Oil and Grease ⁵	20 mg/l	-	-	-
Oil and Grease (total)	200 mg/l	-	-	28
Suspended Solids	3,000 ⁶ mg/l	4 - 88	470	150
Total Dissolved Solids	5,000 ⁷ mg/l	-	-	160
Conventional Pollutant	Local Min Limit			
pH	5	-	-	8

¹For discharges with annual average flows greater than fifty thousand gallons per day through any single sampling location, the maximum allowable limits shall be one-half the values listed in the table, with the exception of Cu, Hg, MTBE, Ni, and Ag, for which the limits shall remain at the values listed in the table, regardless of flow.

²The local max copper limit for cooling system discharges less than 2,000 gpd, Vehicle Services, Photoprocessing, Machine Shops shall be 2.0 mg/L. See Section 16.09.045 of the Sewer Use Ordinance for details and for metal finisher requirements.

³See below list of specific TTO/STO compounds.

⁴The local maximum zinc limit for vehicle service facilities shall be 4.0 mg/L.

⁵Gravity separation at a temperature of 20°C, and a pH of 4.5.

⁶Applies to composite samples only. The local max limit for instantaneous samples shall be 6,000 mg/L (SS) and 10,000 mg/L (TDS).

TOXIC ORGANICS - 40 CFR, Section 433.11(e)

Acenaphthene	N-nitrosodi-n-propylamine
Acrolein	Pentachlorophenol
Acrylonitrile	Phenol
Benzene	Bis (2-ethylhexyl) phthalate
Benzidine	Butyl benzyl phthalate
Carbon tetrachloride (tetrachloromethane)	Di-n-butyl phthalate
Chlorobenzene	Di-n-octyl phthalate
1,2,4-trichlorobenzene	Diethyl phthalate
Hexachlorobenzene	Dimethyl phthalate
1,2-dichloroethane	1,2-benzanthracene (benzo(a)anthracene)
1,1,1-trichloroethane	Benzo(a)pyrene (3,4-benzopyrene)
Hexachloroethane	3,4-Benzofluoranthene (benzo(b)fluoranthene)
1,1-dichloroethane	11,12-benzofluoranthene (benzo(k)fluoranthene)
1,1,2-trichloroethane	Chrysene
1,1,2,2-tetrachloroethane	Acenaphthylene
Chloroethane	Anthracene
Bis (2-chloroethyl) ether	1,12-benzoperylene (benzo(ghi)perylene)
2-chloroethyl vinyl ether (mixed)	Fluorene
2-chloronaphthalene	Phenanthrene
2,4,6-trichlorophenol	1,2,5,6-dibenzanthracene (dibenzo(a,h)anthracene)
Parachlorometa cresol	Indeno (1,2,3-cd) pyrene (2,3-o-phenylene pyrene)
Chloroform (trichloromethane)	Pyrene
2-chlorophenol	Tetrachloroethylene
1,2-dichlorobenzene	Toluene
1,3-dichlorobenzene	Trichloroethylene
1,4-dichlorobenzene	Vinyl chloride (chloroethylene)
3,3-dichlorobenzidine	Aldrin
1,1-dichloroethylene	Dieldrin
1,2-trans-dichloroethylene	Chlordane (technical mixture and metabolites)
2,4-dichlorophenol	4,4-DDT
1,2-dichloropropane	4,4-DDE (p,p-DDX)
1,3-dichloropropylene (1,3-dichloropropene)	4,4-DDD (p,p-TDE)
2,4-dimethylphenol	Alpha-endosulfan
2,4-dinitrotoluene	Beta-endosulfan
2,6-dinitrotoluene	Endosulfan sulfate
1,2-diphenylhydrazine	Endrin
Ethylbenzene	Endrin aldehyde
Fluoranthene	Heptachlor
4-chlorophenyl phenyl ether	Heptachlor epoxide
4-bromophenyl phenyl ether	(BHC-hexachlorocyclohexane)
Bis (2-chloroisopropyl) ether	Alpha-BHC
Bis (2-chloroethoxy) methane	Beta-BHC
Methylene chloride (dichloromethane)	Gamma-BHC
Methyl chloride (chloromethane)	Delta-BHC
Methyl bromide (bromomethane)	(PCB-polychlorinated biphenyls)
Bromoform (tribromomethane)	PCB-1242 (Arochlor 1242)
Dichlorobromomethane	PCB-1254 (Arochlor 1254)
Chlorodibromomethane	PCB-1221 (Arochlor 1221)
Hexachlorobutadiene	PCB-1232 (Arochlor 1232)
Hexachlorocyclopentadiene	PCB-1248 (Arochlor 1248)
Isophorone	PCB-1260 (Arochlor 1260)
Naphthalene	PCB-1016 (Arochlor 1016)
Nitrobenzene	Toxaphene
2-nitrophenol	2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD)
4-nitrophenol	
2,4-dinitrophenol	
4,6-dinitro-o-cresol	
N-nitrosodimethylamine	
N-nitrosodiphenylamine	

Table 3.2 – Palo Alto Utilities – Commercial Wastewater Collection and Disposal Fees for Industrial Dischargers.

Charge Category	Detailed Rate
Collection System Operation, Maintenance, and Infiltration Inflow	\$2,078 per million gallons (\$1.55 per 100 cubic feet of metered water).
Advanced Waste Treatment Operations and Maintenance	\$1,404 per million gallons (\$1.05 per 100 cubic feet of metered water).
	\$ 248 per 1000 pounds (lbs) of Chemical Oxygen Demand
	\$ 597 per 1000 lbs of Suspended Solids
	\$ 3,984 per 1000 lbs of NH3 (Ammonia)
	\$ 14,781 per 1000 lbs of toxics (chromium, copper, cyanide, lead, nickel, silver, and zinc)

Table 3.3. Estimated Total 20-Year costs and annual costs for Construction, Operation and Maintenance, and POTW fees associated with the Palo Alto Diversion Structure.

Cost Category	Total Cost (20 year timeframe)	Annual Cost
Design/Construction/O&M		
Planning/Administrative	\$36,000	\$1,800
Design	\$37,000	\$1,850
Construction	\$107,000	\$5,350
Operation and Maintenance:	\$60,000 - \$200,000	\$3,000 - \$10,000
Subtotal	\$240,000 - \$380,000	\$12,000 - \$19,000
POTW Fees		
	Cost Basis	Annual Cost
Connection Fees	\$2,080 per MG per year	\$2,500 - \$4,200
Treatment Fees		
• Water	\$1,400 per MG per year	\$1,700 - \$2,800
• Solids	\$597 per 1,000 lbs of SS per year	\$200 - \$360
• Toxics	\$14,781 per 1,000 lbs of toxics per year	\$40 - \$70
Administrative or Permit Fees	Unknown	
Subtotal	\$90,000 - \$150,000	\$4,400 - \$7,400
TOTAL (ALL COSTS)	\$330,000 - \$530,000	\$16,400 - \$26,400

4.0 COST AND BENEFIT ANALYSIS

The hydraulic analysis, water quality characterization and pollutant loading data and general understanding of the operation and functioning of the diversion structure reported in Section 2.0 were combined with the cost information documented in Section 3.0 to evaluate the cost effectiveness of a range of potential diversion implementation scenarios. Cost effectiveness was defined as the annual cost per gram of POC removed through diversion. This metric was used to understand the feasibility, costs and projected benefits associated with the existing Palo Alto diversion structure, and for implementing additional diversion projects in the Bay Area during subsequent MRP terms.

First, the cost effectiveness of the Palo Alto diversion structure during WY13 and WY14 in terms of mercury and PCBs loads diverted was estimated from the loading data in Tables 2.5 and 2.6, and the annual cost data in Table 3.3. The 20 year costs provided in Table 3.3 were scaled to 22 years, to amortize the design and construction costs over the current age of the Palo Alto diversion structure. For the Palo Alto diversion structure, the cost effectiveness during WY13 and WY14 was approximately \$73,000 to \$78,000 per gram of PCBs diverted, and \$160,000 to \$170,000 per gram of mercury diverted.

Next, cost effectiveness was estimated for four potential diversion scenarios that were selected to represent a range of catchment sizes and urban runoff suspended sediment and POC concentrations that could be expected in Bay Area watersheds where diversions may be implemented. Two diversion scenarios focused on small catchments, modeled after the Palo Alto diversion structure's catchment in size and flow volumes, while the other two scenarios were modeled after a larger catchment that would produce higher flow volumes. Higher flow volumes diverted could be achieved through construction of multiple diversion structures similar to the Palo Alto structure or by structures designed to divert higher flow volumes. The model for the larger catchment was the Northern half of the Pulgas Creek Pump Station watershed, which is a highly impervious, predominantly industrial, urban catchment located in the City of San Carlos. This catchment was selected as the model for the large catchment scenario because (1) the catchment size (approximately 130 acres) was large relative to the Palo Alto diversion structure's catchment size; (2) this catchment is also a highly impervious, urban catchment, known to have elevated stormwater POC concentrations, and (3) monitoring data on rainfall, runoff, and pollutant loads in the catchment during WY13 and WY14, reported elsewhere, (SMCWPPP, in preparation) were available for developing a rainfall-runoff regression to estimate annual stormwater runoff volume, and average daily dry weather flows were available to estimate annual dry weather flow for the catchment.

The 30-year average annual rainfall in Palo Alto of 16.15 inches (NCDC, 2010) was used in all diversion scenarios tested to represent normal conditions and allow better comparison across the four diversion scenarios. Drier or wetter than normal rainfall years would have higher or lower flows and associated SSC/POC loads. Based on the rainfall-runoff regression for the Palo Alto diversion structure catchment reported in Section 2.0, the expected flow for this catchment in a normal rainfall year would be approximately 4.4 MG. This was the volume used in the small catchment diversion scenarios. For the large catchment scenarios, the rainfall-runoff regression for monitored flows in the Northern half of the Pulgas Creek Pump Station watershed during WY13 and WY14, reported elsewhere (SMCWPPP, in Preparation) were used to calculate a total annual storm flow volume of approximately 28 MG during a normal rainfall year of 16.15 inches. Similarly, dry weather flows were estimated from the percent of the total annual flow accounted for by dry weather from the data reported in Section 2.0 for the Palo Alto diversion catchment, and from data

for the North Pulgas Creek Pump Station catchment. In Palo Alto, dry weather accounted for only 3.4% of the total annual flows at the site; however, in the North Pulgas catchment, dry weather accounted for 25% of the total annual flows at the site. For all scenarios, the percent of flow diverted that was calculated in Section 2.0 for dry and storm flow at the Palo Alto diversion structure (73% and 66%, respectively) was applied to estimate the total annual flow volumes diverted.

SSC and POC concentrations measured in urban Bay Area watersheds reported in McKee et al (2012) were used in the diversion scenarios to represent the range of POC concentrations in Bay Area watersheds where stormwater diversions could be implemented. McKee et al., (2012) categorized a number of Bay Area watersheds as baseline or elevated based on water quality data. Baseline watersheds were characterized by higher SSC, lower POC concentrations, and smaller POC particle ratios (POC concentration normalized to SSC) considered typical of urban background. Elevated watersheds were characterized by lower SSC, higher POC concentrations, and higher POC particle ratios, and were typically known or suspected PCB or mercury hotspots (Figure 4.1). For baseline watersheds, the calculated average SSC, PCB and mercury concentrations were 510 mg/L, 12 ng/L, and 100 ng/L, respectively. For elevated watersheds, the calculated average SSC, PCB and mercury concentrations were 82 mg/L, 87 ng/L, and 50 ng/L, respectively. POC particle ratios for baseline and elevated watersheds were calculated from these averages (Table 4.1). Note, although mercury concentrations were higher in the baseline watersheds, the elevated mercury particle ratios were larger because of the lower SSC in elevated watersheds. For dry weather flow concentrations, SSC and POC concentrations measured in Palo Alto (this study) and the North Pulgas Creek Pump Station Catchment were assumed to represent baseline and elevated watersheds in the Bay Area, as few other data are available on dry weather flow concentrations.

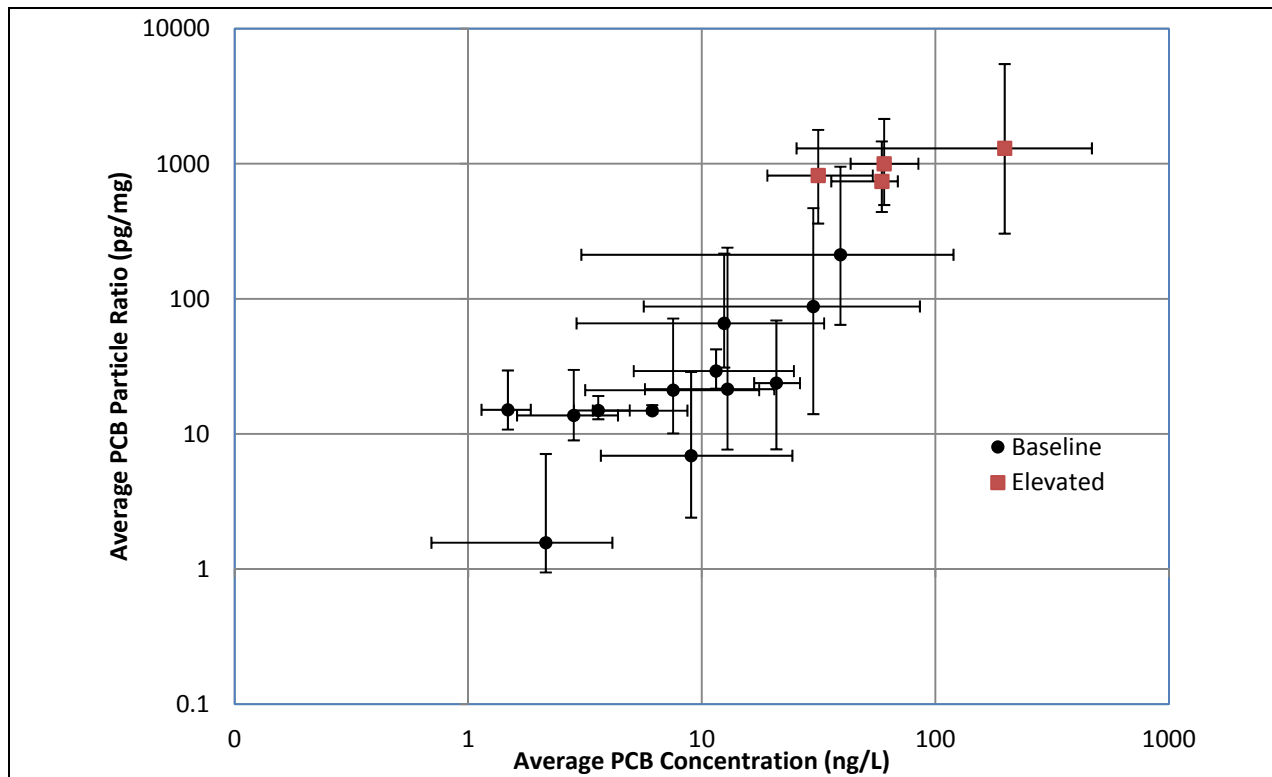


Figure 4.1. Comparisons between measured PCB mean concentrations and calculated particle ratios in various Bay Area watersheds. Data Source: McKee et al., 2012.

For each of the diversion scenario catchment sizes, the load of suspended sediment diverted was calculated from the average baseline or elevated SSC, and the corresponding volume of flow diverted under that scenario. The suspended sediment loads were then multiplied by the average POC particle ratios to estimate the total load of POCs diverted under each scenario. A description of the variables included in each of the four diversion scenarios tested, the SSC and POC concentrations, particle ratios, and calculated loads diverted are presented in Table 4.1.

To estimate the cost effectiveness of each diversion scenario, the costs estimated in Section 3.0 were combined with the diverted POC loads achieved for each diversion scenario (Table 4.2). To account for the increased costs due to the increased daily flow volumes of the diversion scenarios in the large catchment, design, construction and O&M costs were multiplied by a factor of 1.8. This is based on the calculation that diversion capacity in the large catchment would need to increase from 0.5 MGD to 1 MGD, or a factor of 2, in order to accommodate the increased daily flows in the large catchment, and that these larger flows would require more frequent maintenance of the diversion structure. Although the diversion size is doubled, there would likely be some economies of scale for both construction and O&M costs. Sanitary sewer fees were applied per MG of runoff volume diverted under each diversion scenario. Assuming a twenty year timeframe, both the total and annual costs for each diversion scenario were calculated. The cost effectiveness was calculated for storm flows only, dry weather flows only, and for the total flow, to provide additional insight into how the type of flow affects cost effectiveness. This is especially important in cases where only dry flows can be diverted due to wet weather capacity limitations at the sanitary sewer.

The most cost effective scenario was for storm flows with elevated POC concentrations in a large watershed (\$16,000 per gram of PCBs diverted), followed by storm flows with elevated POC concentrations in a small watershed (\$28,000 per gram of PCBs diverted). These results clearly demonstrate that cost effectiveness is maximized for storm flow diversions in watersheds with elevated POC concentrations. Moreover, even if POC concentrations are elevated, because dry weather flows are small, and SSC concentrations are low, the resulting costs per gram of PCBs diverted from dry weather flows are high, ranging from \$130,000 per gram of PCBs diverted to \$2.4 M per gram of PCBs diverted. Thus, diverting only dry weather flows may not be cost effective, unless there are locations identified that have greater dry weather flows, higher SSC in those flows, and substantially elevated POC concentrations. Generally, diversions in watersheds with baseline POC concentrations were not cost effective, ranging from \$170,000 to \$250,000 per gram of PCBs diverted in storm flows, and \$890,000 - \$16 M per gram of PCBs diverted in dry weather flows.

The largest factor contributing to increased costs in the scenarios presented in Table 4.2 was the sanitary sewer fees. On an annual basis, the sanitary sewer fees represented 43% to 54% of the total annual costs for the small catchment scenarios, and 74% to 81% of the total annual costs for the large catchment scenarios. Because the sanitary sewer fees used here to estimate costs were based on fees for industrial discharges, these costs could potentially be reduced if POTWs were to apply lower fees for stormwater discharges relative to industrial discharges.

Table 4.1. Urban Runoff Diversion Scenarios, Assumed SSC, PCBs and Mercury Concentrations and Particle Ratios, and Estimated Annual Suspended Sediment, PCBs, and Mercury Loads Diverted.

Diversion Scenario	Description	Flow Diverted	Annual Runoff (MG)	Annual Diverted (MG)	Average Concentration			Average Particle Ratio		Loads Diverted		
					SSC (mg/L)	PCBs (ng/L)	Mercury (ng/L)	PCB (ng/mg)	Mercury (ng/mg)	SS (Kg)	PCB (g)	Mercury (g)
1	Small Catchment; Baseline POC Concentrations	Storm Flow	4.4	2.9	510	12	100	0.02	0.20	5,600	0.13	1.1
		Dry Weather	0.13	0.10	20	2.7	6.2	0.14	0.31	7	0.001	0.002
		All Flow	4.5	3.0	-----NA-----					5,607	0.13	1.1
2	Small Catchment; Elevated POC Concentrations	Storm Flow	4.4	2.9	82	87	50	1.1	0.61	900	0.96	0.55
		Dry Weather	0.13	0.10	3.3	18	5.5	5.5	1.7	1.2	0.007	0.002
		All Flow	4.5	3.0	-----NA-----					901	0.96	0.55
3	Large Catchment; Baseline POC Concentrations	Storm Flow	28	18	510	12	100	0.02	0.20	35,700	0.84	7.0
		Dry Weather	7.0	5.1	20	2.7	6.2	0.14	0.31	400	0.05	0.12
		All Flow	35	24	-----NA-----					36,100	0.89	7.1
4	Large Catchment; Elevated POC Concentrations	Storm Flow	28	18	82	87	50	1.1	0.61	5,700	6.1	3.5
		Dry Weather	7.0	5.1	3.3	18	5.5	5.5	1.7	60	0.35	0.1
		All Flow	35	24	-----NA-----					5,760	6.5	3.6

Table 4.2. The Estimated Cost Effectiveness of Urban Runoff Diversions to the Sanitary Sewer for Four Potential Diversion Scenarios in Bay Area Catchments.

Diversion Scenario	Description	Flow Diverted	Total 20-Year Cost	Annual Cost for 20 Years	Annual Cost per Mass of POC Diverted (\$/g)	
					PCBs	Mercury
1	Small Catchment; Baseline POC Concentrations	Storm Flow	\$660,000	\$33,000	\$250,000	\$30,000
		Dry Weather Flow	\$320,000	\$16,000	\$16,000,000	\$7,000,000
		All Flow	\$670,000	\$33,000	\$250,000	\$30,000
2	Small Catchment; Elevated POC Concentrations	Storm Flow	\$540,000	\$27,000	\$28,000	\$50,000
		Dry Weather Flow	\$320,000	\$16,000	\$2,400,000	\$7,900,000
		All Flow	\$540,000	\$27,000	\$28,000	\$50,000
3	Large Catchment; Baseline POC Concentrations	Storm Flow	\$2,800,000	\$140,000	\$170,000	\$20,000
		Dry Weather Flow	\$930,000	\$46,000	\$890,000	\$390,000
		All Flow	\$3,200,000	\$160,000	\$180,000	\$22,000
4	Large Catchment; Elevated POC Concentrations	Storm Flow	\$2,000,000	\$100,000	\$16,000	\$29,000
		Dry Weather Flow	\$920,000	\$46,000	\$130,000	\$430,000
		All Flow	\$2,400,000	\$120,000	\$18,000	\$33,000

4.1. Conclusions and Recommendations

This report documented the knowledge and experience gained through the evaluation of an existing urban runoff diversion structure in the City of Palo Alto, CA. Overall, the current POC loads diverted at the site were small (< 1 gram per year), due to the small volume of flow from the catchment and low SSC in the runoff. The detailed methods, results and conclusions from water quality monitoring, combined with the information documented on the challenges, constraints, and costs of the Palo Alto diversion structure provided the data needed to evaluate the current cost effectiveness of the Palo Alto diversion structure, as well as a range of other potential diversion scenarios. Implementation of urban runoff diversions in locations with elevated POC concentrations was clearly more cost effective than diversions in locations with baseline POC concentrations. However, even for the scenarios with elevated POC concentrations, diversion of storm flow was substantially more cost effective than diversion of dry weather flows, primarily because of the relatively small dry weather flow volumes and low SSC compared with the storm flow volumes and higher SSC characteristic of storm flows. Additional data on concentrations of POCs in dry weather flow would provide higher confidence in the load estimates, and may vary depending on site-specific variables. If sites were located which had higher dry weather flows, relative to the volumes presented here, and/or higher SSC and POC concentrations in dry weather flows, the cost effectiveness of diverting these flows would likely increase. Loads were not observed to increase during first flush conditions during monitoring at the Palo Alto diversion structure.

Currently, few locations in the Bay Area have been identified which have both elevated POC concentrations and meet all of the other conditions and constraints that would be required for a stormwater diversion to be both feasible and cost effective. However, the information provided in this report will be helpful in identifying locations within the Bay Area that are potential candidates for cost-effective stormwater diversions. Because POTW capacity issues are a major constraint to implementing stormwater diversions in the Bay Area, the feasible upper size limit for diversion implementation opportunities in the Bay Area may be less than the large catchment scenarios presented here for all but a very small number of locations (if any). In addition, because the concentrations of POCs in stormwater discharges are likely well below local limits (Table 3.1), and because sewer rates to some extent reflect the expected pollutant loads, the issue of sanitary sewer connection and treatment fees for stormwater diversions should be carefully reviewed on a site-specific basis, which may result in different cost estimates for a given diversion project than those presented here. Overall, the results of the cost-effectiveness evaluation highlight the importance of working closely with a POTW to achieve the maximum amount of stormwater diversion possible at the lowest cost. The results presented here will facilitate comparison of pollutant loads removed/avoided and associated costs and constraints with other PCBs and mercury control measure strategies outlined in MRP provisions C.11 and C.12 to manage PCB and mercury loads and help guide future selection and implementation of mercury and PCB stormwater controls.

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Appendix A

Palo Alto Diversion Field Summary Report 2012-2014

Palo Alto Diversion Field Summary Report 2012-2014

Prepared by Kinnetic Laboratories Inc.

25 June 2014

1.0 Station Installation and Removal

Installation of sampling equipment was initially performed for the two sampling sites associated with this diversion project on 3 January 2013. The installation at this site was originally delayed when approval of the written traffic control plan took more time than expected. Secondly, when it was discovered that the turbidity sensor (FTS DTS-12 SDI turbidity sensor) was not communicating properly with the data logger (ISCO 2105 interface module) at another installation site (Pulgas Diversion), installation was delayed until a remedy could be found to this communications problem. Eventually an FTS Axiom Datalogger was obtained to replace the ISCO data logger.

Installation at the influent site (Site A) consisted of an ISCO area velocity sensor connected to an ISCO 2150 area velocity flow module and a FTS DTS-12 SDI turbidity sensor connected to a FTS Axiom Datalogger. A mounting ring was used to secure the velocity sensor in the pipe and the turbidity sensor was mounted in the wet well where the sensor would likely be constantly submerged by at least standing water in the manhole vault. Both data loggers and a 12-volt marine battery (to power the system) were suspended just below the manhole cover.

Installation at the diversion site (Site B) consisted of an ISCO area velocity sensor connected to an ISCO 2150 area velocity flow module. A mounting ring was used to secure the velocity sensor in the pipe and the data logger and a 12-volt marine battery were suspended just below the manhole cover.

After the 2012-2013 storm season the station was demobed and the equipment was removed from both Site A and Site B on 7 May 2013.

Installation for the 2013-2014 storm season was performed on 22 October 2013 in the same manner as before. During a maintenance visit on 19 December 2013 it was discovered that data was no longer downloadable from the FTS Axiom Datalogger though it appeared to be still logging data. A decision was made to leave the data logger in place and attempt to recover the turbidity data after the storm season was over. The logging capacity of this instrument was extensive enough that there was likely no chance any data would be overwritten prior to the season ending demobilization. At the time the logger was 26% full and had 236 days of capacity left.

After the 2013-2014 storm season the station was demobed and all equipment was removed from both Site A and Site B on 12 June 2014.

2.0 Field Sampling

All field samples were collected by use of a grab pole. Sample bottles were attached directly to the grab pole and water was then collected from the water flowing either into the vault (Site A) or at the diversion flowing out of the vault (Site B). Sandbags were often needed to back up water at Site B to provide enough depth to submerge the sample containers.

Field data sheets were filled out describing environmental conditions including descriptive details of the water collected.

Disposable powder free nitrile gloves were worn while collecting water and sediment samples to mitigate potential contamination. Gloves were changed between each sample to reduce the potential for cross-contamination.

Samples were labeled for proper identification in the field and for tracking in the laboratory. The sample labels contained the following information: station location, date of collection, analytical parameter(s), and method of preservation.

At the conclusion of sample processing; all samples were wrapped in protective bubble wrap and stored on ice in the field. At the conclusion of the day's sampling, all samples were either stored overnight in KLI's refrigeration unit or delivered directly to the analytical laboratories.

All sample shipments for analyses were be accompanied by a Kinnetic Laboratories chain-of-custody record (COC). COCs were completed and sent with samples for each laboratory and each shipment. The COC identified the contents of each shipment and maintained the custodial integrity of the samples.

2.1 Dry Weather Sampling

Dry weather sampling was performed twice in the first storm season (2012-2013) on 9 January 2013 (6 days after the initial installation was completed) and on 7 May 2013 during the demobilization of the station after the first year of sampling.

PCBs, particle size, total mercury, and SSC were collected at both Sites A & B on 9 January 2013. TOC was collected from both sites but the sample jar for Site B apparently had a crack in it and the sample drained out of the jar prior to analysis. An additional total metals sample was collected at Site A and analyzed for Al, Ag, As, Cd, Cr, Cu, Mn, Ni, Pb, Se, and Zn.

PCBs, particle size, total mercury, TOC, and SSC were collected at both sites A & B on 7 May 2013. An additional total metals sample was again collected at Site A and analyzed for Al, Ag, As, Cd, Cr, Cu, Mn, Ni, Pb, Se, and Zn.

2.2 Wet Weather Sampling

Over the course of two storm seasons (2012-2013 and 2013-2014) three storms were sampled on 5 March 2013 (storm season 2012-2013) and on 6 and 8 February 2014 (storm season 2013-2014). There was one false start where field crews were deployed to the site on 30 January 2014.

In all three cases, four sample sets were collected at both Sites A & B spread out over the storm as best as possible. Each sampling set consisted of PCBs, particle size, total mercury, TOC, and SSC. Approximately 50% of the sample sets also had total metals (Al, Ag, As, Cd, Cr, Cu, Mn, Ni, Pb, Se, and Zn) collected for analysis. Finally, field duplicate sample sets were collected and submitted blind to the analytical laboratories for the 6 and 8 February storm events.

The 5 March 2013 storm deposited approximately 0.23” of rain in the area (Allied Arts KCAMENLO7 in Menlo Park) as measured approximately 1.3 miles to the west. The first samples were collected between 22:12 (Site A) and 22:45 (Site B) with accumulative rain approximately 0.08” by midnight. Another 0.15” of rain fell ending at approximately 04:30 on 6 March 2013.

Storm 1: 5-6 March 2013 Sample Times.

Grab Sample	Site A time (date)	Site B time (date)
1	22:12 (5 March 2013)	22:45 (5 March 2013)
2	00:50 (6 March 2013)	01:10 (6 March 2013)
3	02:10 (6 March 2013)	02:20 (6 March 2013)
4	03:15 (6 March 2013)	03:45 (6 March 2013)

The 6 February 2014 storm deposited approximately 0.54” of rain in the area (Allied Arts KCAMENLO7 in Menlo Park) as measured approximately 1.3 miles to the west. Rain started at approximately 00:30 just prior to the initial grab sampling at the two sites and approximately 0.48” of rain fell by the end of sampling at 06:45. Another 0.06” of rain fell in the subsequent hour with rain ending at approximately 07:45 and a cumulative total of 0.54” of rain.

Storm 2: 6 February 2014 Sample Times.

Grab Sample	Site A time (date)	Site B time (date)
1	01:15 (6 February 2014)	00:45 (6 February 2014)
2	03:10 (6 February 2014)	02:40 (6 February 2014)
3	05:20 (6 February 2014)	05:00 (6 February 2014)
4	06:45 (6 February 2014)	06:30 (6 February 2014)

The 8 February 2014 storm deposited approximately 0.25” of rain in the area (Allied Arts KCAMENLO7 in Menlo Park) as measured approximately 1.3 miles to the west. Rain started at approximately 04:20 and deposited approximately 0.02” in the first half hour (until 04:50) and then drizzle brought the cumulative total to 0.04” by 06:00. From 06:00 to 8:45 approximately 0.16” of rain fell to bring the cumulative total to 0.20” of rain. Drizzle on and off through the remainder of the day brought the cumulative total to 0.25” of rain by midnight of February 8th.

Storm 3: 8 February 2014 Sample Times.

Grab Sample	Site A time (date)	Site B time (date)
1	08:55 (8 February 2014)	08:45 (8 February 2014)
2	09:30 (8 February 2014)	09:20 (8 February 2014)
3	10:30 (8 February 2014)	10:20 (8 February 2014)
4	12:00 (8 February 2014)	12:00 (8 February 2014)

Appendix B

Palo Alto Diversion Data Validation/Verification Report 2012-2014

Palo Alto Diversion Data Validation/Verification Report 2012-2014

Prepared by Kinnetic Laboratories, Inc.

27 June 2014

1.0 INTRODUCTION

Kinnetic Laboratories conducts its activities in accordance with formal QA/QC procedures. The objectives of the QA/QC Program were to fully document the field and laboratory data collected, to maintain data integrity from the time of field collection to storage at the end of the project, and to produce the highest quality data possible. The program was designed to allow the data to be assessed by the following parameters: Precision, Accuracy, Comparability, Representativeness, and Completeness. These parameters were controlled by adhering to documented methods and procedures outlined in the QAPP, and by the analysis of quality control (QC) samples on a routine basis. This report is a general review of both the analytical results generated by the laboratories and to verify proper procedures were followed.

Field Quality Control included the analysis of duplicate samples, adherence to SOPs and formal sample documentation and tracking. Analytical chemistry QC was formalized by EPA and State certification agencies, and involved internal QC checks such as method blanks, matrix spike/spike duplicates (MS/MSDs), laboratory control spike/laboratory control spike duplicates (LCS/LCSDs), laboratory replicates, and calibration standards. Standard Reference Materials (SRMs) or Certified Reference Materials (CRM) were also run along with calibration standards for each batch of samples.

2.0 QA/QC METHODS

The overall quality of the dataset was determined to a large degree by the thoroughness, accuracy and precision of the laboratory QC records and explains why the majority of this section is devoted to examining them in detail. The QC is discussed individually by topic.

2.1 Precision

Precision provides an assessment of mutual agreement between repeated measurements. These measures may apply to blind field duplicates (FD), laboratory duplicates (DUP), matrix spike duplicates (MSD), laboratory control spike duplicates (LCS), and laboratory control sample duplicates (LCSD). Monitoring of precision through the process allows for the evaluation of the consistency of field sampling and laboratory analysis.

The Relative Percent Difference (RPD) is used to evaluate duplicate samples. The RPD is the difference between the two samples divided by their average expressed as percent and is calculated as:

$$RPD = 100 * \left(\frac{|x_1 - x_2|}{\frac{1}{2}(x_1 + x_2)} \right)$$

where:

x_1 = Concentration of sample 1

x_2 = Concentration of sample 2

RPDs can be large when analyzing differences between small numbers, a situation that is common when analyzing DUPs with values near the reporting limit. When one or both concentrations are less than five times the reporting limit, replication is assessed by determining if the two values

differ by more than 1 times the reporting limit. When one or both values are less than the reporting limit, then precision cannot be ascertained.

2.2 Accuracy

An assessment of the accuracy of measurements is based on determining the difference between measured values and the known or “true” value and is applied to MS/MSDs, LCS/LCSDs, BS/BSDs and SRMs.

In general, Percent Recovery (%R) is calculated as:

$$\% R = 100 * \left(\frac{\text{Measured_Value}}{\text{True_Value}} \right)$$

Matrix Spike
the concentration of the source sample:

recoveries take into account

$$\% R_{MS} = 100 * \left(\frac{\text{Measured_Value} - \text{Sample_Value}}{\text{True_Value}} \right)$$

2.3

Representativeness, Comparability and Completeness

Representativeness is the degree to which data accurately and precisely represents the natural environment.

Comparability is the measure of confidence with which one dataset can be compared to other relevant studies. The use of standardized methods of chemical analysis, field sampling and processing are ways of assuring comparability. Implementation of thorough QA/QC methods such as laboratory QC is essential.

Completeness is a measure of the percentage of the data judged valid after comparison with specific validation criteria. This includes data lost through accidental breakage of sample containers or other activities that result in irreparable loss of samples. Implementation of standardized Chain-of-Custody procedures which track samples as they are transferred between custodians is one method of maintaining a high level of completeness. A high level of completeness is essential to all phases of this study due to the limited number of samples. Of course, the overall goal is to obtain completeness of 100 percent. However, a realistic data quality objective of 95% will insure an adequate level of data return.

Close adherence to ‘Standard Operating Procedures’ (SOPs) assures that the resulting data is representative, complete and comparable. Results are further assessed with a thorough validation process.

2.4 Data Qualifier Codes

Data qualifier codes are assigned by the analytical laboratories when applicable. Common codes developed by U.S. EPA are described in the table 1 below.

Table 1. Common Data Review Qualifiers

U	Not Detected The compound was analyzed for but was not detected above analytical reporting limits. The associated value is the sample reporting limit.
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UJ	Estimated Detection Limit The compound was analyzed for but was not detected above the adjusted reporting limit. The associated reporting limit is an estimate and may be inaccurate or imprecise.
J-	Estimated Value The associated value is a low estimate.
J	Estimated Value The associated value is an estimated quantity.
J+	Estimated Value The associated value is a high estimate.
R	Rejected The data are unusable. The analyte may or may not be present.

The EPA guidance documents are clear that data review and qualification rules are to be tempered using professional judgment.

3.0 QA/QC RESULTS

The project sampled dry weather and storm water flow at the two Palo Alto Diversion sampling sites generating 167 sample results, and another 113 lab QAQC records. Counts of the QC-types are summarized in Table 2. Generally the results were well within the appropriate ranges and limits and any significant exceptions and any resulting data qualifications are presented and discussed in detail in this section.

Table 2. Count of QC Types.

Analyte (Water)	Method Blank	Lab Duplicate	LCS/SRM	Matrix Spike	Totals
PCBs	4		8	35	47
Particle Size Distribution		2			2
Total Mercury	5	2	6	6	19
TOC	5	2	5	5	17
SSC	5		5		10
Total Metals	5	2	6	5	18

3.1 Verification

Data verification was the first step in the data quality assessment process. The verification process generally included checks to verify compliance with the sampling plan and with the QA/QC practices. Information contained in the laboratory reports was verified to be complete, correct and free of inconsistencies.

3.2 Validation

All laboratory and field data generated under the program were reviewed for accuracy, precision and completeness. The review included:

- Data Package Completeness
- Chain-of-Custody
- Analytical Methods
- Holding times
- Method Blanks
- Field Duplicates
- Laboratory Duplicates
- Certified or Standard Reference Materials (CRMS or SRMS)
- Laboratory Control Samples

Matrix Spike and Matrix Spike Duplicates
Reporting Limits

3.2.1 Data Package Completeness

Two different laboratories were used to complete the data analysis requirements for CW4CB. Each lab provided a pdf of the final results and an electronic data deliverable (EDD) as an excel file with analytical data results.

3.2.2 Chain-of-Custody

A chain-of-custody (COC) record was completed according to the QAPP requirements indicating date and time of sample collection and the analysis requested. COCs were handled as outlined in the QAPP and successfully transferred to the contracted laboratories, shown through relinquished and received by signatures found on each COC.

3.2.3 Analytical Methods

Recommended analytical methods for water samples are detailed in the table below along with methods used.

Table 3. Analytical Methods Recommended and Used.

Analyte	Analytical Method (Recommended)	Target Reporting Limit and Units	Analytical Method (Used)	Reporting Limit and Units
Total Organic Carbon (TOC)	SM5310B	0.6 mg/L	SM5310D	0.50 mg/L
Total Mercury	EPA 7471	0.0002 ug/L	EPA 1631E	0.0005 ug/L
Total PCBs	EPA 1668A	0.002 ug/L (per congener)	EPA 1668A	0.000005 ug/L
Suspended Sediment Concentration (SSC)	ASTM D3977-97 (Method C)	0.5 mg/L	ASTM D3977-97 (Method C)	1.0 mg/L
Particle Size Distribution	ASTM D4464(M)	TBD %	ASTM D4464(M)	0.01%
Total Recoverable Metals	EPA 6020 ICP/MS	<1.0 ug/L	EPA 1640	<1.0 ug/L

TOC was analyzed using SM5310D instead of SM5310B. SM5310B, the combustion-infrared method, is suitable for samples with TOC ≥ 1.0 mg/L. For lower concentrations, one should use either SM5310C or the wet-oxidation method SM5310D. By using SM5310D the reporting limit was lowered to 0.50 mg/L and more in line with the target reporting limit of 0.6 mg/L.

Total mercury was analyzed using EPA 1631E instead of EPA 7471. EPA 7471 is a method used for solid or semisolid waste with EPA 1631E more appropriate for aqueous samples. The target reporting limit (0.0002 ug/L) was elevated slightly (0.0005 ug/L) but measured sample values were all an order of magnitude greater than the reporting limit.

Total recoverable metals were analyzed using EPA 1640 instead of EPA 6020. EPA 1640 provides lower reporting limits for most of the eleven metals analyzed for. In many cases reporting limits were an order of magnitude lower using EPA 1640 and better met the targeted reporting limit of < 1.0 ug/L.

The recommended analytical methods were used for total PCBs, suspended sediment concentration (SSC), and particle size distribution. Targeted reporting limits were met for PCBs and particle size distribution but not for SSC. The actual reporting limit for SSC (1.0 mg/L) was twice the targeted reporting limit (0.5 mg/L) but all measured values were greater than 1.0 mg/L. The reporting limit

for PCBs were much lower than the targeted reporting limits with at least three orders of magnitude greater resolution.

3.2.4 Holding Times

All samples were submitted to the lab within the holdings time specified in the QAPP. Additionally, all samples were extracted within the specified time frames.

3.2.5 Method Blanks

Method blanks measure laboratory contamination during all stages of sample preparation and analysis. Labs conducted at least one method blank per batch. Only minor contaminant concentrations were found in the method blank samples.

Trace levels of mercury were detected in method blank samples for dry weather events 1 and 2, and storm event 1. The measured values for mercury in their associated method blanks were estimates less than their reporting limits and no qualification of sample results were necessary.

Trace levels of arsenic (dry event 1), silver (storms 1 and 3), manganese (storms 2 and 3) were detected in their associated method blanks. Additionally for storm 3, trace levels of cadmium, copper, nickel, and zinc were also detected in the associated method blank. In all these cases the measured values in the method blanks were estimates less than their reporting limits and no qualification of the sample results were necessary.

3.2.6 Field Duplicates

Field duplicates are collected to provide additional precision information on sample homogeneity, sample handling and laboratory results. Field duplicates were sampled during the 2nd and 3rd storm events (6 February and 8 February 2014 respectively).

Table 4. Field Duplicate Results from Palo Alto Diversion Study.

Analyte	Storm Event 2 2/06/2014		Storm Event 3 2/08/2014	
	RPD	Abs. Diff	RPD	Abs. Diff
Total PCBs	24	5,836.7	1	426.2
Total Mercury	10	2.3	7	0.71
Total Organic Carbon (TOC)	4	1	6	1
Suspended Sediment Concentration (SSC)	18	7	87	5.7
Particle Size Distribution				
Clay (less than 0.00391 mm)	15	0.56	60	6.07
Silt (0.00391 to 0.0625 mm)	14	6.18	29	13.67
Total Silt and Clay (0 to 0.0625 mm)	14	6.75	35	19.66
Very Fine Sand (0.0625 to 0.125 mm)	10	2.0	8	2.59
Fine Sand (0.125 to 0.25 mm)	1	0.1	176	22.24
Medium Sand (0.25 to 0.5 mm)	20	1.89	NA	NA
Coarse Sand (0.5 to 1 mm)	82	6.84	NA	NA
Very Coarse Sand (1 to 2 mm)	NA	NA	NA	NA
Gravel (greater than 2 mm)	NA	NA	NA	NA
Total Metals				
Aluminum	1	8	-	-
Arsenic	3	0.023	-	-
Cadmium	5	0.008	-	-
Chromium	5	0.12	-	-
Copper	5	2.4	-	-
Lead	16	1.7	-	-
Manganese	3	0.9	-	-
Nickel	0	0.01	-	-
Selenium	1	0.0004	-	-
Silver	NA	NA	-	-
Zinc	1	2	-	-

Strict criteria are not established for the evaluation of field duplicates. Rather samples are evaluated based upon best professional judgment. RPDs were highlighted in yellow when greater than 50% and red when greater than 100% and were given closer scrutiny.

As a general rule, Kinnetic Laboratories/2NDNATURE considers values to be of concern if they exceed 50% provided both values are greater than five times the reporting limit. In cases where one or both values are less than five times the reporting limit those values are considered to be of potential concern if the difference between the two values is greater than twice the reporting limit.

Field duplicate samples cannot be collected simultaneously and need to be collected consecutively from the storm drain vaults. The high RPD values for suspended sediment concentration (SSC) and particle size data are likely a reflection of the heterogeneous character of sediment in the storm water flow.

3.2.7 Laboratory Duplicates

Laboratory duplicates are a measure of precision. Because the field samples are split and analyzed, these duplicates measure both the laboratory analysis and the sample homogeneity. When the RPD between sample and duplicate is above the objective it is flagged for further review. Small values below the reporting limit can lead to large RPDs but the differences between the values are small (less than the RL) and not a concern. All other cases with elevated RPDs are subjected to extended review. All RPD values were within method control limits.

3.2.8 Certified or Standard Reference Materials (CRMs or SRMs)

CRMs/SRMs are analyzed to verify the laboratory's ability to analyze a matrix that is comparable to that of the field samples. All CRMs/SRMs were in range for this project.

3.2.9 Laboratory Control Samples

Laboratory Control Samples (spikes), and their duplicates (LCS/LCSD) are solutions of known compounds and selected concentrations in clean laboratory water. Precision and accuracy are evaluated in a similar fashion as MS/MSDs with the exception that there is no source sample to subtract and no matrix interference issues. All LCS/LCSD QC records were reported within range for this project.

3.2.10 Matrix Spike and Matrix Spike Duplicates

Matrix Spike and Matrix Spike Duplicate (MS/MSD) percent recoveries were evaluated to determine acceptable accuracy based on method-specific percent recoveries. Precision was evaluated by calculating the RPD of the MS/MSD recovery results. When spikes are reported below the accepted range they indicate a low bias to the results and when reported above the accepted range they indicate a high bias. QA/QC guidelines indicate that no action needs to be taken on MS/MSD data alone. The data reviewer may use the MS/MSD results in conjunction with other QC criteria when determining the need for further qualification.

The concentration of several metals in the first dry weather sample (Al, Cu, Mn, and Zn), the second dry weather sample (Cu and Mn), the first storm event (Al, As, Cu, Mn, Ni, and Zn), the second storm event (Al, Cu, Ni, Pb, Mn, and Zn), and the third storm event (Al, Cu, Mn, Ni, and Zn) were four times or more higher than the matrix spike concentration causing the MS, MSD and RPDs to fall outside of the control limits. No qualification was necessary since LCS/LCSD recoveries and associated RPDs were in control.

Several metals displayed poor spike recoveries during the second dry weather event (Ag and Al), the first storm event (Ag and Pb) and the second storm event (Se) due to matrix interference but no qualification was performed since LCS/LCSD recoveries and associated RPDs were in control.

3.2.11 Reporting Limits

Reporting limits are important for values reported as non-detect. The data archive was filtered for non-detects and those cases were checked and compared with the target minimum levels.

3.3 Completeness

One container for TOC was lost during the first dry weather (9 January 2013) sampling. Although the container looked in good condition there was apparently a crack in the container that allowed the sample contents to drain out over a short period of time. No other containers were lost or broken and all other samples were received in good condition by the laboratory. No data were rejected during the QC process and with the exception of the one lost TOC sample, 100% completeness was achieved for the rest of the project.

4.0 QA/QC CONCLUSIONS

A careful review of the results confirmed that the laboratories met most QA/QC requirements. Overall evaluation of the QA/QC data indicates that the chemical data are, for the most part, within established performance criteria and can be used for general characterization of the storm water discharged at the two Palo Alto Diversion sites.