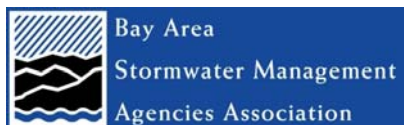


Selenium Sub-Report

Urban Runoff Characterization and Control Measures Plan

Submitted on behalf of all Permittees in Compliance with Provision C.14.a of Order R2-2009-0074

Prepared as a Regional Project for:



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ABBREVIATIONS

BASMAA	Bay Area Stormwater Management Agencies Association
BMP	Best Management Practice
CRWQCB	California Regional Water Quality Control Board
CTR	California Toxics Rule
DL	Detection Limit
MRP	Municipal Regional Stormwater NPDES Permit
MS4s	Municipal Separate Storm Sewer Systems
NPDES	National Pollutant Discharge Elimination System
OEHHA	Office of Environmental Health Hazard Assessment
POTW	Publicly Owned Treatment Works
RMP	Regional Monitoring Program
SCVURPPP	Santa Clara Valley Urban Runoff Pollutant Prevention Program
SFEI	San Francisco Estuary Institute
SFBRWQCB	San Francisco Bay Regional Water Quality Control Board
SWAMP	Surface Water Ambient Monitoring Program
SWRCB	State Water Resource Control Board
TMDL	Total Maximum Daily Load
USEPA	United States Environmental Protection Agency

1.0 INTRODUCTION

This *Selenium Control Measures Plan* was prepared for the Bay Area Stormwater Management Agencies Association (BASMAA) representing all towns, cities, counties and flood control agencies (i.e., Permittees) subject to the Municipal Regional Stormwater NPDES Permit (MRP, Order R2-2009-0074) issued by the San Francisco Regional Water Quality Control Board (Regional Board) on October 14, 2009. This report addresses the requirements of MRP Provisions C.14.a.iii-vii for characterizing selenium concentrations in urban runoff and identifying control measures and/or management practices to eliminate or reduce discharges of selenium discharged by urban runoff conveyances systems.

Requirements associated with selenium are included in the MRP because regulatory agencies have previously identified selenium as impairing beneficial uses in the San Francisco Bay, and determined that urban runoff is a likely or potential cause or contributor to the impairment (SFRWQCB 2009). In 1986, a health advisory was issued to hunters against the consumption of San Francisco Bay Area diving ducks. After a Selenium Verification Study conducted from 1985 to 1990 showed potentially toxic concentrations of selenium in diving ducks, San Francisco Bay was listed as impaired by selenium in 1998 (SFBRWQCB 2011). The 303(d) listing has since been amended to specify inclusion of specific segments as described in Section 3 of this report. The requirement to characterize selenium concentrations in urban runoff and identify control measures is included in the MRP to assist with the development of Total Maximum Daily Loads (TMDLs) for segments of North and South San Francisco Bay in which elevated selenium levels in some fish and diving birds threaten beneficial uses.

Provision C.14 of the MRP includes the same requirements for legacy pollutants, polybrominated diphenyl ethers (PBDEs), and selenium (hereinafter C.14 pollutants) in urban runoff. TMDLs and reevaluations of impairments are planned or are in the early stages of development for each of the C.14 pollutants. Provision C.14 serves as an interim step between impairment listings and TMDL development or delisting. In particular, the MRP provisions require Permittees to implement a plan that characterizes the representative distribution of C.14 pollutants in the urban areas of the San Francisco Bay Region to answer the following questions:

- Are C.14 pollutants present in urban runoff?
- Are C.14 pollutants (relatively) uniformly distributed in urban areas?
- Are storm drains or other surface drainage pathways sources of C.14 pollutants in themselves?
- Are there specific locations within the urban watershed where prior or current uses result in land sources contributing to discharge of C.14 pollutants to the Bay via urban runoff conveyance systems?

Permittees are also required to provide information to allow for the calculation of C.14 pollutant loadings to San Francisco Bay from urban runoff conveyance systems and identify control measures and/or management practices to eliminate or reduce discharges from these systems. This report addresses all questions and requirements regarding selenium that are included in the MRP. With regard to urban runoff characterization data, results of monitoring studies implemented during the MRP via the Regional Monitoring Program for the San Francisco Bay's (RMP) Small Tributaries Loading Strategy (STLS) are also described.

2.0 BACKGROUND

Selenium is a naturally occurring trace element that can be found in sedimentary rocks, soils, and mineral deposits of marine origin throughout California. Average concentrations of total recoverable selenium (total selenium) found in sediments and soils usually range from 0.01 to 0.02 mg/kg with most seleniferous soils containing less than 2 mg/kg. In natural freshwater and estuarine ecosystems total selenium concentrations are typically low, ranging from 0.1 to 1 µg/L (SFBRWQCB 2011). Selenium is elementally similar to sulfur and is strongly associated with sulfur in nature.

Selenium is also an essential micronutrient for plants and animals that plays an important role in thyroid and immune system functions as well as the prevention of oxidative stress or inflammation. However, too much selenium can be harmful. In fact, the disparity between the selenium concentrations required for a healthy diet in plants, animals, and humans and the levels at which selenium becomes toxic or poisonous, is very small compared to other micronutrients (SFBRWQCB 2011).

2.1. Selenium Speciation

Selenium species found in San Francisco Bay include the following:

- Elemental selenium (Se^0);
- Selenide (Se^{2-});
- Selenite Se^{4+} (SeO_3^{2-}); and
- Selenate Se^{6+} (SeO_4^{2-})

Elemental selenium is insoluble and occurs in particulate form. In the Bay, elemental selenium is most common in bed sediments (SFBRWQCB 2011, Tetra Tech 2008a). The oxidized and more stable form, selenate, is more likely found suspended in the water column. The relatively reduced form, selenite, is the most readily bioavailable species. It readily sorbs to particulate matter and therefore is more likely found in suspended particulates. (SFBRWQCB 2011, Abu-Saba and Ogle 2005) In the Bay, as in most aerobic surface waters, selenate and selenite are the most soluble and most mobile forms of selenium (SFBRWQCB 2011).

Biological uptake of selenium species results in biological conversion to the most reduced species, selenide, which is incorporated into organic compounds called organoselenides (Abu-Saba and Ogle2005). This process is generally carried out by algal or bacterial species (Tetra Tech 2008a).

Although particulate selenium typically only accounts for 2-18% of the total selenium in the Bay, this portion is important to Bay food webs (Abu-Saba and Ogle 2005, SFBRWQCB 2011). Particulate selenium consumed by aquatic organisms is bioaccumulated into, and transformed and transported through the food web, thus increasing the potential for toxicity to organisms. Particulate selenium suspended in the water column of the Bay is likely a result of: 1) deposition from various non-point sources discharging into the Bay, 2) generation in situ (by phytoplankton uptake of dissolved selenium), or 3) erosion from the sediment bed (SFBRWQCB 2011). Riverine and non-point sources discharging into the Bay are the primary source of particulate selenium, with smaller contributions from generation and erosion (SFBRWQCB 2011). Table 2-1 provides further description of the four common selenium species, their key characteristics, and importance to selenium cycling.

Table 2-1. Selenium Speciation Information (Abu-Saba and Ogle 2005).

Oxidation State	Selenium Species	Key Characteristics	Importance to Selenium Cycling
Se +6	Selenate (SeO ₄ +2)	Extremely soluble with a very low affinity for sorption to particulates. Thermodynamically most stable in oxic waters.	Principal form in minerals (e.g. marine shales), therefore dominant species in leached agricultural drainwaters. Very low bioaccumulation and/or biotransformation by algae. Uptake is inhibited by sulfate.
Se +4	Selenite (SeO ₃ +2)	Extremely soluble with a much greater affinity for sorption to particulates than selenate. Thermodynamically less stable in oxic waters, but still common due to very slow oxidation rate.	Principal form of concern as it accumulates in phytoplankton ~10-fold more readily than selenate; Uptake is not inhibited by sulfate.
Se 0	Elemental Selenium	Insoluble precipitate, formed primarily from dissimilatory reduction of selenite in anoxic sediments.	Removal pathway from water bodies; conversion to particulate organoselenium is important bioaccumulation pathway for benthic invertebrates.
Se -2	Inorganic selenide (Se ²⁻)	Highly reactive, forms insoluble precipitates with metals analogous to sulfide; Se ²⁻ often co-occurs with inorganic sulfide ores (e.g., cinnabar)	Formation of highly insoluble HgSe (cinnabar analogue) may explain mechanism of Hg detoxification by Se.
	Cellular (aka particulate) Organoselenium	Selenium that has been incorporated into phytoplankton/higher organisms. Selenium substitutes for sulfur in amino acids (e.g. selenomethionine)	Particulate organoselenium is major bioaccumulation pathway for benthic invertebrates (particularly for bivalves like <i>Corbula/Potamocorbula</i>)
	Dissolved Organoselenium (aka, organoselenide)	Dissolved organic compounds (e.g. selenomethionine) released from decaying cellular tissues.	Regenerative pool of selenium with uncertain bioavailability
	Dimethylselenide, Dimethydiselenide	Methylated selenium is produced by microbes, plants, and animals.	Provides gaseous escape from sediments and surface waters into the atmosphere.

2.2. Selenium Bioaccumulation

In the San Francisco Bay, Asian clams (*Corbula amurensis*, formerly *Potamocorbula amurensis*) play a notable role in the bioaccumulation of selenium. This non-native clam feeds on particles containing selenium. Studies show that this clam displays a rate constant for selenium loss that is 10 times slower compared to common crustaceans (SFBRWQCB 2011). Figure 2-1 depicts the process of bioaccumulation of selenium through the foodweb as observed in North San Francisco Bay.

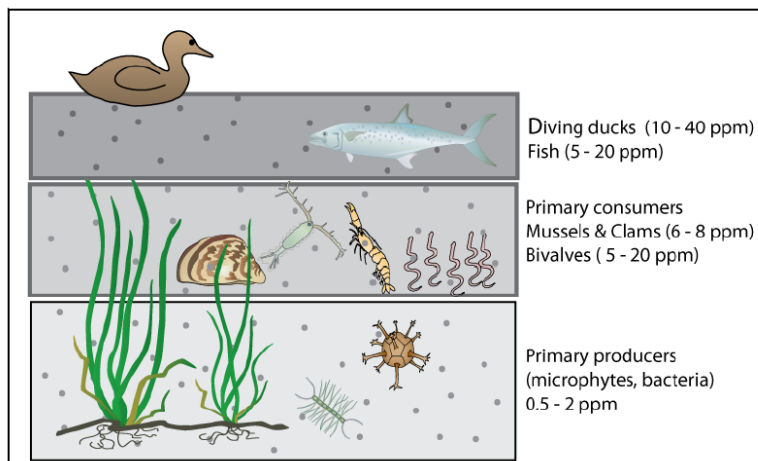


Figure 2-1. Conceptual representation of selenium biomagnification in the North San Francisco Bay. Concentrations (ppm) illustrate the range of selenium found in the North Bay species (SFBRWQCB 2011).

2.3. Selenium Thresholds

Selenium has been observed in San Francisco Bay in the tissues of diving birds and benthic-feeding fish at concentrations that are potentially toxic to aquatic life. Selenium toxicity is of greatest concern for higher trophic level species because, much like mercury, bioaccumulation magnifies the element’s toxic effects. Selenium in excess can cause reproductive impacts, such as those observed in bird embryos and hatchlings in the Central Valley’s Kesterson wildlife refuge in the early 1980s (Abu-Saba and Ogle2005). Selenium-rich agricultural drainage waters discharging into the refuge were determined to be the cause of these defects. The deformities and fish mortality at the site sparked concern over selenium pollution in California waters and the San Francisco Bay.

Potential declines in the reproduction of benthic-feeding species in the Bay are currently a concern to the Water Board (SFBRWQCB 2011). These include fish, such as white sturgeon and Sacramento splittail, and diving ducks, such as Greater Scaups and Surf Scoters. Existing ecological risk guidelines for selenium in fish and wildlife reported by Beckon et al. (2001) are presented Table 2-2. More stringent site-specific thresholds relevant to North San Francisco Bay are summarized by SFBRWQCB (2011) in the North Bay TMDL Preliminary Project Report. Site-specific thresholds are currently proposed for the North Bay by the Regional Board due to concerns of selenium toxicosis and reproductive impairment in diving ducks.

Table 2-2. Selenium Ecological Risk Guidelines for Fish and Wildlife (Beckon et al. 2001).

Matrix	Effect on	Ecological Risk Guidelines - $\mu\text{g/g-dw}$		
		No Effect	Concern	Toxicity
Warm Water Fish (Wholebody)	Fish growth/condition/survival	<4	4-9	>9
Vegetation (as diet)	Bird Reproduction	<3	3-7	>7
Invertebrates (as diet)	Bird Reproduction	<3	3-7	>7
Sediment	Fish and bird reproduction	<2	2-4	>4
Avian Eggs	Egg Hatchability	<6	6-10	>10

3.0 REGULATORY STATUS

The Federal Clean Water Act (CWA) requires that states develop water quality standards protective of human health and the aquatic environment. Section 303(d) of the CWA requires the development of a list of “impaired” water bodies that do not meet these standards. The State Water Resources Control Board (State Board) and its Regional Water Quality Control Boards are responsible for compiling and periodically updating the 303(d) list of impaired water bodies in California. The list is subject to approval by the United States Environmental Protection Agency (USEPA). The 303(d) list in California was last updated in 2010. TMDLs are a type of water quality obtainment strategy used in an effort to restore impaired water bodies.

3.1. Water Quality Objectives and Criteria

The USEPA promulgated numeric water quality criteria on behalf of the State of California in 2000 to protect and maintain freshwater and marine aquatic ecosystems (USEPA 2000). The California Toxics Rule (CTR) establishes water quality criteria for acute (1-hr) and chronic (4-day average) concentrations of potentially harmful pollutants. While the USEPA did approve criteria for total selenium through the promulgation of the CTR, the agency specified that for San Francisco Bay and Delta, more stringent criteria must apply due to the scientific evidence of selenium bioaccumulation in the Bay (SFBRWQCB 2011, USEPA 2000). Therefore, the USEPA promulgated the freshwater National Toxic Rule (NTR) criteria for selenium in San Francisco Bay and Delta. These applicable numeric criteria are listed in Table 3-1 and are also described in the Basin Plan (SFBRWQCB 2007).¹ At this time, no water quality objectives for the protection of human health have been adopted by the Regional Board, State Board, or the USEPA (USEPA 2000).

Table 3-1. Selenium Water Quality Criteria for protection of aquatic life in the San Francisco Bay. (USEPA 2000, SFBRWQCB 2007)

Water Quality Criteria	Fresh Water		Salt Water	
	1-hr	4-day	1-hr	4-day
California Toxics Rule (µg/L)	20	5	290	71
National Toxics Rule (µg/L)	20	5	20	5

3.2. Beneficial Use Impairment and Trends

In 1986, a health advisory was issued to hunters against the consumption of Bay area diving ducks (Greater Scaups and Surf Scoters) (SFBRWQCB 2011). In response to the advisory, and a subsequent second health advisory about diving duck consumption, a Selenium Verification Study was conducted from 1985 to 1990 by the Regional Board. The study showed that selenium levels in surf scoters were three times higher than thresholds determined by the US Fish and Wildlife Service (USFWS) to cause selenium toxicosis and reproductive impairment (SFBRWQCB 2011). The advisories and the observed presence of elevated selenium levels in wildlife led to the 303(d) listing of all segments of the San

¹ The USEPA is currently reevaluating the selenium criteria for the protection of semi-aquatic wildlife in the San Francisco Bay and Delta. Modeling of the fate and transport of selenium in San Francisco Bay conducted by the United State Geological Survey (USGS) serves as the basis for the reevaluation. When USEPA completes its reevaluation, it will formally request public comment on the USGS modeling report as well as draft revised selenium criteria for the San Francisco Bay and Delta (USEPA 2011).

Francisco Bay as impaired by selenium in 1998. Since that time, the 303(d) list has been amended to specify inclusion of specific Bay segments listed in Table 3-2. Figure 3-1 provides an illustration of all segments of the San Francisco Bay.

Table 3-2. San Francisco Bay segments listed as impaired by selenium on the in 2010 303(d) list (SFBRWQCB 2011).

San Francisco Bay Segment		Impairment Description	TMDL Under Development
North Bay	Sacramento-San Joaquin Delta	Hatchability in nesting diving birds; Health consumption advisory in effect for scaup and scoter (diving ducks)	Yes
	Suisun Bay		
	Carquinez Strait		
	San Pablo Bay		
	San Francisco Bay - Central		
Lower & South Bay	San Francisco Bay – Lower <ul style="list-style-type: none"> • Central Basin • Oakland Inner Harbor - Pacific Dry Dock (Part of Lower Bay) 	Health consumption advisory in effect for benthic-feeding ducks	No
	<ul style="list-style-type: none"> • San Francisco Bay - South 		



Figure 3-1. The San Francisco Bay system and specific segments.

Specific beneficial uses in North San Francisco Bay that are reported by the Water Board as threatened by selenium bioaccumulation include Estuarine Habitat (EST), Preservation of Rare and Endangered Species (RARE), and Ocean, Commercial and Sport Fishing (COMM) (SFBRWQCB 2011). Descriptions of each use are included in Table 3-3.

Table 3-3. Descriptions of North Bay beneficial uses potentially impaired by selenium (SFBRWQCB 2007; SFBRWQCB 2011).

Designated Beneficial Use	Description
Estuarine Habitat (EST)	Uses of water that support estuarine ecosystems, including, but not limited to, preservation or enhancement of estuarine habitats, vegetation, fish, shellfish, or wildlife (e.g. estuarine mammals, waterfowl, shorebirds), and the propagation, sustenance, and migration of estuarine organisms.
Preservation of Rare and Endangered Species (RARE)	Uses of waters that support habitats necessary for the survival and successful maintenance of plant or animal species established under state and/or federal law as rare, threatened, or endangered.
Ocean, Commercial and Sport Fishing (COMM)	Uses of water for commercial or recreational collection of fish, shellfish, or other organisms in oceans, bays, and estuaries, including, but not limited to, uses involving organisms intended for human consumption or bait purposes.

Although impairment listings for the northern and southern portion of the Bay are currently in place, concentrations of selenium in the water column of San Francisco Bay are well below numeric water quality criteria listed in Table 3-2 (SFEI 2011, SFBRWQCB 2011). Average concentrations of total selenium measured in water throughout the San Francisco Bay from 2002 through 2010 by the Regional Monitoring Program for the San Francisco Estuary (RMP) are shown in Figure 3-2. Bay-wide, the average concentration of selenium in water during this timeframe was 0.13 µg/L (SFEI 2011). The highest concentration was 1.15 µg/L, well below the 5 ug/L water quality criteria. As illustrated in Figure 3-1, Bay-wide average selenium concentrations post-2002 are relatively consistent.

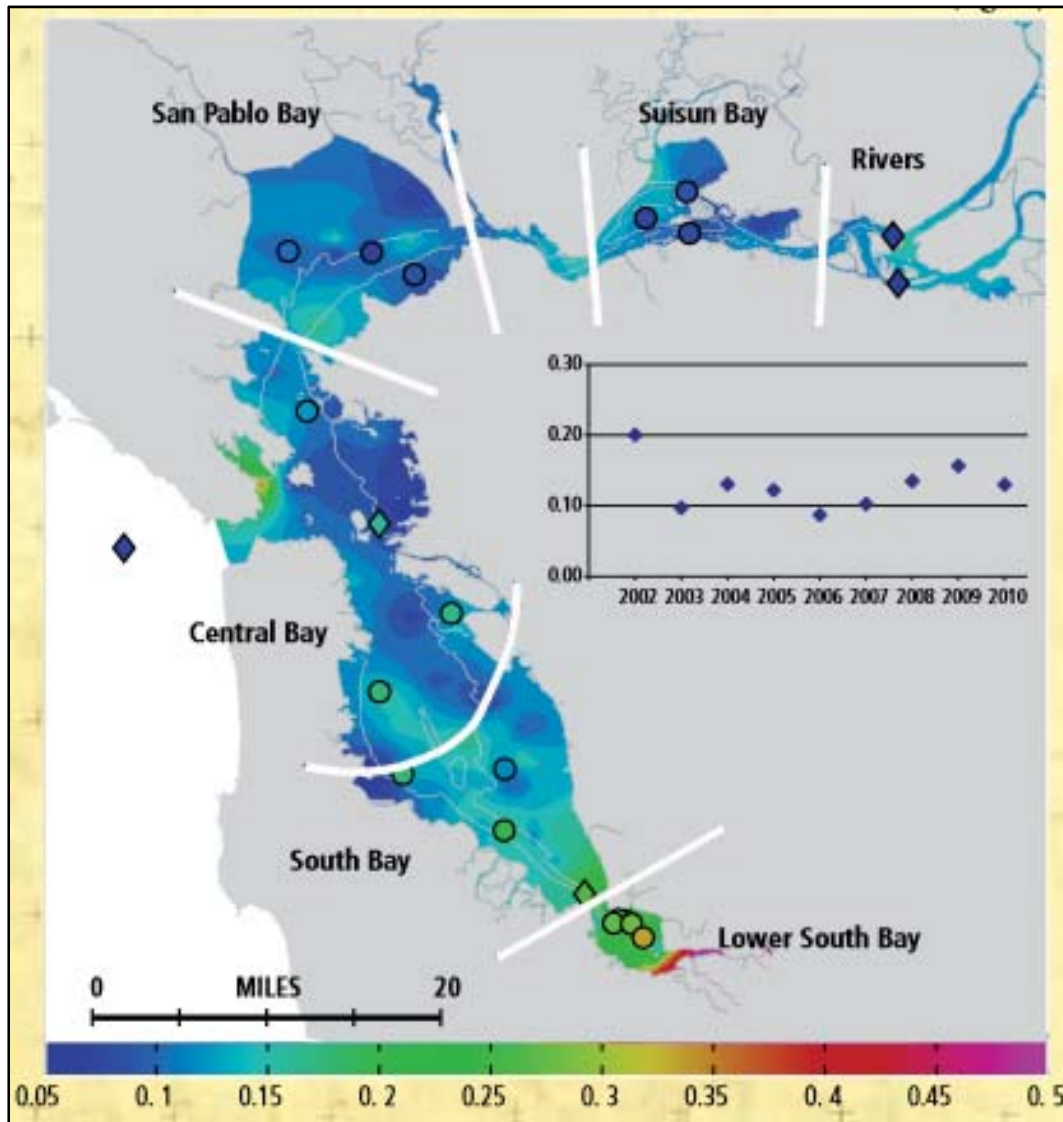


Figure 3-2. Selenium concentrations (ug/L) in the San Francisco Bay between 2002 and 2010 (SFEI 2011).

Triennially, the RMP also conducts monitoring of pollutants in sport fish tissue. The most recent monitoring was conducted in 2012, but data for this year are not yet available. As illustrated in Figure 3-2, concentrations of selenium in white sturgeon between 1997 and 2009 show no trend. Additionally, the RMP monitoring in 2009 indicates that selenium concentrations in multiple sport fish species are well below guidelines set by the Office of Environmental Health and Hazard Assessment (SFEI 2012). The OEHA guideline for white sturgeon is 2.5 ppm (mg/kg – wet weight) (OEHA 2011).

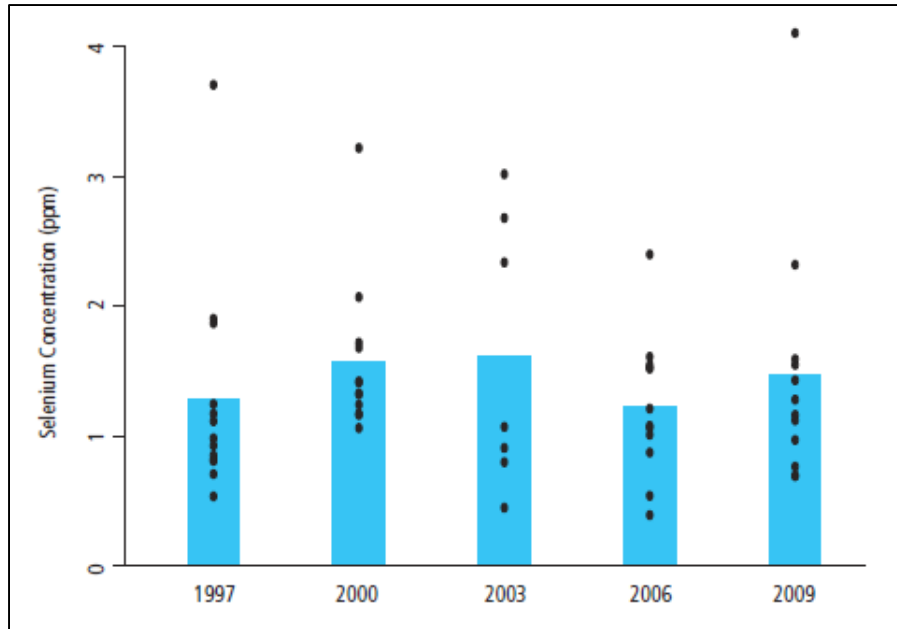


Figure 3-1. Selenium concentrations (ppm wet weight) in white sturgeon in San Francisco Bay between 1999 and 2009. Bars indicate average concentrations. Points represent individual samples (either composites or individual fish) (SFEI 2012).

3.3. Status of TMDL Development

The Regional Board is currently addressing 303(d) listing of the North and South San Francisco Bay through separate regulation strategies because of their differences in selenium sources (SFBRWQCB 2011). Primary sources for the North and South Bays are described in Section 4 of this report. The TMDL development process for all segments of North San Francisco Bay is currently underway with the goal of addressing the issue of selenium bioaccumulation in fish and birds. The North Bay Selenium TMDL Project was initiated by the Water Board in 2007 (SFBRWQCB 2011). After data collection and analysis in support of TMDL development, a Preliminary Project Report was released in 2011 summarizing findings and current knowledge regarding selenium impairment and relevant sources. As described in the report, a TMDL target based on fish tissue will likely be proposed for adoption instead of a water-based, total selenium target that is not directly representative of toxic effects to wildlife (SFBRWQCB 2011). The initial proposed fish tissue target for white sturgeon is 6.0 – 8.1 ug/g (dry weight).² The target is based on the proposed USEPA wildlife criterion for San Francisco Bay/California and represents the estimated selenium concentration in fish at which an effect is observed in 5 - 10% of the population (SFBRWQCB 2011). The North Bay TMDL is currently progressing and is scheduled for completion in 2014 or 2015.

The process for developing a selenium TMDL for Lower and South Bay segments has not formally begun. Based on the TMDL development schedules recently presented by Water Board staff, the process will begin within the next 2 to 5 years, unless other regulatory processes are implemented as alternatives to a TMDL.

² Concentrations of total selenium presented in Figure 3-1 should not be compared to the proposed fish tissue target due to the difference in units (wet v. dry weights).

4.0 USES, SOURCES, PATHWAYS AND FATES

Selenium uses, sources, transport pathways and environmental fates are described in this section. Additionally, conceptual models of these processes are presented. Sources and transport pathways differ geographically for North and South San Francisco Bay segments (SFBRWQCB 2011) and therefore these segments are discussed separately.

4.1. Selenium Uses

Selenium is a naturally occurring trace element that is widely distributed but dispersed in the environment. Selenium is used in a variety of applications, including those listed in Table 4-1. The vast majority of uses (~70% of the market share) are associated with the manufacturing of glass, metal, chemicals and pigments.

Table 4-1. Selenium uses and estimated market shares (SFBRWQCB 2011, Lent and McKee 2011, USGS 2004).

Selenium Use	Use Description	Market Share
Glass Manufacturing	<ul style="list-style-type: none"> • Combined with other chemicals to produce colored glass • Used as decolorizer in windows • Used in powdered glass applied to ceramic products 	25%
Metal Manufacturing	<ul style="list-style-type: none"> • Additives to steel, copper and lead alloys 	24%
Chemical and Pigment Manufacturing	<ul style="list-style-type: none"> • Catalyst and oxidizing agents in organic chemical production • Used as pigments in coloring of plastics 	22%
Pharmaceutical, Cosmetic and Nutrition Industries	<ul style="list-style-type: none"> • Catalyst in pharmaceutical manufacturing • Feed additive for livestock • Dietary supplement • Antidandruff shampoos 	19%
Electronics	<ul style="list-style-type: none"> • Photographic exposure meters • Xerographic copiers • Solar photocells 	10%

4.2. Conceptual Model of Selenium Sources and Pathways

Primary sources and transport pathways for selenium in the Bay are listed in Table 4-2 and depicted in the conceptual model (Figure 4-1) developed via the Selenium Conceptual Model and Impairment Assessment (CM/IA) funded through the Clean Estuary Partnership (Abu-Saba and Ogle 2005). Due to the differences in sources and transport pathways for North and South San Francisco Bay are listed separately in Table 4-2 and described separately in the following sections.

Table 4-2. Selenium sources and transport pathways to North and South San Francisco Bay (SFBRWQCB 2011).

Bay Segment	Prominent Sources	Prominent Transport Pathways
North Bay	<ul style="list-style-type: none"> • Natural sources <ul style="list-style-type: none"> ○ Groundwater ○ Soils/sediment • Extracted petroleum 	<ul style="list-style-type: none"> • Urban Runoff • Agricultural Runoff • Agricultural Drainwater • Petroleum Refinery Discharges • Municipal and Industrial Wastewater • Resuspension of sediments in Bay • Atmospheric Deposition
South/Lower South Bay	<ul style="list-style-type: none"> • Natural sources <ul style="list-style-type: none"> ○ Groundwater ○ Soils/sediment 	<ul style="list-style-type: none"> • Urban Runoff • Pumped Groundwater • Municipal and Industrial Wastewater • Resuspension of sediments in Bay • Atmospheric Deposition

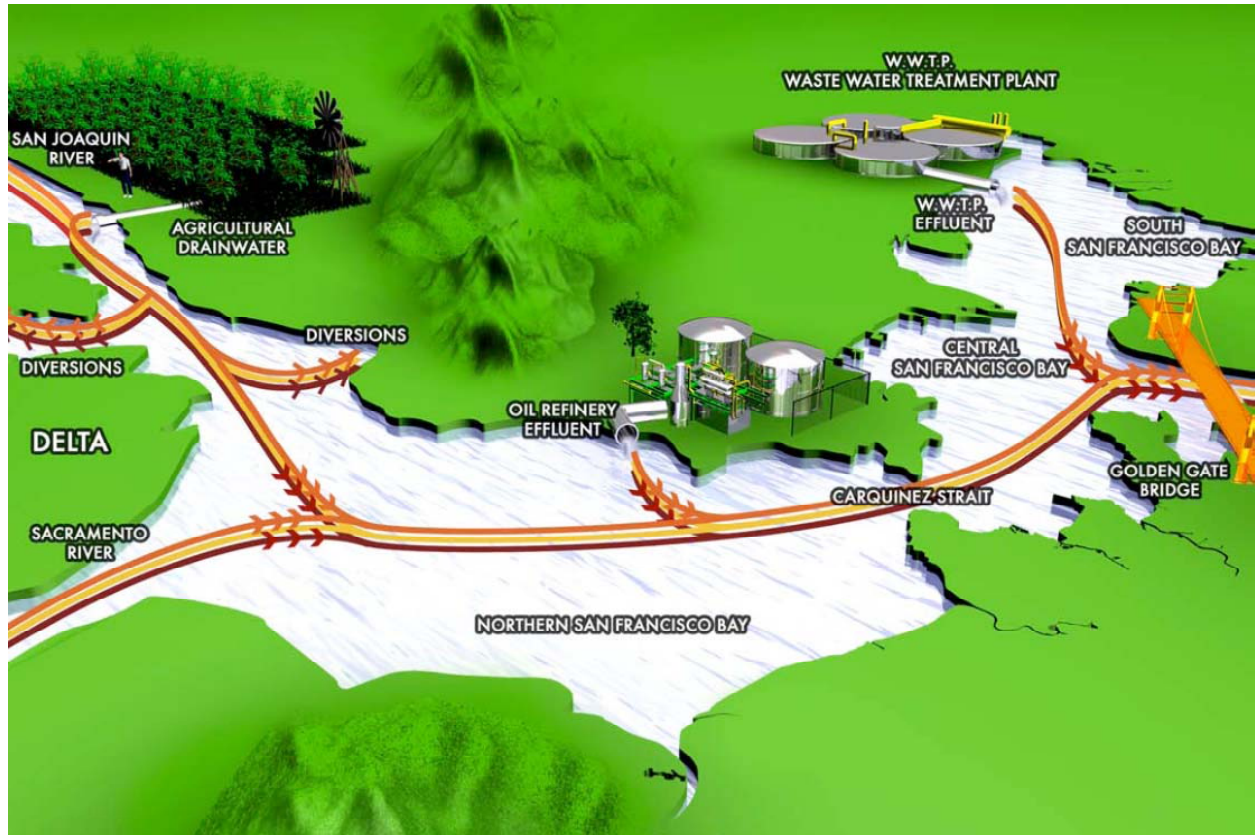


Figure 4-1. Generalized conceptual model of selenium sources and pathways in San Francisco Bay (Abu-Saba and Ogle 2005).

4.3. North Bay Sources, Transport Pathways and Loads

Information on major sources and pathways of selenium to the North Bay is included in North Bay Selenium TMDL – Preliminary Project Report (SFBRWQCB 2011). The primary source to the North Bay is naturally occurring selenium in soils, sediments and groundwater. Petroleum that is extracted and refined provides an additional source of selenium via discharges of refinery treatment plant effluent. Annual loading estimates for the primary source and pathways presented in the TMDL Project Report indicate that the Sacramento and San Joaquin Rivers provide the greatest load of both dissolved and particulate selenium to the North Bay. At roughly an order-of-magnitude less load than the two rivers, petroleum refineries, municipal and industrial wastewater discharges, and urban and non-urban run-off each provide roughly the same mass of total selenium to the North Bay. Atmospheric deposition is believed to contribute a relatively small load to the Bay. Loading estimates developed by the Water Board (SFBRWQCB 2011) for each selenium source and pathway are included in Table 4-3.

Table 4-3. Characteristics and loads of selenium sources and transport pathways to North San Francisco Bay (SFBRWQCB 2011).

Source/Transport Pathway		Description/Notes	Dominant Forms and Species	Estimated Load [kg] ^a
External	Municipal and Industrial wastewater	POTWs and industrial wastewater effluents	Predominantly dissolved Se: selenate (60%), selenite (25%), organic and elemental Se (15%)	230
	Petroleum Refineries	Refinery effluents	Predominantly dissolved Se: selenate (56-64%), organic selenide (~20%), selenite (15- 22%)	540
	Central Valley watersheds via Delta inflow	Delta inflow consists of flow from the San Joaquin and Sacramento Rivers. Much of San Joaquin River flows are currently diverted before entering the Bay.	Dissolved selenium: <u>Sacramento River</u> - selenate (50-70%), selenite (10-20%), organic selenide (15-20%) <u>San Joaquin River</u> - selenate (60-70%), selenite (3-10%), organic selenide (15-20%)	3940 (annual average) (1110 - >11000)
			Particulate selenium	770 (part. Se annual average) (170 - 1660)
	Urban and non-urban runoff	Includes both agricultural and urban runoff.	Speciation not measured but assumed to be similar to Sacramento River	350-840 (>1500)
	Atmospheric deposition	Includes both dry and wet deposition to the Bay water surface.	Wet deposition (selenite) Dry deposition	20 (120) <10 (130)
Internal	Erosion and sediment transport in the Bay	Can be either a source or sink of selenium.	Particulate selenium	280

^aUnless noted, loads are expressed as total selenium. Values in bold represent the best estimate, values in parenthesis show the range and/or the highest estimate. Estimates are rounded to the nearest 10 kg

4.4. South Bay Sources, Transport Pathways and Loads

Sources and pathways of selenium to the South Bay (including Lower South Bay) are not well documented (Abu-Saba and Ogle 2005). Sources are likely natural and similar to the North Bay, with the exception of petroleum from refineries that are strictly located in the North Bay. Loading estimates for selenium sources to the South Bay have not yet been developed.

Compared to the North Bay, the South Bay receives much less freshwater inflow and is typically characterized by more localized occurrences of high selenium levels. Because selenium concentrations are primarily locally elevated in the South Bay, the widespread effects of bioaccumulation of selenium are less pronounced than in the North Bay (SFBRWQCB 2011). Data collected by the RMP in between 1989 and 2004 indicate that in sloughs at the outlet of tributaries to the South Bay, selenium concentrations are typically higher than average South Bay or Lower South Bay concentrations (Figure 4-2). Specifically, selenium concentrations in water in Alviso Slough during low-tides are substantially higher than high-tide concentrations (Watson et al. 1998), suggesting that freshwater sources of selenium may play an important role in the slough. Furthermore, based on surface water and groundwater studies conducted in the Guadalupe River watershed (Zawislanski 2003, SCVWD 1994), elevated concentrations in the slough may be attributable to the discharge of pumped groundwater from dewatering operations in the lower Guadalupe River. The relative magnitude of selenium load to the slough from this pathway is currently unknown.

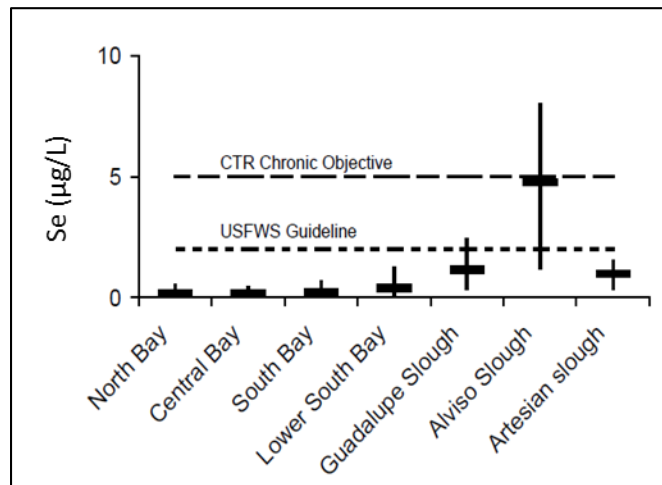


Figure 4-2. Selenium concentrations in segments and sloughs of the San Francisco Bay in 1986-2004.

4.5. Environmental Fate of Selenium

Cycling of selenium in the Bay is carried out through four main processes. Selenium can be:

- absorbed to or ingested by organisms,
- bound or complexed with particulate matter,
- free in solution, or
- released to the atmosphere through volatilization.

Selenium associated with particulate matter and embedded in sediment of the Bay will likely remain in the Bay longer than suspended or dissolved selenium in the water column. As shown in Figure 4-3, water borne selenium is cycled by water flows much more quickly than sediment-bound selenium (Abu-Saba and Ogle 2005). Therefore, even when dissolved selenium concentrations decrease, ecological effects may continue for a longer period of time due to the long residence time (T in Figure 4-4) of selenium in Bay sediments. This is especially important because low-trophic level organisms, consume particulate selenium in sediment, which facilitates the bioaccumulation, and thus the potential for toxicity associated with selenium.

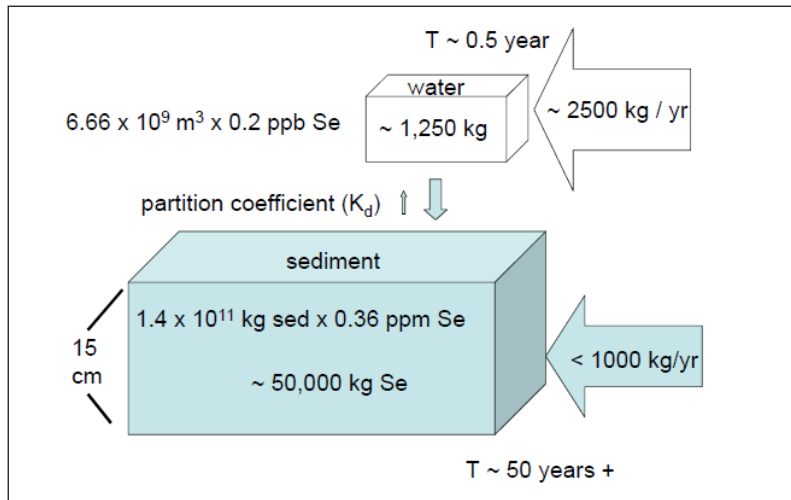


Figure 4-3. Mass balance for selenium in water and sediment of the San Francisco Bay. T = Residence time of selenium in water and sediments. (Abu-Saba and Ogle 2005).

5.0 URBAN RUNOFF AND TRIBUTARY CHARACTERIZATION

Permittees are required to provide information to allow for the calculation of selenium (dissolved and/or total) loadings to San Francisco Bay from urban runoff conveyance systems. To address this requirement, Permittees are conducting pollutants of concern (POC) monitoring and modeling of selenium from local tributaries and urban runoff. Watershed modeling and monitoring of urban runoff, pollutants and sediment discharged to San Francisco Bay are conducted through the RMP's Small Tributaries Loading Strategy (STLS). Information gained to-date through these efforts is summarized in this section, which includes data from urban runoff conveyances and within receiving water bodies (i.e., tributaries).

5.1. Selenium in Urban Runoff

Through a brief literature review, Lent and McKee (2011) summarized "central tendency" total selenium concentrations in urban runoff. Selenium concentrations are presented by land use in Table 5-1 and include values derived from studies in Southern California, Western Maryland and two cities of the San Francisco Bay Area. Based on the review, central tendency concentrations of total selenium in runoff from agricultural land uses are predicted to be an order-of-magnitude greater than runoff from other land use types (Lent and McKee 2011). Typical concentrations are intended to represent average annual concentrations that may be used as inputs to the regional watershed spreadsheet model currently under development through the STLS. Dissolved selenium concentrations or selenium species are currently unavailable for urban runoff.

Table 5-1. Total selenium concentrations in urban runoff by land use type (Lent and McKee 2011).

Land Use Category	Location	Minimum (µg/L)	Maximum (µg/L)	Central Tendency (µg/L)
Commercial	Southern CA	<MDL	13.2	0.1
Open	Southern CA	<MDL	13.9	0.1
Residential	Southern CA	<MDL	24	0.2
Industrial	Southern CA	<MDL	11.9	0.2
Agriculture	Southern CA	<MDL	5.6	1.6
Mixed urban	Hayward, CA	0.053	2.9	0.14
Open	Western Maryland	-	-	0.04
Open	Western Maryland	-	-	0.03
Industrial	Richmond, CA	0.342	7.5	-

MDL = Method Detection Limit

BASMAA also conducted studies in the late 1980's through the mid 1990's in efforts to characterize the concentrations of pollutants in urban runoff in the Bay area. Monitoring at stations representing light and heavy industrial, residential, commercial, transportation, and open space land uses were monitored for a variety of constituents, including total selenium. Although the compilation of the BASMAA data was not part of the scope for this report, the data are readily available and could be used to further assess the contributions of selenium to San Francisco Bay from urban runoff conveyance systems.

5.2. Selenium in Tributaries to the Bay

Given that selenium is present in groundwater that infiltrates to local tributaries independently from urban runoff conveyances, this section specifically discusses concentration of selenium measured in local small tributaries to the Bay.

Selenium in tributaries is mostly dissolved, but similar to urban runoff, little information is available about selenium speciation or bioavailability in Bay tributaries (Tetra Tech 2008c). Data that are available were collected through Pollutant of Concern (POC) monitoring conducted as part of the STLS by BASMAA member agencies and the RMP in fulfillment of Provision C.8.e of the MRP. The POC monitoring program was designed with the primary goal of addressing pollutants of concern in local tributaries and providing one mechanism to assess progress toward achieving waste load allocations (WLAs) for existing TMDLs (BASMAA 2013). While the primary goal of this study was to assess priority POCs, it also aimed to provide a limited characterization of additional lower priority analytes, including selenium. The results available to-date from four stations monitored as part of the STLS, and in compliance with the MRP are presented in Table 5-2. All data presented were collected during a combination of dry weather and storm flows. A report summarizing POC loads monitoring data collected in Water Year 2012 (October 2011 – September 2012) was submitted to the Water Board on March 15, 2013 as part of the *Water Year 2012 Urban Creeks Monitoring Report* (BASMAA 2013).

Table 5-2. Selenium concentrations in San Francisco Bay Area small tributaries monitored in Water Year 2012 (BASMAA 2013, McKee et al. 2013)

Site Location	Analyte	Mean (µg/L)	Min (µg/L)	Max (µg/L)
Marsh Creek	Total Se	0.72	0.65	0.78
	Dissolved Se	0.64	0.48	0.80
San Leandro Creek	Total Se	0.21	0.11	0.29
	Dissolved Se	0.13	0.07	0.20
Guadalupe River	Total Se	1.30	1.20	1.60
	Dissolved Se	1.04	0.77	1.32
Sunnyvale East Channel	Total Se	0.41	0.33	0.49
	Dissolved Se	0.32	0.31	0.33

As discussed in section 4.4, monitoring data collected in Water Year 2012 further illustrate that selenium concentrations in the Guadalupe River, while well below applicable water quality criteria, are notably higher than samples from other monitoring sites. The results are not surprising given that the region surrounding the Guadalupe River is known to have high concentrations of selenium in groundwater. The Santa Clara Valley Subbasin is shown to have concentrations typically ranging from 2.5 to 3.8 µg/L in the Principal Aquifer Zone and 0.4 to 2 µg/L in the Upper Aquifer Zone based on data from 1997 to 2000 (SCVWD 2001). Other studies have also found elevated concentrations in soils and groundwater samples from this area, ranging from less than the method detection limit to 12 µg/L (Alvarez et al. 1998, Anderson 1998).

6.0 CURRENT AND PLANNED CONTROL MEASURES

This section provides a summary of control measures implemented by Permittees to control the discharge of selenium from municipal urban runoff conveyance systems to the San Francisco Bay. Control measures are implemented in compliance with the MRP. Given that monitoring data and conceptual models indicate that urban runoff conveyances are not likely causing or contributing to exceedances of water quality standards for selenium (SFEI 2011, SFEI 2012, BASMAA 2013), new control measures for Permittees in the Bay Area are currently not planned or included in this section. However, as discussed, the continued implementation of current urban runoff control measures, and the implementation of pilot and new control measures focused on other high priority pollutants (e.g., PCBs and mercury) will likely have further reduction benefits for selenium in the future. Reduction benefits associated with some new control measures, however, may be limited for selenium due to fact that most selenium in urban runoff is dissolved and new controls are generally focusing on high priority sediment-bound POCs such as PCBs and mercury.

Applicable urban runoff control measures described in this section focus on both preventing selenium from entering the environment and intercepting selenium once available for transport to the Bay via urban runoff. Control measures fall into three general categories: 1) Pollution Prevention, 2) Interception, and 3) Treatment.

6.1. Pollution Prevention Activities

6.1.1. Industrial Facility Inspections

Provision C.4 of the MRP requires Permittees to implement an industrial and commercial site inspection and control program at all sites that could reasonably be considered to cause or contribute pollutants to urban runoff. Follow-up and enforcement actions consistent with local Enforcement Response Plans (ERPs) to prevent discharges of pollutants and impacts on beneficial uses of receiving waters are implemented as needed. Inspections are carried out to ensure that the facilities have implemented adequate and appropriate control measures. Facilities that may use equipment that contains selenium are inspected via this program and therefore may reduce the risk of selenium discharges to the urban runoff conveyance system.

6.1.2. Household Hazardous Waste Disposal

Permittees also successfully promote, coordinate and staff household hazardous waste (HHW) facilities and collection events that result in the proper disposal of items that contain selenium. Items that contain selenium that are collected at HHW facilities and events include:

- Electronics (selenium used in photocopying, photocells, light meters and solar cells, selenium rectifiers, DC power surge protectors, xeroradiography and in solid state, flat-panel x-ray cameras, blue and white LEDs);
- Print photography products (selenium used in toners, intensifiers, and extenders); and,
- Pharmaceuticals (selenium in small amounts in dietary supplements).

6.1.3. Commercial and Industrial Site Controls

Provision C.4 requires Permittees to implement an industrial and commercial site inspection and control program at all sites which could reasonably be considered to cause or contribute to pollution of urban runoff, with follow-up and enforcement consistent with local Enforcement Response Plans (ERPs), to

prevent discharges of pollutants and impacts on beneficial uses of receiving waters. These programs assist Permittees in preventing pollutants such as selenium from entering urban runoff conveyances.

6.1.4. Illicit Discharge Control Activities

Provision C.5 requires Permittees to implement an illicit discharge control program that includes an active surveillance component, a centralized complaint collection component, and a follow-up component to target illicit discharge and non-urban runoff sources. Similar to commercial and industrial site inspection programs, illicit discharge control programs also assist Permittees in preventing pollutants such as selenium from entering urban runoff conveyances.

6.1.5. Construction Site Inspection and Enforcement

Provision C.6 of the MRP requires Permittees to implement a construction site inspection and control program at all construction sites, with follow-up and enforcement. Permittees require all construction sites to have site-specific and seasonally- and phase-appropriate control measures that fall into the following six categories:

- Erosion control;
- Sediment control;
- Good site management; and
- Run-on and Run-off control;
- Non urban runoff management.
- Active treatment systems (as necessary);

Permittees also conduct inspections to determine compliance and effectiveness of the construction site measures, and require timely correction if violations are found.

6.2. Activities to Intercept Pollutants in Urban Runoff

6.2.1. Urban Runoff System Operation and Maintenance

Permittees currently remove sediment and organic materials through routine maintenance of their urban runoff conveyance systems. Control measures include inlet/catch basin cleaning, street sweeping and channel desilting. Frequencies and efficiencies of these control measure vary widely due to site-specific conditions and different levels of implementation by Permittees. Through pilot studies conducted in compliance with provisions C.11/12.c of the MRP, Permittees are currently evaluating the effectiveness of enhanced operation and maintenance activities and assessing the costs of implementing enhanced actions. The focus of these studies is PCBs and mercury, however, all pollutants, including selenium, will benefit from the information being collected. Although sources and pathways differ between selenium and other targeted pollutants, potential focused implementation of enhanced urban runoff system operation and maintenance for PCBs/mercury in the future may also assist Permittees in reducing the load of selenium to the Bay from urban runoff.

6.3. Urban Runoff Treatment and Diversions

6.3.1. New and Redevelopment Runoff Controls

Provision C.3 of the MRP requires Permittees to use their planning authority to require source control, site design, and urban runoff treatment measures in new and redevelopment projects to prevent urban runoff pollutant discharges from and prevent increases in runoff from projects that create and/or replace more than 10,000 ft³ of impervious surface area. Increases in runoff may cause excess erosion

in stream channels, releasing potentially contaminated sediments, including those with elevated concentrations of selenium.

6.3.2. Urban Runoff Treatment Retrofits

Storm drain inlet inserts, flow through separation devices (e.g., hydrodynamic separators), vegetated filtration systems (grassy swales), infiltration trenches/basins, media filtration, detention basins, wet ponds and constructed wetlands can intercept sediments and selenium in the urban runoff conveyance system and may reduce the load of selenium to the Bay. These urban runoff treatment structures may be installed by municipalities on public and capital improvement projects or as retrofits projects targeting pollutants of concern. Through pilot studies conducted in compliance with provisions C.11/12.e of the MRP, Permittees are currently evaluating the effectiveness of urban runoff treatment retrofits and assessing the costs of implementing these actions. The focus of these studies is PCBs and mercury, however, all pollutants in urban runoff, including selenium will likely benefit from the information being collected. Although sources and pathways differ between selenium and other pollutants, potential focused implementation of enhanced urban runoff system operation and maintenance for PCBs/mercury in the future may also assist Permittees in reducing the load of selenium to the Bay from urban runoff.

6.3.3. Conditionally Exempt Groundwater Discharges

Control measures for groundwater discharges to the urban runoff conveyance system are described in Provision C.15 of the MRP, and may assist in reducing impacts associated with selenium.

Uncontaminated pumped groundwater, foundation drains, crawl space pumps and footing drains from single family homes are exempted non-urban runoff discharges allowed by per MRP Provision C.15.a. For all other new discharges of uncontaminated pumped groundwater, foundation drains, crawl space pumps and footing drains that have flows less than 10,000 gallons per day, Permittees encourage discharge to landscape areas or bioretention facilities as a control measure. If the discharge is directed to the urban runoff conveyance system, proper control of the discharge is required by the MRP. New discharges of uncontaminated groundwater greater than 10,000 gallons per day are reported to the Water Board and may be subject to separate NPDES permitting requirements.

Permittees who use groundwater for drinking water must implement control measures when drinking water is discharged. Appropriate control measures may include filtration, settling, coagulant application with no residual coagulant discharge, minor odor or color removal with activated carbon, small-scale peroxide addition, or other minor treatment to remove total suspended solids and silt.

Groundwater discharged from dewatering activities at construction sites disturbing one acre or more of land are subject to the Statewide General Construction Stormwater Permit (Order No. 2009-0009-DWQ). These authorized non-stormwater discharges must have appropriate control measures in place and conduct monitoring, consistent with the General Permit.

6.4. Bay and Watershed Monitoring

6.4.1. San Francisco Bay Status and Trends Monitoring

The RMP monitors contaminants, including legacy pesticides, in Bay water, sediments, and fish/wildlife tissue on an ongoing basis through its Status and Trends Program (SFEI 2012b). The status and trends program currently includes:

- Biennial water chemistry monitoring;

Selenium Sub-Report (C.14)

- Biennial sediment chemistry monitoring, alternating between wet and dry seasons;
- Biennial bivalve bioaccumulation monitoring;
- Sediment toxicity and benthic taxonomic classification;
- Suspended sediment dynamics (USGS);
- Hydrographic studies (USGS);
- Triennial bird egg monitoring (cormorant and tern); and
- Triennial sport fish monitoring.

The RMP is currently funded through Permittee and other discharger contributions. These contributions provide the funding necessary to support water quality and beneficial uses assessments in the Bay.

6.4.2. Small Tributary POC Loads Monitoring/Modeling

Provision C.8 of the MRP prescribes water quality monitoring conducted by Permittees in tributaries to the Bay. Provision C.8.e of the MRP requires Permittees to conduct pollutants of concern (POC) monitoring to assess inputs of POCs to the San Francisco Bay from local tributaries and urban runoff, assess progress toward achieving wasteload allocations for TMDLs, and help resolve uncertainties associated with loading estimates for these pollutants. As a result, Permittees developed the Small Tributaries Loading Strategy Multi-Year Plan, which includes the following:

- Watershed modeling of runoff, pollutants, and sediment discharged to San Francisco Bay, using the Regional Watershed Spreadsheet Model, including legacy pesticides;
- Bay margins modeling;
- Source area runoff monitoring;
- Small tributaries monitoring in local watersheds.

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