Summary of Monitoring Data/Results and Interim Report on Bioavailability and Effects of Selenium

Newport Bay Watershed

INTERIM REPORT

December 11, 2006

Prepared by CH2M HILL for the
Nitrogen and Selenium Management Program (NSMP) Working Group

Acknowledgements

The thoughtful review and comments of the NSMP Working Group on the Field Sampling Plan and the Blue Ribbon Panel on the preliminary selenium results are gratefully acknowledged.

This report partially fulfills the requirements under Task 1.3 of the NSMP Year 2 Work Plan, and fits within the overall NSMP framework as shown below:

	NSMP Task – Document Key
	Task 1 Complementary Monitoring
	Task 1.1.3 Identify Data Gaps
	Task 1.2 Sources and Loads of Nitrogen and Selenium
➲	**Task 1.3 Bioavailability and Impacts of Selenium**
	Task 1.4 Impacts of Nitrogen
	Task 1.5 Lines of Evidence Approach for BMP Implementation
	Task 1.6 Selenium Speciation Method(s)
	Task 1.7 Support for BMP and Trading Tasks
	Task 2 Develop and Evaluate BMPs/Treatment Technologies
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Acronyms and Symbols

AMAV: American avocet

AMCO: American coot

BLSK: Black skimmer

BMP: Best Management Practice

BNST: Black-necked stilt

DFG: California Department of Fish and Game

Diss-Se: dissolved selenium

dw: dry weight

FOTE: Forster's tern

FSP: field sampling plan

IRWD: Irvine Ranch Water District

MeSe (IV): methylseleninic

mg/kg: milligram per kilogram

mg/L: milligram per liter

NSMP: Nitrogen and Selenium Management Program

Part-Se: particulate selenium

PBGR: Pied-billed grebe

SCCWRP: Southern California Coastal Water Research Program

Se (IV): selenite

Se (VI): selenate

SeCN: selenocyanate

SeMet: selenomethionine

SWRCB: State Water Resources Control Board

T-Se: total selenium

TSS: total suspended solids

UCI: University of California, Irvine

µg/L: micrograms per liter

EXECUTIVE SUMMARY

This report summarizes data compiled for the Nitrogen and Selenium Management Program (NSMP) from the period of 2002 through 2006 and assesses selenium bioavailability and toxicity in the watershed. The report is presented in three parts. The first part provides the results of the 2006 sampling effort conducted for the NSMP. Based on the needs of the Conceptual Model (CH2M HILL 2006a), the field sampling plan (FSP; CH2M HILL 2006b) outlined the conceptual approach and general methods for the 2006 sampling of biotic and abiotic media to support the NSMP. Sampling included collection and analysis of water, sediment, food-chain items, fish, and bird eggs from various locations in the Newport Bay watershed. The second and third parts summarize the latest selenium concentrations in water, sediment, and biota throughout the upper Newport Bay watershed and interpret those results with regard to sources and potential effects of selenium to ecological receptors (particularly birds).

The 2006 results verified the hypothesis that the upper areas of the watershed draining upper Peters Canyon Wash and upper San Diego Creek represent regional background values for selenium concentrations. The pattern for water, sediment, and biota was one of low selenium concentrations upstream of the influence from the historic Swamp of the Frogs (where groundwater discharges to the surface) followed by sharply increased concentrations in surface water and other media downstream of the general area of groundwater influence.

Key findings from the 2006 sampling to fill data gaps in the Conceptual Models included:

- Waterborne selenium concentrations followed a clear pattern of low concentrations in the uppermost reaches of the watershed, sharply increased concentrations in the mid-watershed area of groundwater influence, and decreased concentrations farther downstream through the lower creek, wetlands, and the bay.
- Selenium speciation in water highly favored selenate (Se 6^{+}) vs. other inorganic species; no organic forms were detected.
- The biota followed the same general spatial pattern as water. In addition, algae, plants, and grazers (such as snails) had the lowest tissue concentrations, while invertebrates, fish, and birds were consistently higher in bioaccumulated selenium.

The summary and analysis of water, sediment, and biota tissue selenium concentrations from recent historical samples (during 2002-2006) revealed a clear spatial pattern of ambient selenium in the environment and associated bioaccumulation. Key findings included:

- The upper watershed drainages, including upper Peters Canyon Wash and the upper portions of San Diego Creek, are strikingly lower in selenium concentrations in all media than are the areas below the Swamp of the Frogs influence.
- The mid-watershed region of sharp increases in surface water selenium concentrations is an area of notably poor aquatic ecological habitat. The creek in that area is primarily a linear flood control channel with purposefully minimized habitats resulting from an

artifact of flood control maintenance and channel design. Minimal habitat and periodic drying are severely restrictive of stable fish populations in this area. Few food-chain organisms were available for sampling and few birds nest there.

- The lower creek, wetland ponds, and the upper bay are areas of sediment accumulation, and provide invertebrate, fish, and bird nesting habitats in areas with intermediate waterborne concentrations of selenium.
- The reduced bioaccumulation in invertebrates and fish in the bay as compared to the lower watershed (e.g., **Figure 5**) is likely related to the significant physical loss processes, coupled with dilution and dispersion in the deeper, tidal environment of the bay. The highest concentrations in bay fish were found in the uppermost part of the bay (i.e., in areas of direct creek influence).

The conceptual models developed for the watershed and bay provided a useful tool for grouping information on the concentrations of selenium in the watershed and to the bay and to follow the fate and transport and eventual losses and bioaccumulation of selenium. In particular, the summary of data was used in the third section of the report to relate observed concentrations in bird eggs with potential effect levels and the likelihood of observing toxicological impacts to nesting shorebirds (as percentages of inviable eggs). Key findings were that:

- The information on bioaccumulation of selenium and the potential toxicity from water and diet concentrations indicates the potential for low-level reproductive toxicity to birds, mostly limited to the middle and lower portions of the creek and wetland ponds.
- Potential inviability of shorebird eggs in the watershed ranged from 2.4 to 10.1 percent above background. This is a small and essentially unmeasureable difference from background (see **Figure 13**) because of the large numbers of samples that would be required to detect the difference and low probability of being able to obtain that many samples.

Areas for which the most information is available about selenium fate, transport, and toxicity in the watershed and bay include watershed groundwater and surface water concentrations and surface water loading, as well as selenium concentrations in invertebrate and fish tissues. In contrast, the Newport Bay food web and sediment dynamics are less well known with respect to selenium.

Although elevated selenium concentrations are found in the Newport Bay watershed, lower-than-expected concentrations were observed in bird eggs. Factors that may be responsible for lower egg concentrations include restricted diet and foraging areas, possible lack of a high-selenium prey species, number and patchiness of areas of high selenium, and limited tendency of the watershed to convert inorganic selenium to selenomethionine or other more bioaccumulative organic forms.

Water speciation analyses indicate the presence of only very low concentrations of organic selenium compounds in samples, including those with high concentrations of total selenium. Tissue data also suggest that selenium concentrations in bird eggs appear lower than might be expected based on the concentrations of total selenium in the water, particularly in certain watershed locations.

The Newport Bay watershed may differ from others in which selenium toxicity problems have occurred in terms of the relative absence of species intermediate in the food web that can convert selenate/selenite to selenomethionine (a bioaccumulative organic form, undetected in the watershed samples) and/or accumulate significant amounts of selenomethionine. This structure of the food web may explain the relatively lower concentrations of selenium in bird eggs than might otherwise be expected given the elevated inorganic selenium found throughout most of the watershed.

1. INTRODUCTION

This report summarizes data collected for the Nitrogen and Selenium Management Program (NSMP) in 2006 as well as data collected from the watershed by others during 2002-2005, and it assesses selenium bioavailability and toxicity in the watershed with an emphasis on potential avian reproductive effects.

The first part of this report addresses the results of the 2006 sampling effort. Based on the needs of the Conceptual Model (CH2M HILL 2006a), the field sampling plan (FSP; CH2M HILL 2006b) outlined the conceptual approach and general methods for the 2006 sampling of biotic and abiotic media to support the NSMP. Sampling was conducted under the FSP to fulfill the following three objectives:

- Address data gaps identified in the *Sources and Loads and Interim Identification of Data Gaps for Selenium* report (CH2M HILL 2006c);
- Provide more current data as inputs for a proposed model to describe selenium cycling in the Newport Bay watershed that can be used to evaluate the effects of different Best Management Practices (BMPs) and treatment alternatives relative to selenium; and
- Provide data to evaluate wildlife risk from selenium.

Monitoring included sampling of water, sediment, food-chain items, fish, and bird eggs from various locations in the Newport Bay watershed. Sampling within the watershed was completed by CH2M HILL staff in cooperation with personnel from the California Department of Fish and Game (DFG), other investigators, and the stakeholders in the watershed. This was a one-time sampling event to fill data gaps for spring 2006. Any future sampling events will be described in a future field sampling plan and may include additional monitoring of surface water (e.g., quarterly monitoring to understand selenium loading and speciation over time), groundwater monitoring to supplement the sampling efforts of other investigators (e.g., B.J. Hibbs), or additional collections of biological data. The 2006 sampling results will be summarized as selenium concentrations by media and compared to previous results and screening levels.

The second and third parts of this report provide an updated summary of selenium concentrations in water (year-round), sediment (spring/summer), and biota (spring/summer) throughout the San Diego Creek watershed and Newport Bay and interpret those results with regard to sources and potential effects of selenium to ecological receptors. The updated data summary includes the results of sampling conducted in 2006 to fill data gaps as well as previously collected data from various studies and monitoring efforts. The purpose of this report section is to summarize selenium concentrations grouped by location within the Upper Newport Bay watershed for specific media (e.g., water, sediment, various biotic taxa). The results will be evaluated to derive preliminary conclusions and populate the Conceptual Models for the watershed and bay as previously established by the NSMP (CH2M HILL 2006a). The sampling to date has emphasized spring/summer sample collection to capture low-flow periods of higher selenium concentrations in water coupled with exposure levels for reproducing fish and birds.

2. 2006 FIELD SAMPLING EFFORT

2.1. SAMPLE SITE SELECTION

Sites for sampling sediment, water, and various biota within the Newport Bay watershed were chosen to characterize the creek, marsh, and bay habitats. The previous experience of CH2M HILL personnel with Newport Bay watershed sediment and biota sampling and the NSMP database were used to develop a stratified sampling design that was expected to be an efficient approach for filling the identified data gaps.

Samples were collected, as available, from nine creek and channel sites, the two marshes, and two bay sites as shown on **Figure 1**. The general sampling locations were identified from aerial photographs and were described in the FSP. The actual sampling locations were near the proposed locations, but were identified during a field reconnaissance based on observed habitat availability. This field reconnaissance was especially important for Peters Canyon Wash and San Diego Creek – Reach 2 because they have few areas of potential habitat for aquatic organisms or birds.

Sampling within the watershed was also planned by the DFG, and their probable sampling locations are shown on **Figure 1**. Other investigators (e.g., B.J. Hibbs and Southern California Coastal Water Research Program [SCCWRP]) are also collecting various types of data within the watershed. Results from DFG, Dr. Hibbs, and SCCWRP are not yet available. CH2M HILL will work with those investigators to acquire the results of their sampling efforts.

2.2. SAMPLE SITES AND LOCATIONS

The data needs identified for each subwatershed within the Newport Bay watershed (CH2M HILL, 2006b) are listed in **Table 1**. The table also lists the sample types (e.g., surface water, sediment, and fish) planned for collection by the DFG and by the NSMP for each subwatershed as well as the samples actually collected for the NSMP. At each of seven sampling locations, DFG planned to collect sediment, surface water, and fish, and to deploy mussels for a bioaccumulation study. Based on this information, additional sampling needed to fill the data gaps was identified for NSMP sampling. This additional sampling was expected to include surface water, sediment, benthic invertebrates, water column invertebrates, fish, and bird eggs, as appropriate (and available) for a particular sampling location. The sampling locations and types of samples collected for the NSMP within each subwatershed are discussed below.

2.2.1. *Peters Canyon Wash Subwatershed*

Two sampling locations along Peters Canyon Wash were proposed (**Figure 1, Table 1**). The first is within the historic Swamp of Frogs area (PCW) and the second is upstream of the Swamp of Frogs (UPCW). The DFG proposed to collect water (for total Se), sediment, and fish, and to deploy mussels for bioaccumulation from the Peters Canyon Wash location within the historic Swamp of Frogs area (DFG1; **Figure 1** and **Table 1**). Therefore, CH2M HILL did not collect those media at that site, but collected surface water for

Figure 1. 2006 Proposed and Actual Sampling Locations

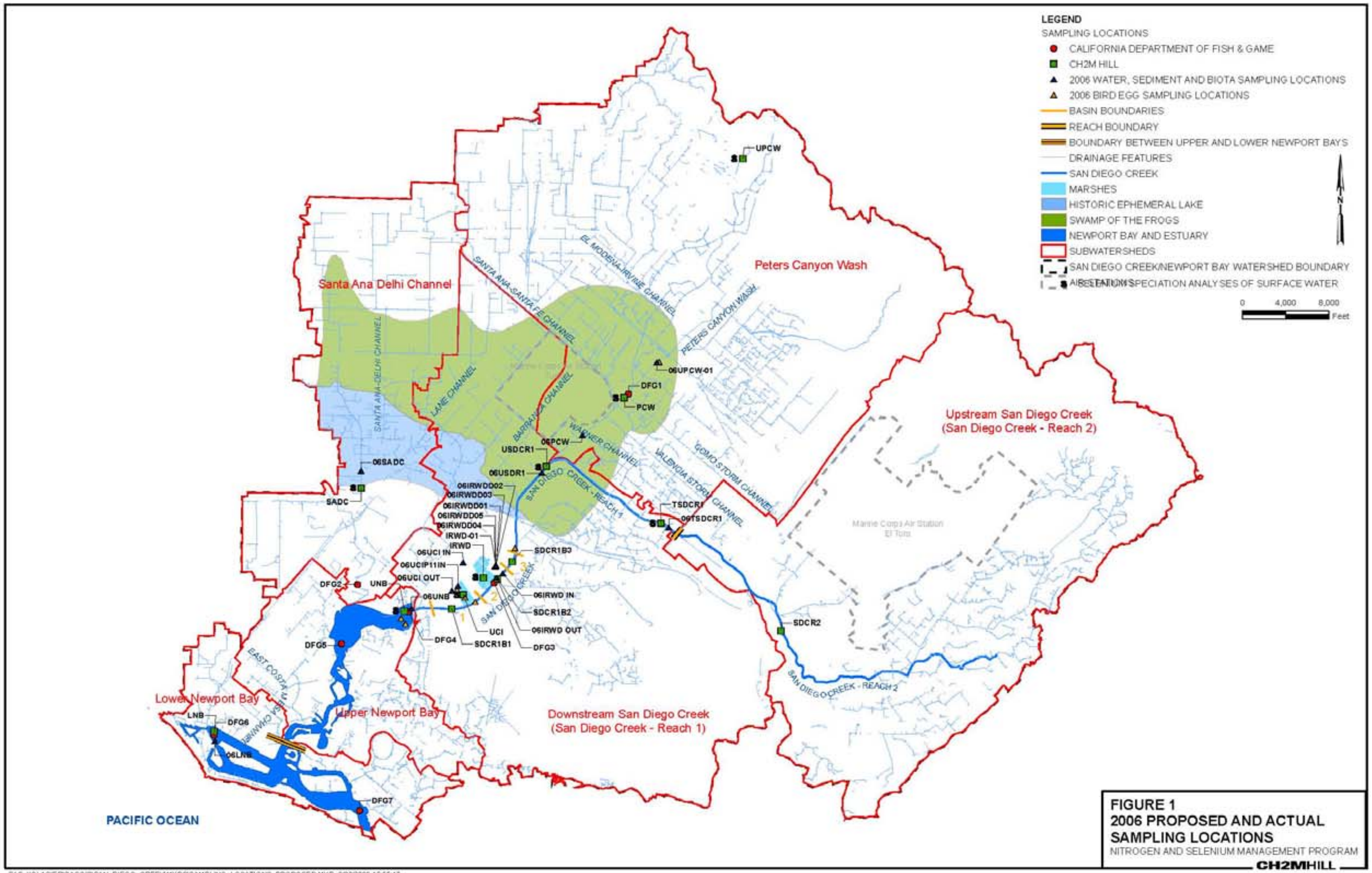


Table 1. Data Needs, Department of Fish and Game (DFG) Proposed Sampling, Proposed Additional Sampling Needs, and Samples Collected for the NSMP in 2006

Subwatershed	Data Needs	Proposed DFG Sampling	Proposed NSMP Sampling	NSMP Samples Collected
Peters Canyon Wash (2 areas)	Flow data Sediment Surface water (speciation) Biota – food chain (benthic invertebrates and water column invertebrates) Fish Bird eggs (if available) Algae	**DFG1**: sampling near the confluence of Como Channel and Peters Canyon Wash -surface water -sediment -fish -mussel deployment	**PCW**: same location as DFG1 -surface water for speciation -benthic invertebrates -water column invertebrates -bird eggs (if available) -algae	**PCW**: -surface water for speciation -algae
		None	**UPCW**: upstream of Como Channel (outside of the Swamp of Frogs) and in riparian area -surface water for speciation -sediment -benthic invertebrates (snails) -water column invertebrates -fish -bird eggs (if available) -algae	**UPCW**: -surface water for speciation -sediment -benthic invertebrates (snails) -bird eggs (one black-necked stilt nest found) -algae

Table 1. Data Needs, Department of Fish and Game (DFG) Proposed Sampling, Proposed Additional Sampling Needs, and Samples Collected for the NSMP in 2006

Subwatershed	Data Needs	Proposed DFG Sampling	Proposed NSMP Sampling	NSMP Samples Collected
Upstream San Diego Creek	Flow data Sediment Surface water Biota – food chain (benthic invertebrates and water column invertebrates) Fish Algae	None	**SDCR2**: sampling in Reach 2 (outside influence of Swamp of Frogs) -surface water without speciation -sediment -benthic invertebrates (snails) -water column invertebrates -fish -algae	**SDCR2**: -surface water -sediment -benthic invertebrates (snails) -tadpoles -algae (nearby)

Table 1. Data Needs, Department of Fish and Game (DFG) Proposed Sampling, Proposed Additional Sampling Needs, and Samples Collected for the NSMP in 2006

Subwatershed	Data Needs	Proposed DFG Sampling	Proposed NSMP Sampling	NSMP Samples Collected
Santa Ana-Delhi Channel	Flow data Surface water (speciation) Sediment and biota -likely not needed in this subwatershed Algae	**DFG2**: sampling upstream of the mouth of Santa Ana-Delhi Channel (outside tidal influence) near Upper Newport Bay -surface water -sediment -fish -mussel deployment	**SADC**: downstream of Swamp of Frogs/historic ephemeral lake -surface water for speciation -algae	**SADC**: -surface water for speciation -algae
Downstream San Diego Creek (5 areas)	Flow data Surface water (speciation) Sediment Biota – expand characterization in IRWD and UCI marshes (invertebrates, fish bird eggs), collect additional food chain biota and fish in sedimentation Basin 2 of San Diego Creek, and food chain biota in Basins 1 and 3 Algae	None	**TSDCR1**: sampling upstream of Swamp of Frogs within Reach 1 -surface water for speciation -sediment -benthic invertebrates -water column invertebrates -fish -bird eggs (if available) -algae	**TSDCR1**: -surface water for speciation -sediment -fish

Table 1. Data Needs, Department of Fish and Game (DFG) Proposed Sampling, Proposed Additional Sampling Needs, and Samples Collected for the NSMP in 2006

Subwatershed	Data Needs	Proposed DFG Sampling	Proposed NSMP Sampling	NSMP Samples Collected
Downstream San Diego Creek (cont)		None	**USDCR1**: sampling near confluence with Peters Canyon Wash -surface water for speciation -sediment -benthic invertebrates -water column invertebrates -fish -bird eggs -algae	**USDCR1**: -surface water for speciation -sediment -benthic invertebrates (clams) -algae
		DFG3: sampling in Basin 2 at locations sampled by Earl Byron in 2005 -surface water -sediment -fish -mussel deployment	**SDCR1B2**: sampling in Basin 2 at same location as DFG3 -benthic invertebrates -water column invertebrates -bird eggs -algae	**SDCR1B2**: -water column invertebrates (water boatmen)

Table 1. Data Needs, Department of Fish and Game (DFG) Proposed Sampling, Proposed Additional Sampling Needs, and Samples Collected for the NSMP in 2006

Subwatershed	Data Needs	Proposed DFG Sampling	Proposed NSMP Sampling	NSMP Samples Collected
Downstream San Diego Creek (cont)		None	**SDCR1B1**: sampling in Basin 1 -benthic invertebrates -water column invertebrates -algae	**SDCR1B1**: sampling in Basin 1 -benthic invertebrates -water column invertebrates (water boatmen) -bird eggs (1)
		None	**SDCR1B3**: sampling in Basin 1 -benthic invertebrates -water column invertebrates -algae	**SDCR1B3**: -water column invertebrates (water boatmen) -bird eggs (1)

Table 1. Data Needs, Department of Fish and Game (DFG) Proposed Sampling, Proposed Additional Sampling Needs, and Samples Collected for the NSMP in 2006

Subwatershed	Data Needs	Proposed DFG Sampling	Proposed NSMP Sampling	NSMP Samples Collected
Downstream San Diego Creek (Wetlands) (2 areas)		None	**IRWD**: IRWD Marsh -surface water for speciation (at inlet and outlet) -sediment -benthic invertebrates -water column invertebrates -fish -bird eggs -algae	**IRWD**: IRWD Marsh -surface water for speciation (at inlet and outlet) -sediment -benthic invertebrates -water column invertebrates -fish -bird eggs (5)
		None	**UCI**: UCI Marsh -surface water for speciation (at inlet and outlet) -sediment -benthic invertebrates -water column invertebrates -fish -bird eggs -algae	**UCI**: UCI Marsh -surface water for speciation (at inlet and outlet) -sediment -benthic invertebrates -water column invertebrates -fish -bird eggs (12)

Table 1. Data Needs, Department of Fish and Game (DFG) Proposed Sampling, Proposed Additional Sampling Needs, and Samples Collected for the NSMP in 2006

Subwatershed	Data Needs	Proposed DFG Sampling	Proposed NSMP Sampling	NSMP Samples Collected
Upper Newport Bay* (2 areas)	Surface water Sediment Biota – food chain (benthic invertebrates), fish, and bird eggs Algae	**DFG4**: near mouth of San Diego Creek -water (surface and at depth) -sediment -fish -mussel deployment	**UNB**: same location as DFG4 -surface water for speciation -benthic invertebrates -bird eggs -algae	**UNB**: -surface water for speciation -benthic invertebrates (mussels) -bird eggs (23)
		DFG5: near the dunes -water (surface and at depth) -sediment -fish -mussel deployment	None	None
Lower Newport Bay* (2 areas)	Surface water Sediment Biota – food chain (benthic invertebrates) and fish	**DFG6**: turning basin -water (surface and at depth) -sediment -fish -mussel deployment	**LNB**: same location as DFG6 -benthic invertebrates -algae	**LNB**: -benthic invertebrates (mussels)
		DFG7: police dock area -water (surface and at depth) -sediment -fish -mussel deployment	None	None

* Dredging of Newport Bay began in 2006; therefore, may need to collect surface water, sediment, and biota data after dredging to get a baseline condition.

speciation analysis and also sampled algae to complement the DFG collection. At the upstream site (UPCW), CH2M HILL collected surface water for speciation analysis, sediment, algae, and benthic invertebrates (snails). A single black-necked stilt nest was found at the UPCW site, and an egg was collected from the nest.

2.2.2. Upstream San Diego Creek Subwatershed (San Diego Creek – Reach 2)

Previous surface water sampling along San Diego Creek – Reach 2 indicated that selenium concentrations are low in this reach of the creek. Additionally, selenium concentrations in groundwater from the Marine Corps Air Station at Tustin were uniformly low. Therefore, this subwatershed is not likely to be a significant contributor of selenium to the system, and bioaccumulation of selenium into biota within Reach 2 of San Diego Creek was expected to be low. To verify this, algae, benthic invertebrates (snails), and tadpoles were collected at one location within Reach 2 (SDCR2; **Figure 1** and **Table 1**). Co-located surface water and sediment also were collected. Speciation analysis for the surface water was not conducted. No sampling of this reach was proposed by the DFG.

2.2.3. Santa Ana-Delhi Channel Subwatershed

Within the Santa Ana-Delhi Channel, DFG planned a collection effort just upstream of the tidal influence from Upper Newport Bay (DFG2; **Figure 1** and **Table 1**). CH2M HILL did not propose to collect any additional media from this location (SADC) other than surface water for selenium speciation analyses (collected upstream of the DFG collection point and just downstream of the historic ephemeral lake). A water sample and algae were collected.

2.2.4. Downstream San Diego Creek Subwatershed (San Diego Creek – Reach 1)

Some of the best quality habitat within the Newport Bay watershed is found in Reach 1 of San Diego Creek, particularly within and near marshes in the lower stretch of the reach. Five sampling locations within the creek, as well as sampling within the Irvine Ranch Water District (IRWD) and University of California, Irvine (UCI) marshes (sometimes referred to collectively as "San Joaquin Marsh"), were accomplished (**Figure 1** and **Table 1**). In the upper portions of Reach 1, two locations were sampled; one was just downstream of the confluence with Peters Canyon Wash (USDCR1), and one was upstream of the confluence and outside the historic Swamp of Frogs area (TSDCR1). Media collection at these sampling locations included surface water for selenium speciation analyses and sediment from each, and included fish from TSDCR1 and algae and benthic invertebrates (clams) from USDCR1.

There are three in-channel sedimentation basins (Basins 1, 2, and 3) in the middle and lower portions of San Diego Creek – Reach 1. The DFG proposed to sample surface water, sediment, and fish and to deploy mussels within Basin 2 (DFG3; **Figure 1** and **Table 1**). Therefore, CH2M HILL did not collect those media at that site but collected water column invertebrates there (SDCR1B2). Because no sampling had been conducted in sedimentation Basins 1 and 3 (and the DFG did not propose there), CH2M HILL collected benthic invertebrates, water column invertebrates, and bird eggs from these areas when they were available (SDCR1B1 and SDCR1B3).

The IRWD and UCI marshes are adjacent to Reach 1 and have inlets and outlets within sedimentation Basins 2 and 1, respectively (**Figure 1**). Surface water samples were collected at the inlet and outlet of each marsh and analyzed for total and dissolved selenium, as well as for selenium speciation. Additionally, sediment, benthic invertebrates, water column invertebrates, fish, and bird eggs were collected from within each of the marshes (**Table 1**).

2.2.5. Upper Newport Bay

The DFG proposed sampling at two locations within Upper Newport Bay, one near the mouth of San Diego Creek (DFG4) and one near the dunes area (DFG5; **Figure 1** and **Table 1**). DFG planed to collect water (at surface and depth), sediment, and fish at both of these locations. CH2M HILL supplemented collection at DFG4 with collection of surface water for speciation analyses, as well as collection of benthic invertebrates (mussels) and bird eggs (at UNB).

2.2.6. Lower Newport Bay

The DFG proposed to sample at two locations within Lower Newport Bay, one within the turning basin (DFG6) and one near the police dock area (DFG7; **Figure 1** and **Table 1**). DFG planned to collect water (at surface and depth), sediment, and fish and to deploy mussels at each of these locations. CH2M HILL supplemented collection at DFG6 with sampling of benthic invertebrates (mussels) (at LNB).

2.3. SUMMARY OF SAMPLING AND RESULTS

CH2M HILL collected water, sediment, and biota samples for the NSMP from nine creek sites, the IRWD and UCI marshes, and two bay sites (as described above and in **Table 1**).

Table 2 indicates the site location of each water sample collected for speciation and provides the results of the analyses. Total suspended solids (TSS) were determined in all speciation samples to establish the relationship between TSS and total selenium. In addition, the particulate fraction (as captured on laboratory filters) was stored frozen for possible future analysis. In **Table 2**, "particulate selenium" is presented as the difference between "total selenium" and "dissolved selenium", and as the estimated percentage of total selenium that was present in particulate form. That percentage varied widely, from 0 to 30 percent.

The selenium speciation results showed uniformly low levels of dissolved organic species (below detection limits) (**Table 2**). However, bioaccumulation is occurring within the watershed, as evidenced from the invertebrate, fish, and bird egg data (**Figure 2**). It is most likely that the primary uptake and sequestration of selenium is occurring into periphyton algae, free-floating planktonic algae, and higher plants. The data on algae and rooted plant bioaccumulation document this level of primary uptake into biota, from whatever dissolved sources (presumably including dissolved organic forms, found only in low concentrations).

Table 2. Selenium Speciation Results, Upper Newport Bay Watershed in May/June, 2006

Site	Waterbody	Sampled	Se (IV) µg/L	Se (VI) µg/L	SeCN µg/L	MeSe (IV) µg/L	SeMet µg/L	T-Se µg/L	Diss-Se µg/L	Part-Se (est.) µg/L	Part-Se %	TSS mg/L
UPCW	Upper PCW	5/10/2006	<0.014	2.68	<0.077	<0.077	<0.077	3.40	3.23	0.17	5.0%	4.4
PCW*	Peters Canyon Wash	5/10/2006	0.772	22.3	<0.077	<0.077	<0.077	23.8	23.5	0.3	1.3%	6
SDCR2	Upper San Diego Creek	5/10/2006	NA	NA	NA	NA	NA	0.79	NA	NA	NA	NA
TSDCR1	Upper San Diego Creek	5/10/2006	0.164	2.79	<0.077	<0.077	<0.077	3.72	3.32	0.4	10.8%	<3.3
USDCR1*	Upper San Diego Creek	5/10/2006	0.89	24.9	<0.077	<0.077	<0.077	27.1	29.1	0	0.0%	9.7
IRWD-IN	Inflow from SD Creek	5/10/2006	1.21	18.8	<0.077	<0.077	<0.077	20.7	20.9	0	0.0%	55.6
IRWD-OUT	Outflow to SD Creek	5/10/2006	2.97	8.04	<0.077	<0.077	<0.077	13.1	12.4	0.7	5.3%	39.2
SADC	Santa Ana-Delhi Channel	5/11/2006	0.487	14.9	<0.077	<0.077	<0.077	15.9	15.6	0.3	1.9%	<3.3
UCI-IN	Isolated pond	5/11/2006	0.127	<0.063	<0.077	<0.077	<0.077	2.95	2.13	0.82	27.8%	19
UCI-OUT	Pond, near terminus	5/11/2006	0.095	<0.063	<0.077	<0.077	<0.077	2.18	1.53	0.65	29.8%	6.7
UCI-IN2	Pond, near inflow	6/15/2006	0.694	0.346	<.088	<0.077	<0.077	2.77	2.42	0.35	12.6%	4.9
UCI-OUT2	Pond, near terminus	6/15/2006	0.678	0.339	<.088	<0.077	<0.077	1.31	1.39	0	0.0%	13.7
UNB	Upper Newport Bay	5/11/2006	1.18	5.53	<0.077	<0.077	<0.077	7.31	6.85	0.46	6.3%	7.5

* historic wetland area (Swamp of the Frogs)

NA = not analyzed

Se (IV) = selenite; Se (VI) = selenate; SeCN = selenocyanate; MeSe (IV) = methylseleninic; SeMet = selenomethionine; T-Se = total selenium; Diss-Se = dissolved selenium; Part-Se = particulate selenium (% of Se mass in water that is in particulate form); TSS = total suspended solids

Some of the water samples from the wetland ponds showed the greatest divergence from the rest of the watershed, with a tendency towards more selenite in proportion to the selenate. In addition, particularly in the UCI pond samples, the sum of dissolved constituents fell significantly short of the total selenium value (**Table 2**). The laboratory report accompanying these results suggested that this finding is most likely related to unaccounted colloid fractions that may sometimes appear in dissolved fractions but are not measured without digestion of the sample. Dissolved fractions were analyzed for dissolved species using appropriate analytical methods, but without digestion of the sample. Colloidal fractions, if present in the dissolved sample, would require further digestion to yield accurate selenium concentration in filtered water. This phenomenon can be investigated further with the UCI and IRWD wetland pond samples by running split samples with and without dissolved fraction digestions.

Eleven sediment samples were collected at locations not being sampled by DFG (UPCW, SDCR2, TSDCR1, USDCR1, IRWD, and UCI; **Table 1**). At least three samples of benthic invertebrates and three of water column invertebrates were collected when available from each of the creek sites (no invertebrates were available at PCW, SADC, or TSDCR1, and either benthic or water column invertebrates were not available at some other locations), as well as from the two marshes (IRWD and UCI). Benthic invertebrates also were collected from the Upper and Lower Newport Bay locations (UNB and LNB). Bird eggs were collected as available. The target was 10 eggs for each species at each site (excluding SDCR2, SADC, SDCR1B1, SDCR1B3, and LNB), with a minimum of 3 eggs per species per site. The target number was met for some species at the IRWD and UCI marsh sites and at the UNB site, but few nests were found in other parts of the watershed.

CH2M HILL is coordinating with DFG, SCCWRP, and Dr. B.J. Hibbs to acquire the results of their 2006 sampling conducted for the State Water Resources Control Board (SWRCB).

2.3.1. Selenium Concentrations in Sediment and Biota Samples, 2006

Selenium concentrations in sediment and biota samples collected in 2006 are shown in **Figure 2**. These samples were collected to fill gaps in the data that were identified in the Conceptual Model (CH2M HILL 2006a) and the Sources and Loads and Data Gaps report (CH2M HILL 2006c). Sample results will be combined with samples collected and analyzed for selenium concentration within the watershed in previous years (e.g., for the Irvine Company or by SCCWRP) and by DFG and Dr. Hibbs in 2006. Note that all box-whisker plots shown in this report provide a 5-percentile bar, 25-percentile bottom of the box, 50-percentile median line, 7-percentile top of the box, 95-percentile upper bar, and high and low outliers.

2.3.2. Selenium Concentrations in Bird Eggs, 2006

Selenium concentrations in eggs collected in 2006 were not significantly different among locations ($P \geq 0.05$). Although there appears to be a trend of decreasing selenium concentrations in eggs from upstream (San Diego Creek, Reach 1) to the wetlands (IRWD and UCI marshes) to Upper Newport Bay (**Figure 3**), the number of samples collected in the creek (especially UPCW) is too small to reach a conclusion concerning such a trend.

Figure 2. Selenium Concentrations (mg/kg dw) in Sediment and Biota Collected from the Newport Bay Watershed in 2006. Number of samples are shown in parentheses below the boxes.

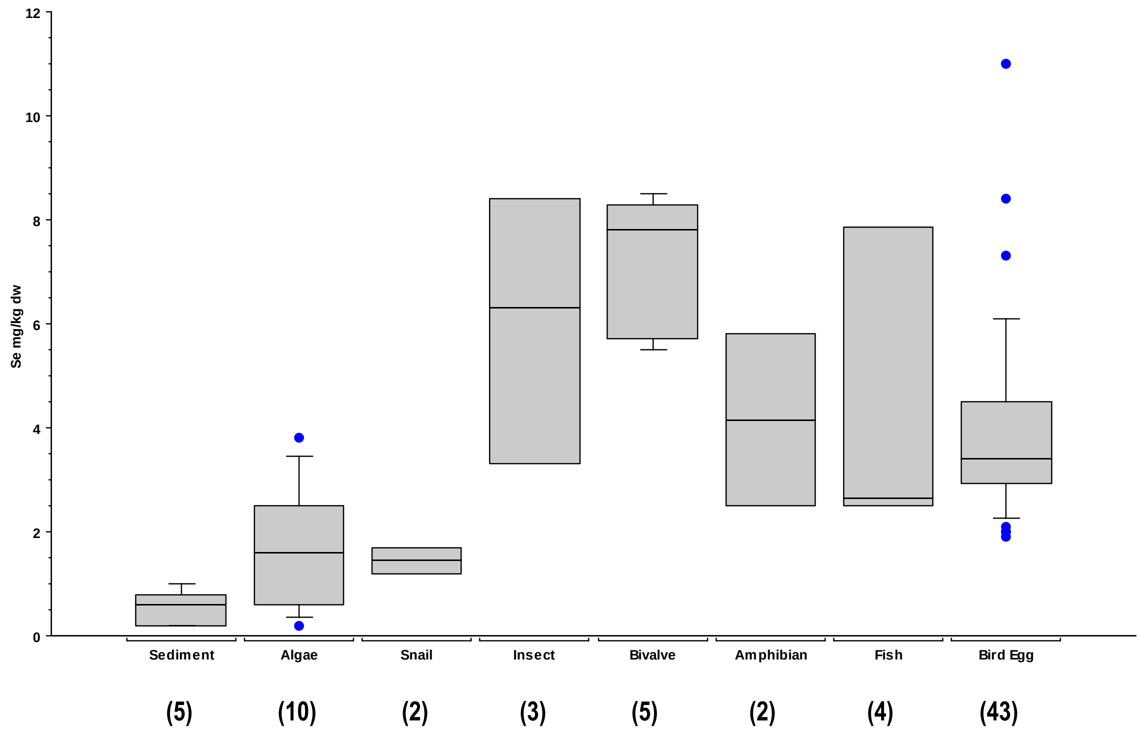
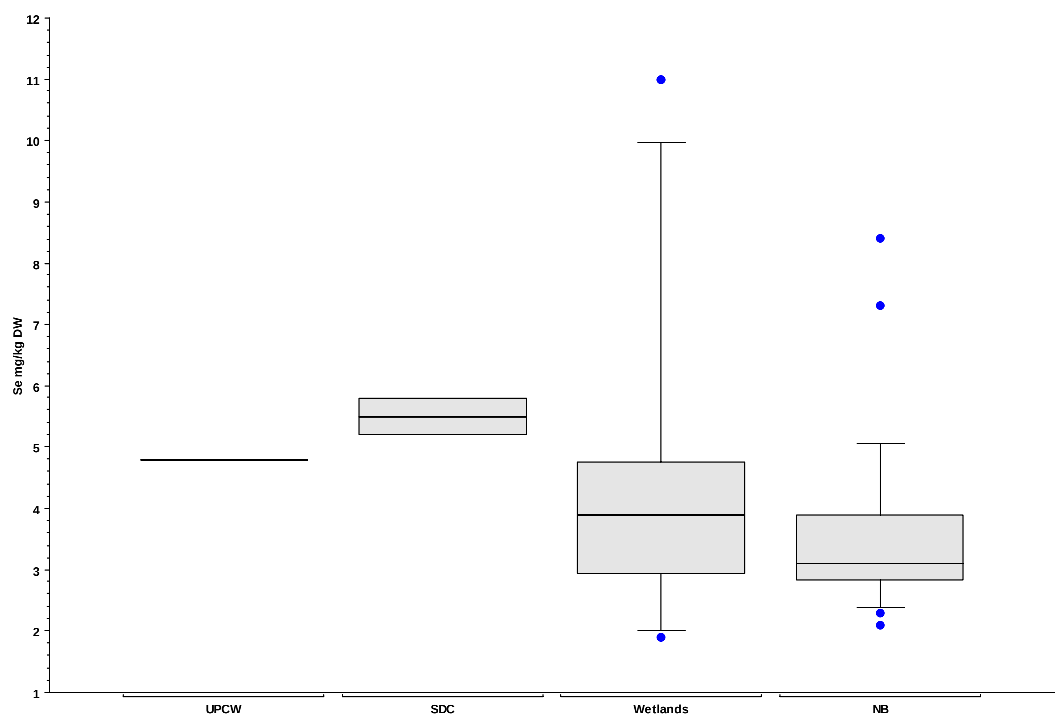
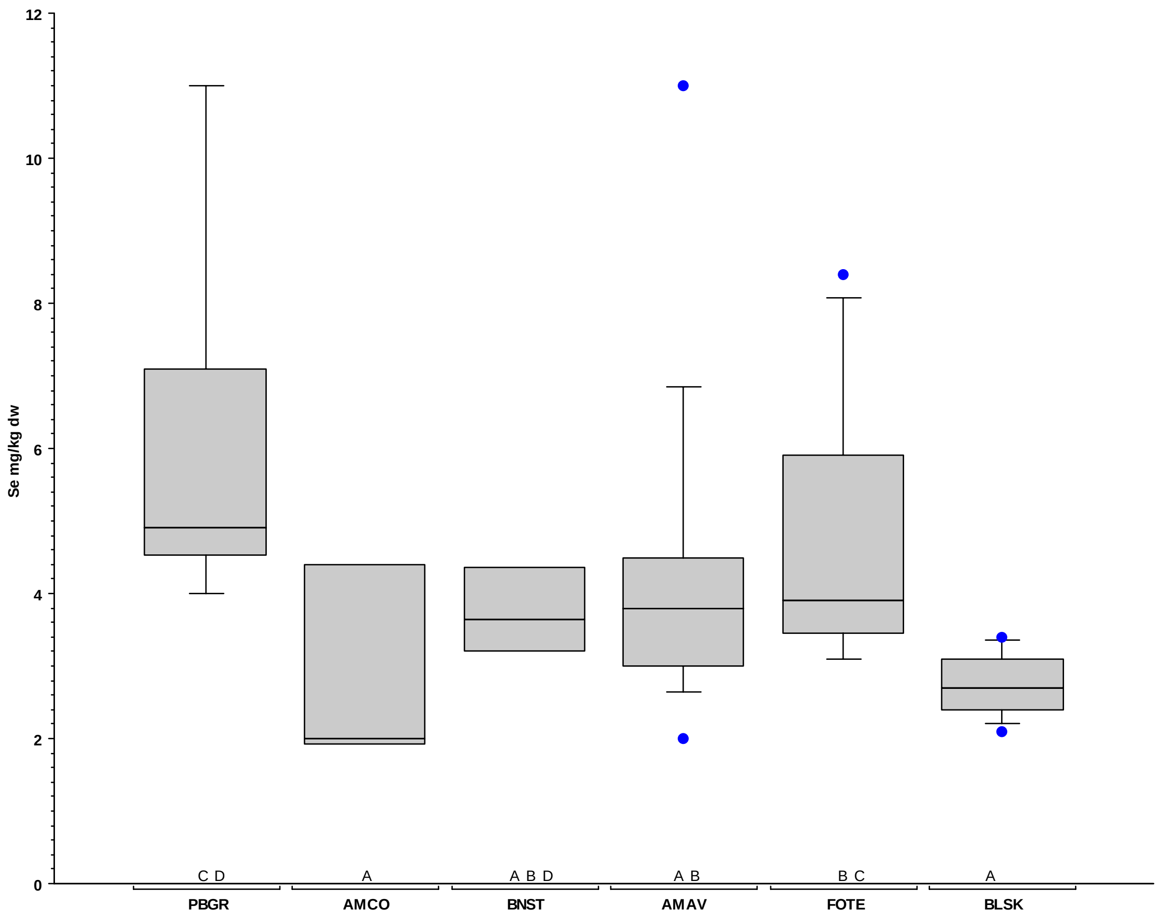


Figure 3. Selenium Concentrations in Bird Eggs (mg/kg dw) Collected from the Newport Bay Watershed (upstream to downstream), 2006.



Pied-billed grebes (PBGR; *Podilymbus podiceps*), Forster's terns (FOTE; *Sterna forsteri*), and American avocets (AMAV; *Recurvirostra americana*) generally had the highest egg selenium concentrations, black-necked stilts (BNST; *Himantopus mexicanus*) had an intermediate concentration, and American coots (AMCO; *Fulica americana*) and black skimmers (BLSK; *Rhynchops niger*) had the lowest concentrations (**Figure 4**).

Figure 4. Selenium Concentrations (mg/kg dw) in Eggs Collected from the Newport Bay Watershed by Species, 2006.



Species with the same uppercase letters are not significantly different ($P \geq 0.05$).

2.4. CONCLUSIONS

The 2006 field sampling yielded results similar to the earlier data on water, sediment, and biota selenium concentrations throughout the watershed. In addition, the 2006 data expanded our knowledge of selenium concentrations for some geographic areas that had been poorly characterized.

The 2006 results verified the hypothesis that the upper areas of the watershed draining Peters Canyon Wash and upper San Diego Creek represent regional background values for selenium concentrations. The pattern for water, sediment, and biota was one of low selenium concentrations upstream of the influence from the historic Swamp of the Frogs (surfacing groundwater) followed by sharply increased concentrations in surface water and other media downstream of the general area of groundwater influence. The waterborne concentrations for selenium speciation show this pattern clearly (**Table 2**).

Selenium concentrations in other media also reflect this same general trend. For example, the upper watershed yielded the lowest concentrations in sediment (0.095 mg Se/kg, dw). Sediment concentrations increased downstream, with the highest values found in the sediment accumulation areas of the wetland ponds and the bay (3 to 5 mg Se/kg, dw) at the most downstream areas of the watershed.

Tissue concentrations in biota also demonstrated the same trend, with upper watershed fish ranging from 2 to 3 mg Se/kg, dw, but up to 13 mg/kg in the wetland ponds. Similarly, invertebrates ranged from below 2 mg Se/kg in upper watershed snails to near 10 mg Se/kg in lower creek water boatmen. However, selenium concentrations in bird eggs were not significantly different among locations, indicating the effects of receptors with wide areas of potential exposure (in contrast to invertebrates, with home ranges limited to the immediate site) as well as small sample sizes for bird eggs from some areas.

Another major conclusion from the 2006 dataset was the trend seen in **Figure 2**. The primary producers that accumulate selenium from the inorganic environment (e.g., algae) and the animals that graze them (e.g., snails) were significantly lower in tissue concentrations of selenium than were the various invertebrates, amphibians, fish, and birds that feed at higher and more variable trophic levels.

These data from 2006 help fill in the Conceptual Models for the watershed and bay by documenting the spatial variability and differences among major trophic groups in terms of selenium bioaccumulation. In addition, the preliminary data on selenium speciation in water suggest that most of the waterborne exposure in the watershed and bay occurs from oxidized selenium (selenate, $Se\ 6^{+}$) (**Table 2**). Chemically reduced selenium (as selenite, $Se\ 4^{+}$) is primarily limited to wetland ponds where organic-rich sediments facilitate the bacterially mediated conversion of selenium to reduced (and more bioaccumulative) forms. Although expected in the wetlands, organo-selenium compounds were not found at levels greater than method detection limits anywhere in the watershed. Most of the waterborne selenium in the watershed exists as inorganic selenate and can be assumed less bioaccumulative than if the selenium were primarily found as selenite or converted to organic compounds. The selenium speciation measured during the summer of 2006 favors relatively lower bioaccumulation from the water phase than if the selenium were in other chemical forms.

3. WATER, SEDIMENT, AND BIOTA IN THE NEWPORT BAY WATERSHED

Other samples have been collected in the Newport Bay watershed that can be used in evaluating selenium concentrations in water, sediment, and biota. These include studies conducted by Orange County, the SWRCB (Dr. B.J. Hibbs, Dr. A.J. Horne), SCCWRP, the Irvine Company, and SCCWRP (Allen et al., 2004). All samples prior to those collected in 2006 (excluding the Horne and SCCWRP data) were presented and summarized by site in the Sources and Loads report (CH2M HILL, 2006c).

3.1. WATER

Water has been extensively characterized within the watershed; those results lead to the initial listings of impairment and the subsequent TMDL for selenium. The recent and ongoing surface and groundwater sampling efforts have been documented in the Sources and Loads and Data Gaps report (CH2M HILL 2006c), and described above as part of the 2006 sampling effort to fill data gaps. The Sources and Loads report included all recent records of groundwater (as recently surfacing groundwater sources) and surface water in the watershed. Results include Orange County routine monitoring for concentrations and load, special study results, compliance monitoring results, and the special studies of Dr. Hibbs. The 2006 selenium speciation results are presented in **Table 2**, above. The basic pattern in the watershed is one of relatively low concentrations of selenium in surface water upstream of the historic Swamp of the Frogs groundwater influence, followed by marked increases in concentration of selenium downstream from that general area. The highest concentrations of selenium in the watershed are found in surfacing groundwater in the mid-watershed region composed of the lower reaches of Peters Canyon Wash and the San Diego Creek (CH2M HILL 2006c). In general, higher concentrations in the lower watershed are found during dry weather, low flows in the spring, summer, and fall months (i.e., higher proportion of baseflow from groundwater). Lower waterborne selenium concentrations are found during the winter months with high rainfall runoff (i.e., higher relative amounts of flow from surface water runoff instead of groundwater).

3.2. SEDIMENT

Sediment has been sampled throughout the watershed in previous years (CH2M HILL 2006c) but the spatial distribution of samples was enhanced through implementation of the 2006 sampling, which was specifically designed to fill data gaps. Summary results by location are shown in **Figure 5**. Sediment concentrations were assumed to be representative of average concentrations by location and were not evaluated as having seasonal variability. Values ranged from 0.1 to 8.3 mg Se/kg dw. The highest sediment concentrations of selenium were found in the IRWD and UCI marshes and Upper Newport Bay, all of which have accumulation of soft sediment, in contrast to the more highly washed, sandy substrates of the creeks. The marshes and bay accumulate soft, organic sediments by virtue of their reduced energy environments. The higher concentrations found in these areas is supportive of the concept that selenium is most commonly associated with living or decaying biological fractions (fine-grained, silty sediment) rather than as inorganic, mineral fractions (sandier fractions). However, the environments may be different in the relative balance of water-column and locally produced sediment (phytoplankton, all decaying particles) vs. those sediments carried in by advection from offsite sources.

3.3. BIOTA

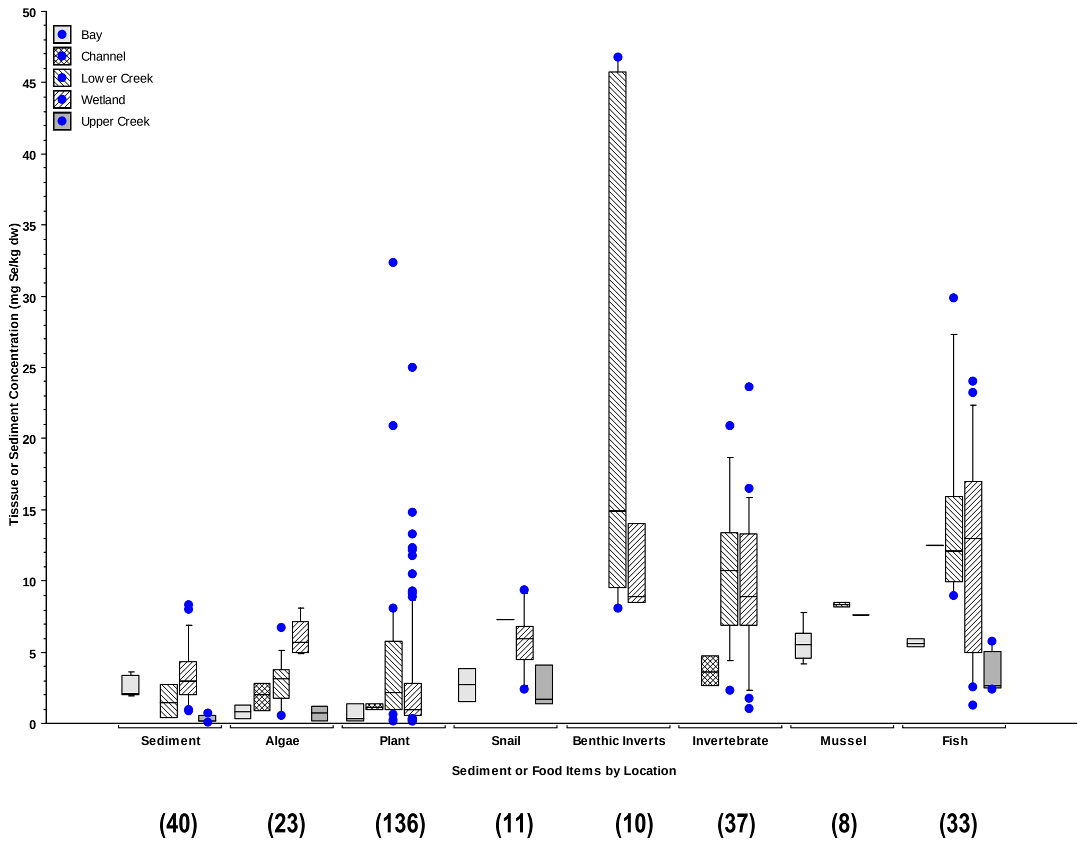
Various biota have been sampled throughout the watershed with the specific goal of identifying selenium concentrations in whole-body tissues of invertebrate and fish species, especially those that are representative of bird prey items, and particularly during the bird nesting season. The following summary includes NSMP sampling results from 2006, results from studies conducted for SCCWRP and SWRCB in 2004 and 2005, the Irvine Company (J. Byard study), and SWRCB (A. Horne study) results from 2002-2005. Samples collected but not yet reported include algae biomass per unit area and DFG samples from 2006. There were no significant trends over time for the period 2002 through 2006 (ANOVA by years, $P > 0.05$).

In contrast to a lack of temporal trends, statistical analyses of taxonomic and feeding groups within various habitats revealed that biota in the watershed differ significantly with respect to tissue selenium concentrations by habitat ($P<0.05$, Fishers PLSD paired comparison test and ANOVA on log-transformed data). The lower creek locations (downstream of the elevated groundwater influence) had significantly higher concentrations of invertebrate and fish tissue selenium as compared to the bay, ponds (wetlands), and upper creek locations.

In addition to variability by habitat type, statistical analysis revealed significant differences in tissue selenium concentrations by taxonomic and feeding groups. In general, algae, rooted plants, and snails were lower in tissue concentrations than all other groups of invertebrates or fish ($P<0.05$, Fishers PLSD paired comparison test and ANOVA on log-transformed data). Note that the “mussels” as presented in Figure 5 include mussels in the bay as well as freshwater clams from the creek.

Figure 5 provides a summary of sample results for the watershed and bay, shown as standard box-whisker plot summaries. Results for individual taxonomic groups are discussed in their respective sections, below. Numbers of samples are shown in parentheses below the boxes.

Figure 5. Sediment and Biota Tissue Concentrations by Watershed and Bay Locations.



3.3.1. Algae

Filamentous algae species (e.g., Cladophora, others; Horne et al. 2006) are commonly found attached to hard substrates throughout the channels and streambeds of the watershed. During spring and summer, their biomass is adequate for quantitative sampling per unit area (results pending for 2006) and for tissue chemistry.

Results from 2002-2004 and 2006 indicated relatively low concentrations of selenium in filamentous algae as compared to other biota. Values ranged from 0.2 to 1.2 mg Se/kg dw in the upper watershed (above the influence of the historical Swamp of the Frogs) to maximum values of 6.7 mg Se/kg dw in the lower creek and 8.1 mg Se/kg dw in the off-channel wetlands (**Figure 5**). Algae tissue concentrations represent short-term bioaccumulation from water, limited to the immediate growing season.

3.3.2. Rooted Plants

Rooted aquatic plants were sampled as leaves and stems, rhizomes and roots, and seeds (Horne et al. 2006). The results indicated somewhat higher selenium bioaccumulation than for algae. The upper creek area was not sampled, but areas of the creek within or downstream of areas of elevated selenium loading had plant tissue values ranging from 0.18 to 32 mg Se/kg, with plants in the bay, wetland ponds, and channels having relatively lower concentrations (**Figure 5**). Rooted plant tissue concentrations represent variable duration of bioaccumulation (mostly annual except for rhizomes) from both sediments and water. The highest values were found in cattail and Olney's rush in Peters Canyon Wash.

3.3.3. Invertebrates

The invertebrates sampled were diverse and highly variable with respect to selenium bioaccumulation. They included predators (dragonfly larvae), herbivores (snails), filter feeders (clams and mussels), and omnivores (crayfish). Habitats included within-sediment (detritivorous chironomid midge larvae, worms, clams) to epibenthic (crayfish, snails), and free-swimming (Daphnia, water boatmen).

Results indicated a strong pattern of variation by association with areas of elevated selenium loading. The highest selenium concentrations were found in the lower creek (water boatmen, midge larvae) and wetland locations (midge larvae; **Figure 5**) rather than more upstream areas or areas of greater dilution and settlement loss (Bay). Values ranged from 0.70 to 47 mg Se/kg dw for horned snails (whole body with shells; soft tissue was 2.3 mg Se/kg) collected from Upper Newport Bay and chironomid larvae from lower Peters Canyon Wash, respectively.

3.3.4. Fish

Selenium in fish was generally similar but often higher than in the co-located invertebrates for any given area (**Figure 5**). Species were all potential bird prey items and included catfish, mosquitofish, small carp, small largemouth bass, and bluegill (creek, ponds), and goby (upper bay). Some amphibian larvae are grouped into this category, and included tadpoles of African clawed frogs (creek) and western tree frogs (ponds). In general, the results for invertebrates and fish (as compared to algae, plants, and snails) indicate an increase in tissue concentrations of selenium moving from primary producers and herbivores to omnivores and predators.

Whole-body fish concentrations varied from 1.3 to 30 mg Se/kg dw. The upper Newport Bay samples of 5.4 and 5.8 mg Se/kg dw in this dataset were very comparable to the range of 3.1 to 9.6 mg Se/kg dw found for similar species collected from the upper bay in 2002 (Allen et al., 2004). Some of the creek and upper bay (Allen et al., 2004) samples were noted to exceed Presser, et al. (2004) threshold guidelines for potential toxicity to fish. In addition, many of the fish samples exceeded the recommended selenium criterion, based on fish tissue values, of 7.9 mg/kg selenium (EPA, 2004).

Amphibian larvae ranged from 2.5 to 5.8 mg Se/kg dw (**Figure 5**).

3.3.5. *Bird Eggs*

Two studies have been conducted and one study is ongoing in the watershed in which selenium data have been collected that are relevant to the NSMP effort. As part of a study conducted for SWRCB by SCCWRP, clapper rail (*Rallus longirostris*) eggs that failed to hatch were collected in 2003 and 2004 from the Upper Newport Bay and the egg contents were examined and analyzed for a variety of contaminants, including selenium (Sutula et al. 2004). A study was conducted for the Irvine Company in which mallard (*Anas platyrhynchos*), killdeer (*Charadrius vociferous*), black-necked stilt, and American avocet eggs were collected (Byard 2003). An ongoing study is being conducted for SCCWRP and SWRCB evaluating contaminants in the San Diego Creek/Newport Bay watershed, and American coot, killdeer, black-necked stilt, American avocet, Forster's tern, and black skimmer eggs have been collected and analyzed for selenium as well as other contaminants as part of that study (Santolo, unpublished data). Bird eggs collected for these three studies in the watershed were combined to evaluate bioaccumulation (**Table 3**).

Table 3. Geometric Mean (mg Se/kg dw), Number of Eggs Collected (n), and Range (mg Se/kg dw) from Studies Conducted during 2003 to 2006 in the Newport Bay Watershed

Species	2003	2004	2005	2006	Study Conducted For
Pied-billed grebe				5.7 (5) 4.0 – 11	NSMP[a]
Mallard	5.2 (2) 4.0 – 6.7				Irvine Company[b]
Clapper rail	3.9 (2) 3.5 – 4.5	3.6 (4) 3.1 – 4.4			SCCWRP/SWRCB[c]
American coot			2.6 (7) 1.7 – 4.4	2.7 (3) 1.9 – 5.2	SCCWRP/SWRCB[d] NSMP[a]
Killdeer	4.3 (2) 2.6 – 7.1	6.4 (3) 2.9 – 9.9	2.2 (1)		Irvine Company[b] SCCWRP/SWRCB[c]
Black-necked stilt	3.4 (1)	9.5 (3) 7.0 – 15	5.5 (11) 2.7 – 8.1	3.7 (4) 3.0 – 4.8	Irvine Company[b] SCCWRP/SWRCB[c]

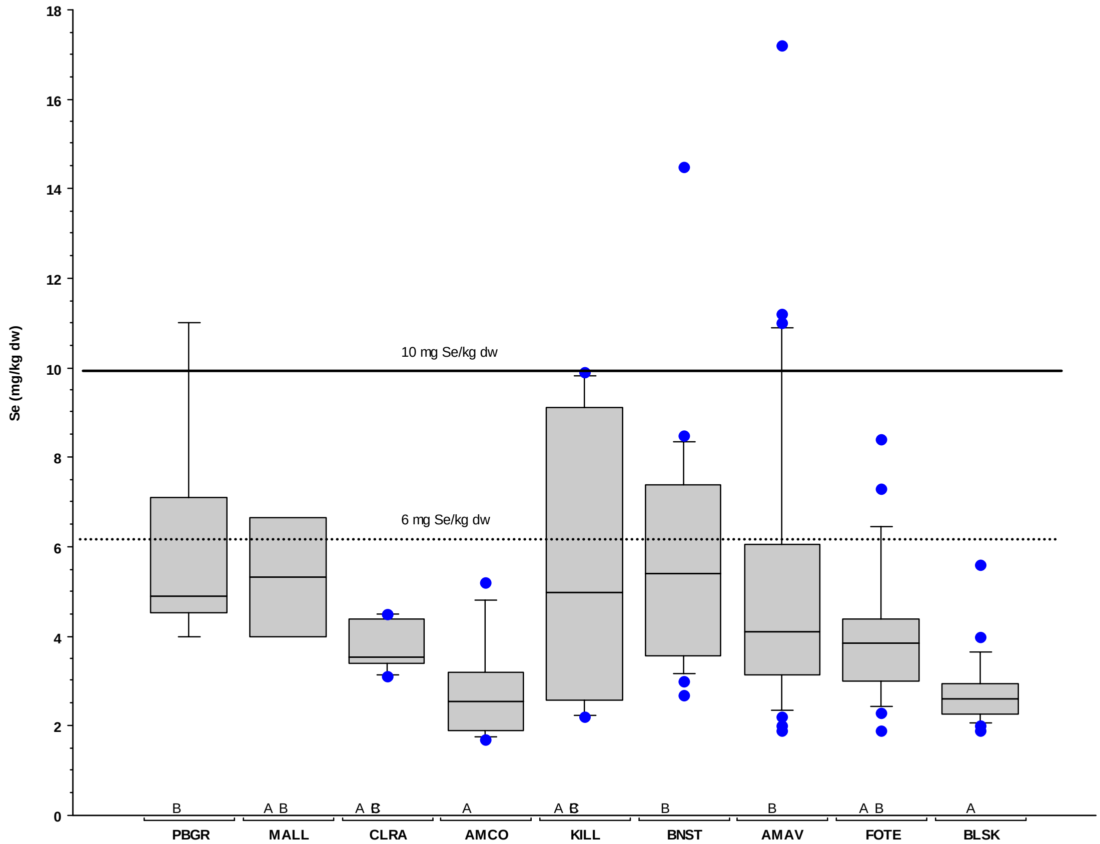
Table 3. Geometric Mean (mg Se/kg dw), Number of Eggs Collected (n), and Range (mg Se/kg dw) from Studies Conducted during 2003 to 2006 in the Newport Bay Watershed

Species	2003	2004	2005	2006	Study Conducted For
					NSMP
American avocet	13.9 (2) 11 – 17	6.9 (5) 3.5 – 11	3.6 (8) 1.9 – 6.3	3.9 (13) 2.0 – 11	Irvine Company[b] SCCWRP/SWRCB[c] NSMP
Forster's tern			3.2 (10) 1.9 – 4.5	4.5 (8) 3.1 – 8.4	SCCWRP/SWRCB[c] NSMP[a]
Black skimmer			2.7 (11) 1.9 – 5.6	2.7 (10) 2.1 – 3.4	SCCWRP/SWRCB[c] NSMP[a]

[a] This project
[b] Byard (2003)
[c] Sutula et al. (2004)
[d] Santolo, unpublished data

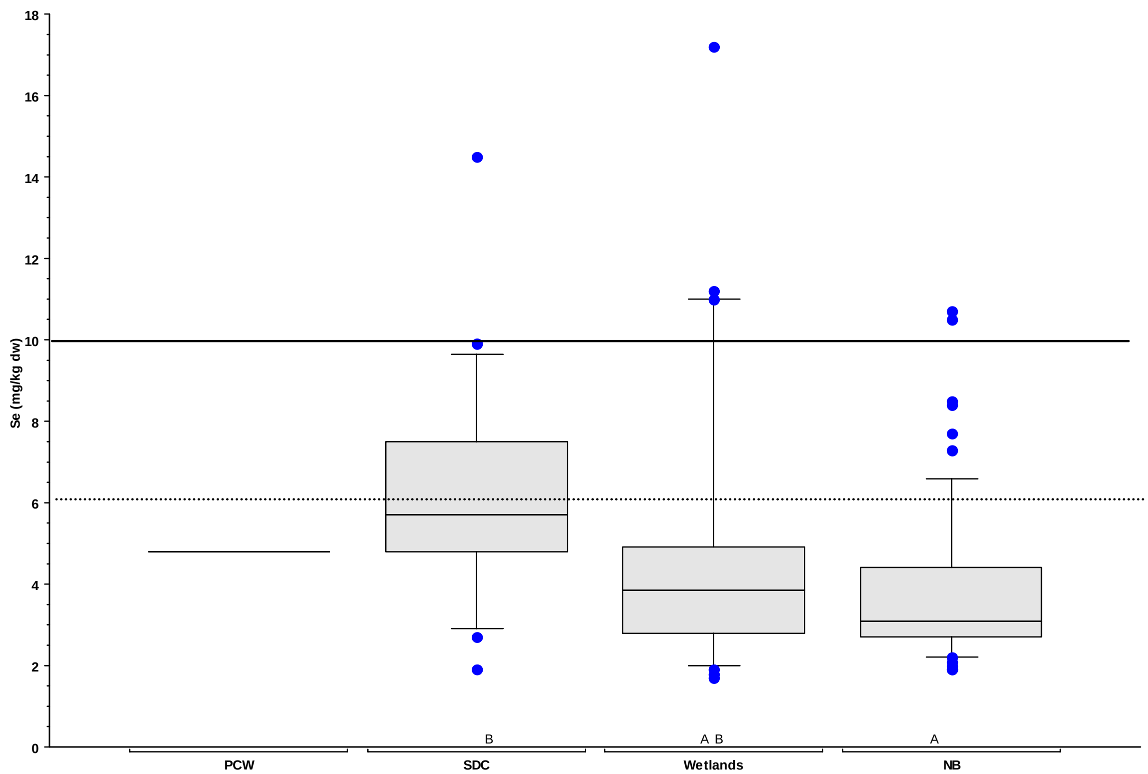
Selenium concentrations varied by species but pied-billed grebe, black-necked stilt, and American avocet eggs had significantly higher geometric mean selenium concentrations ($P \leq 0.05$ Tukey-Kramer HSD log-transformed) than American coot and black skimmer eggs (**Figure 6**).

Figure 6. Selenium Concentration in Eggs Collected from the Newport Bay Watershed During 2003 to 2006 Compared to 6 mg Se/kg dw Lower Toxicity Threshold (dashed line; and 10 mg Se/kg Toxicity Threshold (solid line) Shown (Presser et al. 2004). Species Not Sharing the Same Uppercase Letter Are Significantly Different (*P* ≤ 0.05, Tukey-Kramer HSD Of Log-Transformed Data).



Selenium concentrations varied by area; eggs from San Diego Creek had significantly higher geometric mean selenium concentrations (*P* ≤ 0.05 Tukey-Kramer HSD log-transformed) than those from Newport Bay. However, eggs from the wetland sites (UCI and IRWD marshes) had higher individual eggs than were found at the other sites (**Figure 7**). Both the wetland sites and the Newport Bay site had individual eggs above the 10 mg Se/kg dw threshold for toxicity.

Figure 7. Selenium Concentration in Eggs Collected from the Newport Bay Watershed during 2003 to 2006 Compared to 6 mg Se/ kg dw Lower Toxicity Threshold (dashed line) and 10 mg Se/kg Toxicity Threshold (solid line) Shown (Presser et al. 2004). Areas Not Sharing the Same Uppercase Letter Are Significantly Different (P ≤ 0.05, Tukey-Kramer HSD of Log-Transformed Data).



3.4. CONCLUSIONS

Analysis of the water, sediment, and biota database for the Upper Newport Bay watershed demonstrates a pattern of discrete selenium sources, watershed transformations, bioaccumulation, food-chain transfers, and eventual settlement, dilution, and losses in the bay. The overall pattern is one of elevated groundwater sources of selenium from the area of the historic Swamp of the Frogs followed by downstream displacement, dilution, and dispersion. Most bioaccumulation appears to be downstream of this mid-watershed source area.

The upper watershed drainages, including upper Peters Canyon Wash and the upper portions of San Diego Creek, are strikingly lower in selenium concentrations in all media than are the areas below the Swamp of the Frogs influence. However, the zone of sharp increase in surface water concentrations of selenium is disjunct from areas of significant ecological habitat. The mid-watershed region of strongest groundwater influence (e.g., from Lane Channel, Como Channel, Warner Channel, etc.) is an area of notably poor aquatic habitat quality. The creek in that area is primarily a linear flood control channel with purposefully minimized habitats resulting from an artifact of flood control maintenance and channel design.

In contrast, the lower creek, wetland ponds, and the upper bay are areas of sediment accumulation, and provide invertebrate, fish, and bird nesting habitats in areas with somewhat more diluted waterborne concentrations of selenium. The correspondence between availability of habitat and somewhat elevated selenium peaks in the lower watershed and, consequently, the greatest levels of bioaccumulated selenium are found in that area (**Figure 5**). However, the wider-ranging birds (**Figure 7**) do not show the same spatial pattern of bioaccumulation that is evident from their potential food items (**Figure 5).**

The reduced bioaccumulation in invertebrates and fish in the bay as compared to the lower watershed (e.g., **Figure 5**) is likely related to the significant physical loss processes, coupled with dilution and dispersion in the deeper, tidal environment of the bay. In addition, selenium bioaccumulation in the bay foodweb is still poorly understood and not well characterized. As more focused data are added (e.g., DFG 2006 results) we will be better able to trace selenium as it moves from the creek to the bay. However, current whole body fish samples from the upper bay and lower watershed generally exceed risk guidelines of 4 mg Se/kg dw as presented in Presser et al. (2004) and presented in Section 4. The highest tissue concentrations in birds were found in insectivorous species feeding and nesting in the lower creek area and in fish from that same area.

4. BIOAVAILABILITY AND IMPACTS OF SELENIUM

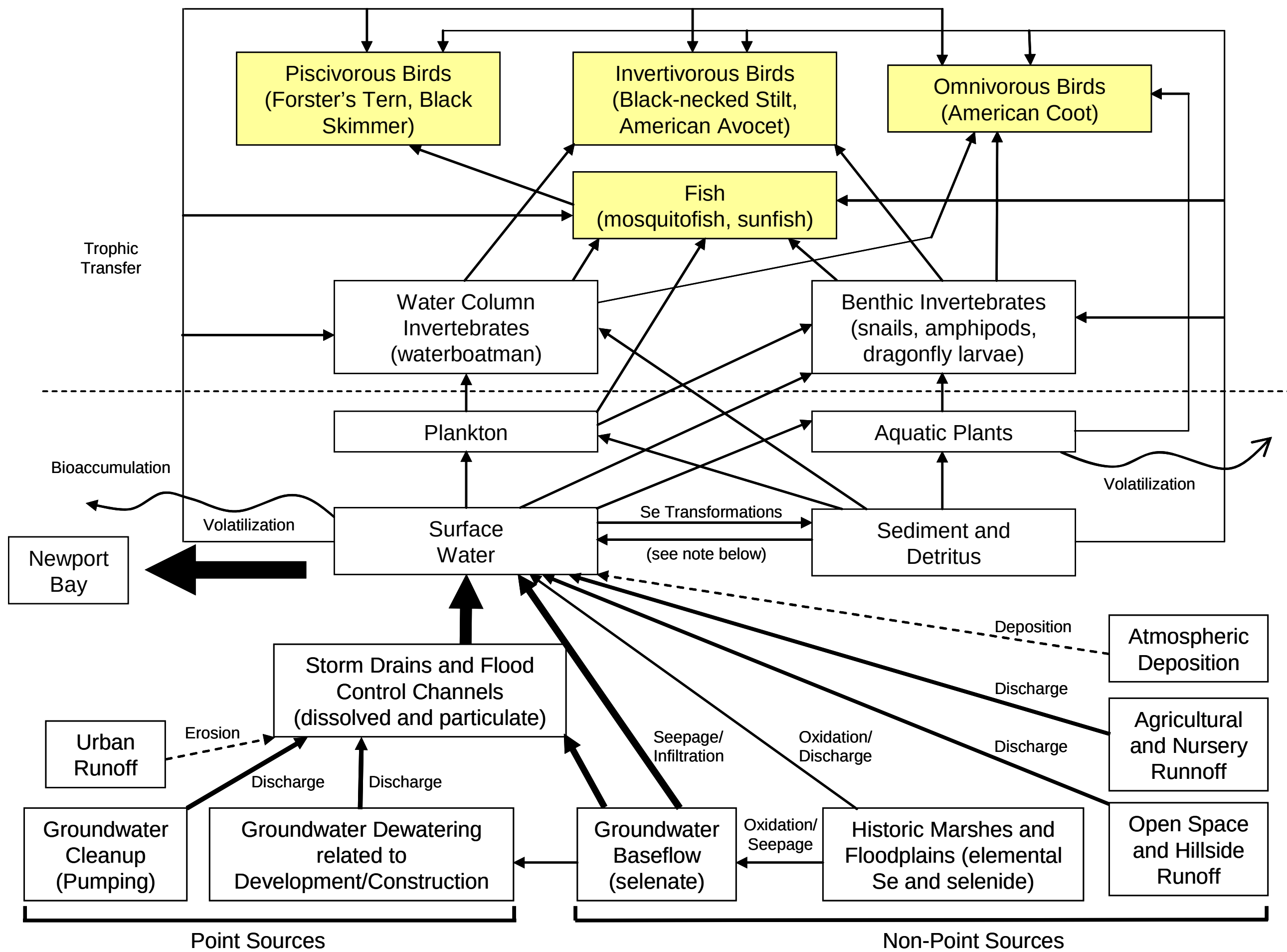
4.1. CONCEPTUAL MODEL

A conceptual model was developed to describe the sources and movement of selenium within freshwater creek and wetland (**Figure 8**) and estuarine (**Figure 9**) habitats of the Newport Bay watershed, the understanding of which is essential toward creating a management plan for selenium discharges to surface waters within the watershed (CH2M HILL 2006a). Using the information that was available, the model was used to determine what additional data were necessary to collect (i.e., it aided in identifying gaps in existing data). The model provides a meaningful framework in which the data can be analyzed, resulting in the ability to answer specific questions and ultimately provide a basis for making sound management decisions. The water, sediment, and biota sampling in 2006 was conducted to fill data gaps identified in the Newport Bay watershed conceptual model.

As described in the *Conceptual Model for Selenium: Newport Bay Watershed Interim Report* (CH2M HILL 2006a), selenium reaches surface waters from many sources, with groundwater sources (both point and non-point) accounting for most of the selenium discharge to surface waters. Once in surface water (in both dissolved and particulate forms), selenium may alternate between immobilization in sediments and mobilization from sediments through various biogeochemical processes. Aquatic plants (including algae) bioaccumulate selenium from surface water or sediment/detritus, whereas invertebrates (benthic and water column), fish, and aquatic birds bioaccumulate selenium primarily from their food. Direct ingestion of surface water and sediment also represents a potential pathway for accumulation of selenium by invertebrates, fish, and aquatic birds.

San Diego Creek (including its tributaries, such as Peters Canyon Wash) is the primary source of selenium to Newport Bay. Primary release mechanisms to the bay include surface water inflow, bedload sediment inflow, and suspended sediment discharge. Once in sediment and surface water, the immobilization and remobilization processes drive the cycling of selenium in the bay. Bioaccumulation and trophic transfer of selenium to biota are similar to that described for the Newport Bay watershed, although benthic invertebrates are likely to be the primary source for trophic transfer. However, the chemistry of the upper water column community of the bay, which is most closely linked to piscivorous birds such as skimmers and terns, is relatively unknown. Bay selenium concentrations are likely to be most elevated in the sediments and sediment community; however, the birds are mostly feeding on surface-dwelling fish such as topsmelt and anchovy, which are more closely linked to the planktonic foodweb.

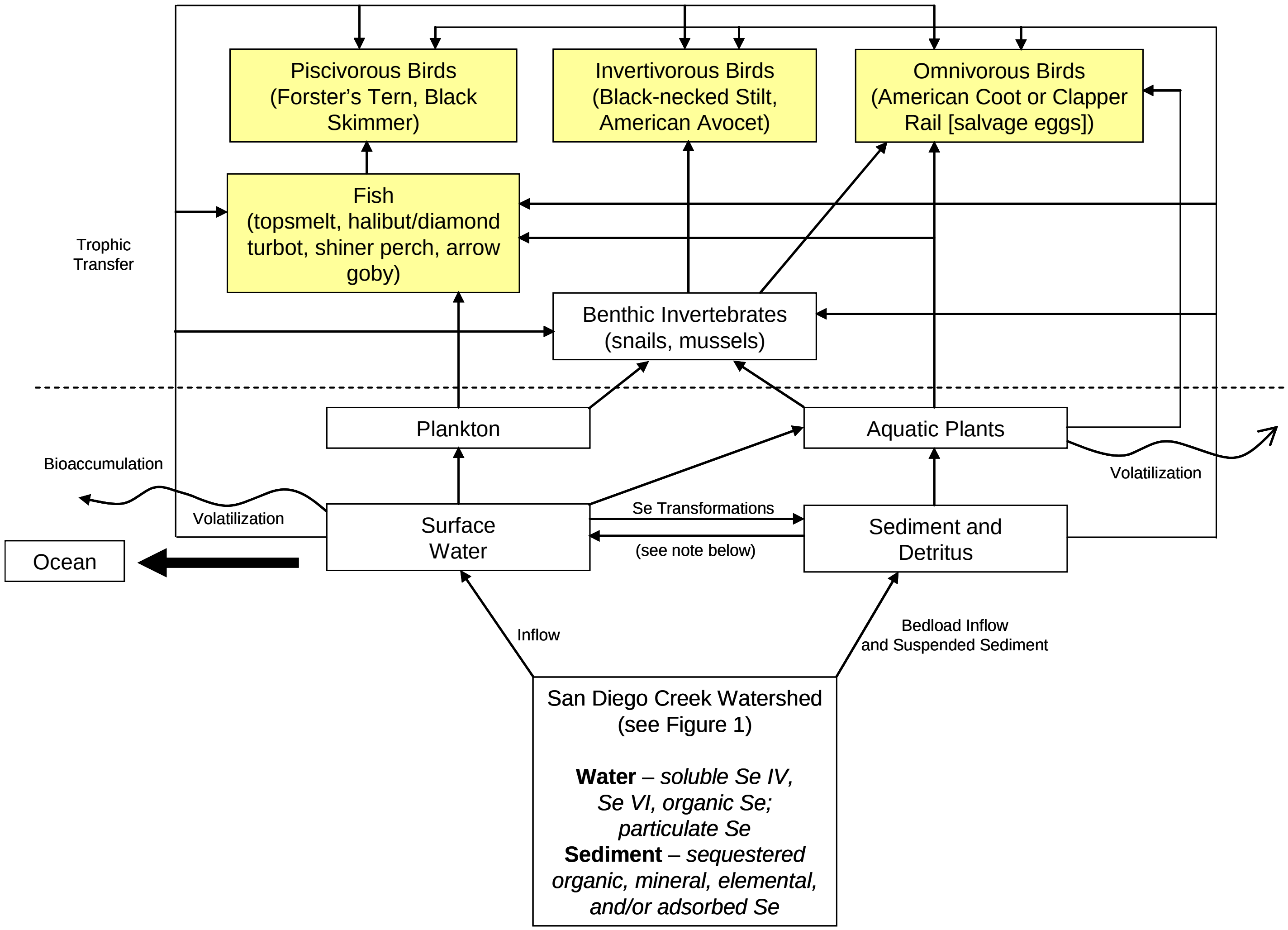
Figure 8. Conceptual Model, Exposure Pathways, and Food-Web Relationships for Freshwater Creek and Wetland Habitat within the Newport Bay Watershed.



Notes: Shaded Boxes = assessment species for effects

Weight of line from source indicates significance of contribution of selenium to the watershed (e.g., dotted line indicates insignificant contribution, whereas a heavy line indicates significant contribution).

Figure 9. Conceptual Model, Exposure Pathways, and Food-Web Relationships for Habitat within Newport Bay.



Notes: Shaded Boxes = assessment species for effects

Although the Newport Bay watershed conceptual models were developed using the Luoma and Presser (2000) model as a guide, there are some basic differences between the two models. As with our model for Newport Bay, Luoma and Presser (2000) used their model to determine loads from major selenium sources (agricultural drains, oil refineries, and the two major rivers, Sacramento and San Joaquin) to the San Francisco Bay-Delta Estuary. However, their model was not used to evaluate exposure or effects in those freshwater reaches of the system. Instead, the focus is on modeling exposure to Bay-Delta aquatic birds. Therefore, bioaccumulation is determined for a single food item (clams) that is assumed representative of the major dietary exposure pathway to aquatic birds using the area. In contrast, bioaccumulation models for multiple food items in both the freshwater habitats of the San Diego Creek watershed and the estuarine habitats of Newport Bay are required for development of adequate exposure models.

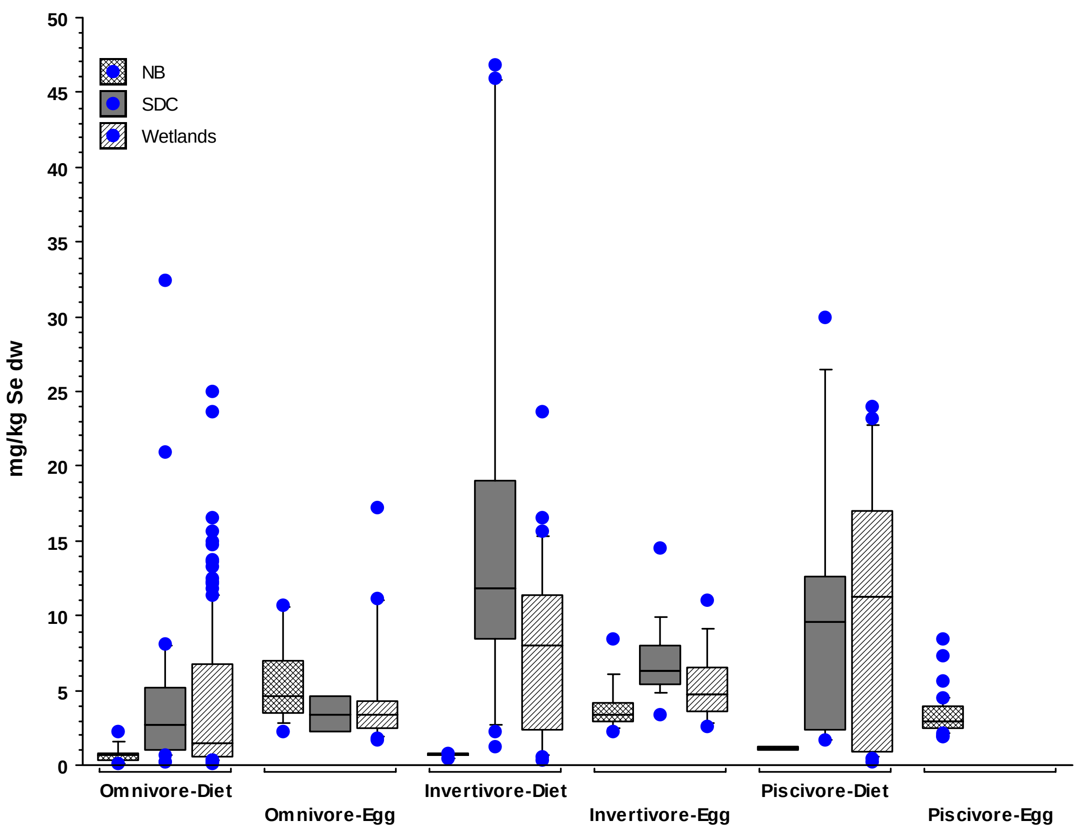
As with the Luoma and Presser model, describing and quantifying selenium in each compartment of the model is essential for its future use as a predictor of the sources and fate of selenium under differing load scenarios within the watershed. Therefore, it is important to fill the identified data gaps to quantify the relevant compartments of the model including the sources and loading, fate and transport of selenium within the watershed (including partitioning, transformation, and distribution coefficients for exposure media), and improve existing data on concentrations of selenium in the watershed.

Selenium concentrations in food-chain biota were generally reflected in bird egg selenium concentrations and were related to feeding guild and location in the watershed (Figure 10). Eggs of invertivores (birds feeding primarily on insects and other invertebrates, such as pied-billed grebe, clapper rail, killdeer, and black-necked stilt) had higher selenium concentrations than those of omnivores (P = 0.043; i.e., mallard, American coot, and American avocet) and ominivores had higher selenium concentrations than piscivores (P = 0.015; i.e., fish-eaters; Forster's tern and black skimmer). Although the correlation between bird feeding guild and egg selenium concentration appears fairly strong, it is affected by the area where the birds do most of their foraging. For example, clapper rails are in the feeding guild (insectivores) with the highest selenium concentrations but all of the (6) eggs analyzed had selenium concentrations below 5 mg Se/kg. This is likely because they are only feeding in the bay and selenium concentrations are low in that part of the watershed. In addition, eggs collected from nests in San Diego Creek and the wetlands tended to have higher selenium concentrations than those collected from nests in Upper Newport Bay (**Figure 10**). However, only 22 of the 115 eggs analyzed from the watershed were above the 6 mg Se/kg lower toxicity threshold only seven eggs were above the 10 mg Se/kg toxicity threshold of Presser et al (2004) and only two piscivore eggs (Forster's tern) were above the lower threshold but below the toxicity threshold (i.e., 7.3 and 8.4 mg Se/ kg).

4.2. POTENTIAL SELENIUM-RELATED EFFECTS

Using the conceptual model developed for the watershed along with measures (or model estimates) of selenium in key foodwebs, fish, or bird eggs, it is possible to assess the presence of, and/or the potential for, selenium-related effects as well as to predict where and when they are most likely to occur. Statistical power analysis and risk analysis tools are used to characterize the magnitude and variability of effects and the degree of reliability associated with these. The results are expected to aid in designing and implementing monitoring efforts targeted at documenting specific predicted impacts.

Because literature-derived protective guidelines for various aspects of the selenium issue (e.g., waterborne concentrations, speciation, particulates, and prey and fish or bird tissue levels) vary across habitats and species as well as the degree of their protectiveness, data for each factor can usefully be expressed as frequency of exceedance of relevant guidelines for each habitat. This will help address inherent uncertainty, since confidence in these indicators will improve as the size of the database increases. A typical approach in assessing risk is to examine a range of potential screening values. Lower-concentration effect levels from literature sources are used as benchmarks showing the upper limits of no harmful effects or toxicity (**Table 4**). Higher-concentration literature-derived benchmarks are typically used to show a point where effects are more likely to occur;



such levels are illustrated in **Table 5**.

Figure 10. Selenium Concentrations in Omnivore, Invertivore, and Piscivore Bird Eggs Compared to Diet Concentrations in the Newport Bay Watershed Bay (NB), San Diego Creek (SDC), and Wetlands.

In general, **Tables 4 and 5** illustrate a weight-of-evidence scheme, based on multiple lines of evidence. Such an approach requires a systematic consideration of each line of evidence and what the data suggest about the potential for adverse effects. **Tables 4 and 5** show the low and higher end of the ecological threshold ranges for risk to aquatic life (generally from Presser et al. 2004). In **Tables 4 and 5**, nearly all water samples from the vicinity of the Swamp of Frogs and downstream show selenium concentrations greater than 5 μg/L; taken alone, this indicates an exceedance of regulatory criteria (and was the driver for the watershed 303(d) listing). Preliminary speciation studies indicate that nearly all selenium is present as selenate, suggesting low bioavailability. Use of information collected from other studies in the watershed and samples collected in 2006 (including water speciation, particulate, and, tissue data) will help to make decisions about potential for effects.

Table 4. Low Selenium Toxicity Threshold Numeric Evaluation of Potential Selenium Toxicity. The Index[a] is the First Number and the Sample Numbers (if greater than one) and Range of Selenium Concentrations are Shown in Parentheses.

Habitat	Water µg Se/L	Speciation %	Particulate[b] mg Se/kg dw	Diet mg Se/kg dw	Fish Tissue mg Se/kg dw	Bird Egg mg Se/kg dw	Total Index[c]
Guideline[d]	**2 µg Se/L (freshwater) 71 µg/L (bay)**	**80% Se (VI)**	**2 mg Se/kg dw**	**3 mg Se/kg dw**	**4 mg Se/kg dw**	**6 mg Se/kg dw**	
Weighting Factor	**0.5**	**0.5**	**0.5**	**1**	**2**	**2**	
Upper San Diego Creek and PCW	4 (3.4)	1 (83%)	4 (38.6)	4 (3; 0.7 – 7.8)	4 (6; 1.2 – 5.8)	1 (1; 4.8)	18.5
Wetlands[e]	4 (4; 13.1)	3 (4; 35%)	4 (17.9)	4 (30; 0.03 – 24)	4 (17; 1.3 – 24)	3 (34; 1.7 – 17)	23.5
San Diego Creek[f]	4 (316; 11.4 – 35)	1 (89%)	NA 4[g]	4 (20; 1.7 – 47)	4 (7; 2.5 – 30)	3 (18; 1.9 – 15)	22.5
Upper Newport Bay[h]	2 (182; 2.13 – 7.31)	1 (81%)	4 (61.3)	4 (9; 0.7 – 7.8)	4 (6; 1.3 – 9.6[i])	4 (62; 1.9 – 11)	23.5

[a] Indicators derived from frequency of exceedance: 1. No exceedances, low probability of effect. 2. Exceedances <10%, uncertainty about exceedance. 3. Exceedances 10 – 50%, uncertainty about exceedance. 4. Exceedance frequency >50%, exceedance likely.

[b] Sediment screening values (Presser et al. 2004) are used for particulate.

[c] Calculated by weighting the water, speciation and particulates as one-half and the fish tissue and bird egg index values as twice the weight for diet.

[d] Presser et al. (2004) except speciation, particulates, and marine value for bay water (71 µg/L). Speciation is scored as higher risk if <80%. Particulates (suspended solids) are scored by comparison to the guideline for sediment. Marine value from USEPA (2002).

[e] UCI and IRWD San Joaquin Marsh.

[f] San Diego Creek (below the historic Swamp of the Frogs), geomean and maximum value for Campus Drive monitoring station, 1973 – 2005 (discontinuous monitoring).

[g] Assumed to be similar to other locations.

[h] Upper Newport Bay, geomean and maximum values, 1976 – 2005 (discontinuous monitoring).

[i] High end of range from Allen et al. (2004)

Table 5. High Selenium Toxicity Threshold Numeric Evaluation of Potential Selenium Toxicity. The Index[a] is the First Number and the Range of Selenium Concentrations in Parentheses.

Habitat	Water µg Se/L	Speciation %	Particulate[b] mg Se/kg dw	Diet mg Se/kg dw	Fish Tissue mg Se/kg dw	Bird Egg mg Se/kg dw	Total Index[c]
Guideline[d]	**2 µg Se/L (freshwater) 71 µg/L (bay)**	**80% Se(VI)**	**4 mg Se/kg dw**	**7 mg Se/kg dw**	**6 mg Se/kg dw**	**10 mg Se/kg dw**	
Weighting Factor	**0.5**	**0.5**	**0.5**	**1**	**2**	**2**	
Upper San Diego Creek and PCW	1 (3.4)	1 (83%)	4 (38.6)	1 (3; 0.7 – 7.8)	1 (6; 1.2 – 5.8)	1 (1; 4.8)	7
Wetlands[e]	4 (4; 13.1)	3 (4; 35%)	4 (17.9)	4 (30; 0.03 – 24)	4 (17; 1.3 – 24)	3 (34; 1.7 – 17)	19.5
San Diego Creek[f]	4 (316; 11.4 – 35)	1 (89%)	NA 4[g]	4 (20; 1.7 – 47)	4 (7; 2.5 – 30)	2 (18; 1.9 – 15)	17
Upper Newport Bay[h]	2 (182; 2.13 – 7.31)	1 (81%)	4 (61.3)	3 (9; 0.7 – 7.8)	3 (6; 1.3 – 9.6[i])	2 (62; 1.9 – 11)	16.5

[a] Indicators derived from frequency of exceedance: 1. No exceedances, low probability of effect. 2. Exceedances <10%, uncertainty about exceedance. 3. Exceedances 10 – 50%, uncertainty about exceedance. 4. Exceedance frequency >50%, exceedance likely.

[b] Sediment screening values (Presser et al. 2004) are used for particulate.

[c] Calculated by weighting the water, speciation and particulates as one-half and the fish tissue and bird egg index values as twice the weight for diet.

[d] Presser et al. (2004) except speciation, particulates, and marine value for bay water (71 µg/L). Speciation is scored as higher risk if <80%. Particulates (suspended solids) are scored by comparison to the guideline for sediment. Marine value from USEPA (2002).

[e] UCI and IRWD San Joaquin Marsh.

[f] San Diego Creek (below the historic Swamp of the Frogs), geomean and maximum value for Campus Drive monitoring station, 1973 – 2005 (discontinuous monitoring).

[g] Assumed to be similar to other locations.

[h] Upper Newport Bay, geomean and maximum values, 1976 – 2005 (discontinuous monitoring).

[i] High end of range from Allen et al. (2004)

Most food chain items collected from the watershed were between the low and high ranges suggested by Presser et al. (2004). Using the low selenium toxicity threshold, there is very little difference among the watershed locations (**Table 4**); however, at the higher toxicity thresholds, the watershed locations show greater separation and illustrate the general trend of decreasing selenium in the food chain moving from upstream (from the Swamp of the Frogs) to lower watershed locations (**Table 5**).

If adequate data for more than two of the factors in **Tables 4 or 5** indicate the potential for adverse selenium effects, then further targeted monitoring should be implemented to the greatest extent possible; for example:

- Assess fish and invertebrate tissue concentrations in areas of highest concentrations with a particular emphasis on identifying concentrations in bird dietary items (for example, upper water column fish in the bay).
- Assess bird eggs for indications of poor hatching success or teratogenesis.
- Evaluate potential for other causes of any findings of teratogenesis or poor reproduction (e.g., organochlorine compounds).

4.3. AVIAN REPRODUCTIVE ENDPOINTS

It is challenging to determine whether fish or birds in the watershed exhibit teratogenesis or other indicators of impaired reproductive success (e.g., low egg hatchability), and results are likely to be inconclusive. Because it is often difficult to find evidence of effects except when they are extreme (and they are not expected to be extreme in this watershed), these approaches can have a high probability of type II error (a finding of no effects even though some effects exist). However, finding such effects would greatly reduce uncertainties about the need for action. In addition, fish are so limited by physical habitat restrictions (channel drying, maintenance dredging, lack of habitat, etc.) that population limitations induced by low levels of selenium toxicity are unlikely to be detectable.

4.3.1. Fertility Effects

Fertility has been measured in only a small number of selenium studies. In American kestrels (*Falco sparverius*) fed selenomethionine at 12 mg/kg, egg fertility was significantly reduced (by over 14 percent) compared to kestrels fed 6 mg/kg selenium (Santolo et al. 1999). Lack of reporting on fertility effects may be due in part to a general practice of simply including infertile eggs as inviable eggs in studies of selenium effects in birds (i.e., "infertility" effects may not be separated from "embryotoxic" effects in the overall measurement of hatchability). Failure to measure infertility as a separate endpoint may be due to the difficulty often associated with distinguishing infertile eggs from those containing embryos that have died very early in development. Nevertheless, decreased fertility is a distinct effect from embryotoxicity, particularly in that it indicates a mechanism that acts on adult, rather than embryonic, physiology. Results obtained in kestrels suggest infertility may be a potentially important factor contributing to the overall reproductive impairment in some species. However, in mallards and black-crowned night-herons (*Nycticorax nycticorax*) fed 10 mg/kg as selenomethionine, egg fertility was not reduced compared with controls (Heinz et al. 1987; Smith et al. 1988; Heinz and Hoffman 1996, 1998). Similarly, fertility was not affected in mallards fed diets containing selenium at 7 mg/kg (Stanley et al. 1996) or 16 mg/kg (Heinz et al. 1989) as selenomethionine, but hatchability of fertile eggs was significantly reduced. Thus, effects on egg fertility are not likely to be as ecologically significant as reduced hatchability.

4.3.2. Egg Hatchability/Teratogenesis Effects

Avian reproductive effects are the most pronounced adverse biological effects documented for birds and mammals (Ohlendorf et al. 1990; Skorupa and Ohlendorf 1991; NIWQP 1998). Prior to the 1980s, studies of avian reproductive effects in relation to selenium were conducted with domestic poultry (summarized by Ohlendorf 1989). Studies of wild birds have been conducted in the field and in the laboratory since 1983 to determine the effects of selenium on reproduction and other aspects of avian biology.

Because the embryo is the avian life stage that is most sensitive to selenium, monitoring of eggs is a good approach for determining whether there are impacts on avian species utilizing the Newport Bay watershed. **Table 6** presents egg tissue thresholds for adverse effects to representative avian species. Based on these studies, selenium-related embryo deformities may occur at selenium concentrations in duck eggs exceeding 10 mg Se/kg dw, although the incidence at >10 mg/kg is low but measurably greater than background, with the avocet being the least sensitive of several species tested (**Figure 11**). Egg hatchability was found to be a more sensitive endpoint, with thresholds ranging from 6 to 10 mg/kg dw (Heinz et al. 1987; 1989; Skorupa 1998a), hatchability decreased rapidly at egg concentrations greater than 10 mg/kg dw. Using the results of six studies with mallards, Ohlendorf (2003) determined that egg concentrations of 12.5 mg Se/kg dw resulted in a 10 percent reduction in hatchability.

Reproductive effects of selenium reported in wild aquatic birds and domestic poultry include embryo mortality and teratogenesis, as well as the failure of adult birds to nest. Such effects have been produced in laboratory dietary studies using both organic and inorganic forms of selenium in mallards (Heinz et al. 1987; 1989; Stanley et al. 1994; Heinz and Hoffman 1996; 1996; 1998) and domestic chickens (Gruenwald 1958; Ort and Latshaw 1978). Selenomethionine, the most bioavailable and toxic of the different selenium compounds studied, is associated with reduced reproductive effects in mallards at dietary concentrations as low as 7 mg/kg selenium (Stanley et al. 1996). This form of dietary selenium has been found to be the best surrogate for use in feeding studies to parallel the dose-effect levels found in field studies with birds (NIWQP 1998; Yamamoto et al. 1998).

Bird embryos are known to be sensitive to selenium exposures in the egg, although the sensitivity varies among species. Predictive criteria for avian selenosis were developed through a broad-scale program that collected response data for avian teratogenesis at selenium-impacted and reference aquatic sites in the San Joaquin Valley, California (NIWQP 1998). The largest cumulative sampling effort occurred within the Tulare Basin area in the southern San Joaquin Valley. In the Tulare Basin, evaporative disposal of subsurface irrigation drainage water was accomplished using 25 shallow impoundments. Even though the impoundments were not constructed to attract wildlife and they were devoid of emergent vegetation (i.e., cattails, bulrush, etc.), large populations of nesting waterbirds used the sites. Two of the most abundant waterbirds that nested at the evaporation basins were American avocets and black-necked stilts. Water discharged to the evaporation basins contained from < 1 to > 1,000 µg Se/L; consequently, selenium concentrations in eggs from this region spanned four orders of magnitude (< 1 to > 100 mg Se/kg).

Using Tulare Basin egg selenium data combined with data from several other western sites where elevated selenium was found, a detailed exposure-response relationship was documented (NIWQP 1998; Skorupa 1998a, b). Statistically distinct teratogenesis response functions were delineated for ducks, stilts, and avocets using the Tulare Basin egg data set. The Tulare curves were used to estimate expected frequencies of teratogenesis for ducks, stilts, and avocets using other sites, and the predicted levels were tested against the observed frequencies from the sites. The predicted and observed frequencies of teratogenesis were not significantly different and therefore the data were combined to generate final response curves. Using this data set, Skorupa (1998a) was able to develop species-specific response curves for stilts and avocets and a composite duck curve (using combined data from gadwalls [*Anas strepera*], mallards, pintails [*A. acuta*], and redheads [*Aythya americana*]; **Figure 11**).

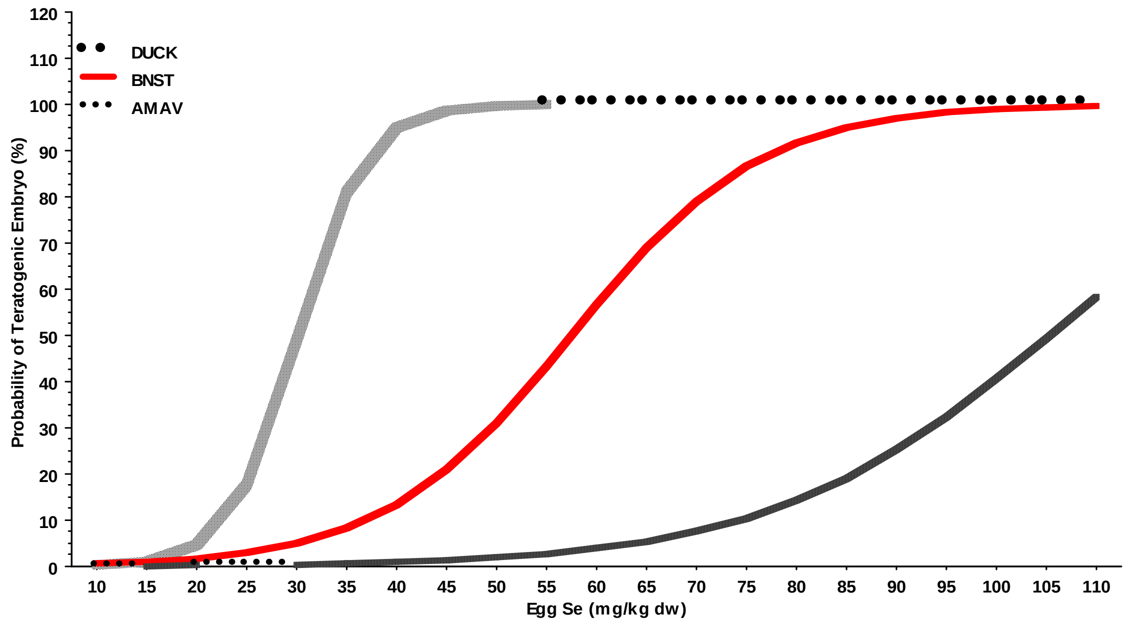
Table 6. Egg Selenium Ranges (mg Se/kg dw) For Ducks, Stilts, and Avocets From NIWQP (1998)

	Mallard		Black-necked Stilt		American Avocet	
Egg Se Range	Observed probability of overt embryo teratogenesis (%)	Observed probability of impaired clutch (%)	Observed probability of overt embryo teratogenesis (%)	Observed probability of impaired clutch (%)[b]	Observed probability of overt embryo teratogenesis (%)	Observed probability of impaired clutch (%)
00–10	0.0[a]	NA	0.4[a]	(0.0-05) 8.7[a]	0.0[a]	13.5[a]
11-20	3.2	NA	1.3	(06-15)18.9	0.0	13.5
21-30	8.7	NA	5.0	(16-30) 26.9	0.0	14.6
31-40	40	NA	5.0	(31-50) 33.7	0.0	14.6
41-60	Insufficient data	NA	24.4	(51-70) 65.4	3.8	11.8

[a] Background rates
[b] Egg selenium range for stilt in parentheses; ranges were defined more precisely for this species.
NA = not available

Based on the response coefficients and their standard errors, the teratogenesis function for ducks, stilts, and avocets were significantly different (Skorupa 1998a). Within that data set, these responses represent "sensitive" (duck), "average" (stilt), and "tolerant" (avocet) species (**Figure 11**). The probability of overt teratogenesis in stilts increases markedly when selenium concentrations are in the range of 41 – 60 mg/kg, with an EC_{10} for teratogenic effects of 37 mg/kg (NIWQP 1998). In contrast, the threshold for teratogenesis (expressed as an EC_{10}) in mallards is 23 mg/kg, and in avocets it is 74 mg/kg.

Figure 11. Probability (as %) of overt teratogenesis in eggs of ducks, black-necked stilts, and American avocets (Data from Skorupa 1998a).



A more sensitive measure of avian selenosis is reduced egg hatchability due to embryo inviability (i.e., mortality) (NIWQP 1998; Skorupa 1998a, Skorupa, 1998 #1477). Egg selenium concentrations that cause embryo mortality are usually below the levels that cause embryo deformities. The threshold for mean egg selenium associated with impaired egg hatchability at the population level for black-necked stilts (and therefore the embryotoxicity threshold) was estimated to be 6 – 7 mg/kg egg selenium. This threshold is approximately equivalent to the EC_{10} on a clutchwise (or henwise) basis, and the EC_{03} on an eggwise basis (Skorupa 1999). Skorupa (1998a) developed a relationship between black-necked stilt egg failures and egg selenium using a database of 409 sample eggs from black-necked stilt nests monitored at Tulare Basin, Kesterson Reservoir, and Salton Sea to identify the background rate of inviable stilt eggs (8.9 percent[1]) and developed the following equation (**Equation 1**) to determine the number of clutches containing at least one inviable embryo where Y is the probability of ≥ 1 inviable egg(s) in a sampled clutch based on egg selenium concentration (X).

[1] Skorupa, J. P. 1998a. Risk Assessment for the Biota Database of the National Irrigation Water Quality Program. National Irrigation Water Quality Program, USDI, Washington, DC. presented 8.9 percent as the background rate for stilt egg inviability but he used 8.7 percent in National Irrigation Water Quality Program (NIWQP). 1998. Guidelines for the Interpretation of Biological Effects of Selected Constituents in Biota, Water, and Sediment. National Irrigation Water Quality Program, Department of the Interior.

Equation 1. Probability of ≥ 1 inviable egg(s) in a sampled clutch.

$$Y = \exp(-2.327 + 0.0503X) / (1 + \exp(-2.327 + 0.0503X));\ r2 = 0.18$$

Actual percentage of hens affected =

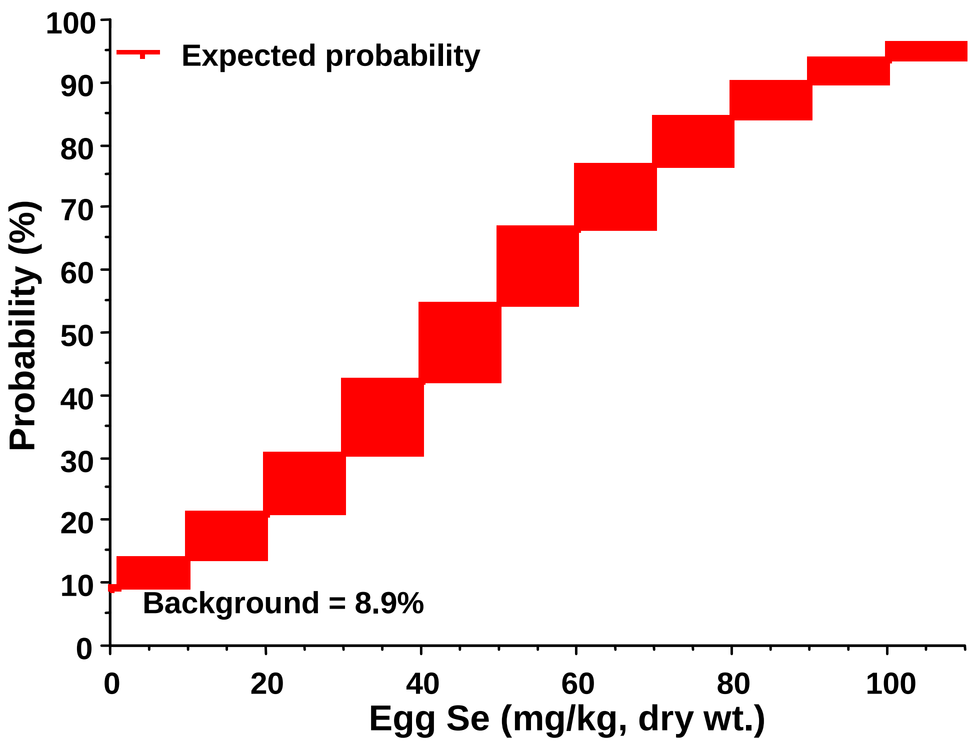
[(1-background%) – (1-raw%)]/(1-background%)

Number of hens affected=

(No. of birds counted/2) × Percentage of hens affected where background % = 8.9%

This relationship is illustrated in **Figure 12:**

Figure 12. Probability (as %) of Inviable Eggs in a Black-necked Stilt Clutch (Data from Skorupa 1998a).

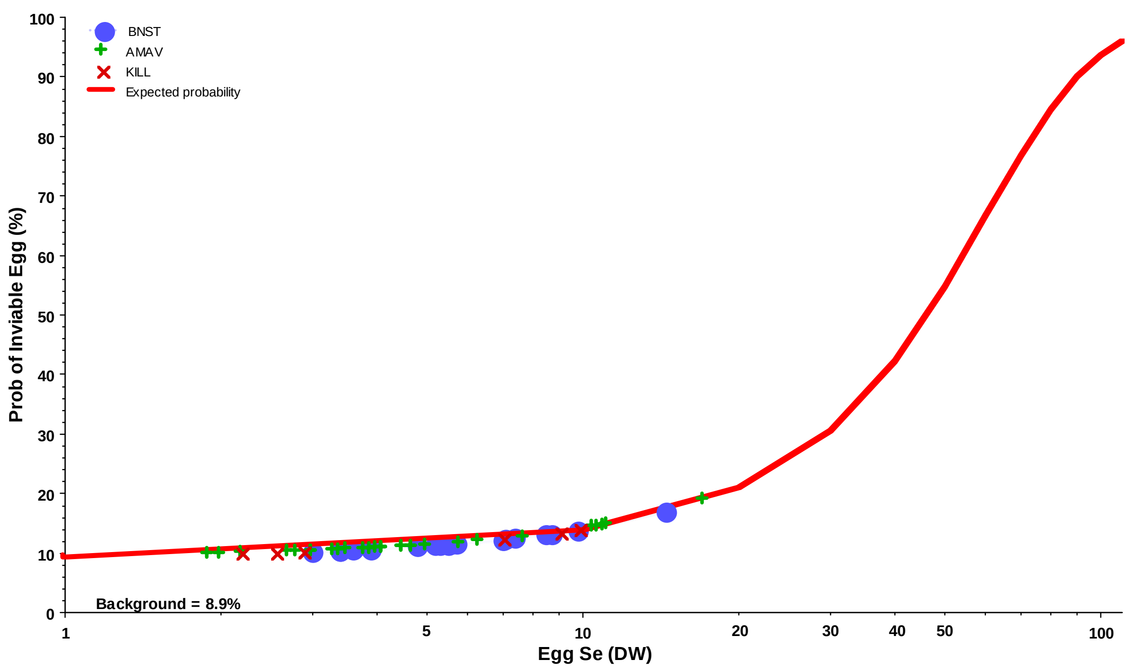


In contrast to the stilt, with a threshold of 6 – 7 mg/kg for effects on egg hatchability, the avocet is much less sensitive, with no effects on hatchability at concentrations below 60 mg/kg. In his review of the available information concerning reproductive effects of selenium in birds, Heinz (1996) suggested 3 mg Se/kg wet weight (equivalent to about 10 mg/kg dw) in avian eggs as a threshold for effects on hatchability. Conclusions concerning egg-selenium threshold levels for effects in waterfowl depend on which data are included in the analyses, how the effects are expressed, and statistical approaches used in the analyses. For example, Fairbrother et al. (1999; 2000) used some of the data available from experimental studies with mallards and concluded that the threshold for reduced hatchability (EC_{10}) is 16 mg/kg in the egg. However, Skorupa (1999) disagreed with this conclusion. Subsequently, both Adams et al. (2003) and Ohlendorf (2003) analyzed data from the available laboratory studies with mallards and estimated the EC_{10} for egg hatchability effects as 13 to 15 mg Se/kg.

Use of the Newport Bay watershed by water-associated birds is limited by a lack of suitable foraging and nesting sites, management activities, and other disturbances. To increase the number of samples for statistical analyses and comparisons for the NSMP, egg-selenium concentrations in killdeer and American avocet (species with similar feeding habits to stilts) eggs were combined with stilt egg concentrations. Inclusion of the killdeer and avocet eggs is intended only to represent likely bioaccumulation of selenium in surrogates for stilts, for which interpretive predictions of effects can be made statistically using the equation from Skorupa (1998b), and does not necessarily imply effects would occur in those species.

Egg selenium concentrations from the Newport Bay watershed are generally below or just above expected effect levels. Six of the 52 shorebird eggs collected in the watershed had selenium concentrations above 10 mg Se/kg dw, and the highest concentration of 17 mg Se/kg dw was found in an American avocet egg from the San Joaquin Marsh (Byard 2003). Based on **Equation 1** for stilts and combining killdeer, stilt, and avocet egg concentrations, the geometric mean selenium concentration in shorebird eggs from the watershed would result in a 2.4 percent (11.1 percent – 8.7 percent background) probability of being inviable due to selenium, and the highest egg-selenium concentration would result in a 10.1 percent (18.8 percent – 8.7 percent background) probability of being inviable due to selenium (**Figure 13**).

Figure 13. Probability of Inviability (%) of Black-necked Stilt (BNST) Eggs, Including Use of American Avocet (AMAV) and Killdeer (KILL) Eggs Collected from the Newport Bay Watershed as Surrogates for Estimation of Selenium Bioaccumulation to Stilt Eggs.



4.4. CONCLUSIONS

The information on bioaccumulation of selenium and the potential toxicity from water and diet concentrations indicate the potential for low-level reproductive toxicity to birds, mostly limited to the middle and lower portions of the creek and wetland ponds. The upper watershed has much lower selenium exposure and extremely limited aquatic habitats where concentrations are elevated, while Newport Bay has a great potential for dilution, dispersion, and sediment burial for the watershed sources of selenium. The piscivorous estuarine birds (e.g., terns, skimmers) nesting in upper Newport Bay are primarily eating surface-dwelling fish, for which selenium concentrations have not been measured.

In contrast to piscivorous estuarine birds, shorebird eggs were sampled from throughout the watershed and are the best indicator of potentially toxic effects to birds, as inferred from egg selenium concentrations. Black-necked stilt, American avocet, and killdeer were examined as the set of representative shorebirds to compare to potential effect levels (as percent inviability of eggs, **Figure 13**). Potential inviability of shorebird eggs in the watershed ranged from 2.4 to 10.1 percent above background. This is a small and essentially unmeasureable difference from background (see **Figure 13**) because of the large numbers of samples that would be required to detect the difference and low probability of being able to obtain that many samples. In addition, there is limited foraging and nesting habitat in the San Diego Creek watershed for shorebirds, which acts to limit the total number of birds exposed.

The potential for direct toxicity to fish in the middle reaches of the watershed (the wetlands and lower creek), perhaps at a level greater than that expected for birds, is reflected in the summary provided by Tables 4 and 5. However, it is unlikely that the fish populations in San Diego Creek are limited by these levels of tissue and dietary selenium (that would most likely be expressed as a reduction in reproductive success). For selenium toxicity to be limiting, the abundance and diversity of fish would be expected to be limited by impaired reproductive success and viability of the populations. Instead, the late summer drying, winter flood scouring, frequent IRWD pond water management, and constant channel maintenance activities of these environments are likely to produce strong physical effects that limit fish populations. The species found in the creek are all introduced, warmwater fish that are relatively strong colonizing species (e.g. carp, sunfish, mosquitofish, catfish). When locally extirpated they can easily recolonize. Without population studies it will not be possible to further support or refute this hypothesis. It seems likely that physical characteristics of the watershed may have a greater effect on populations of both fish and birds than does selenium-induced reproductive impairment of their populations. However, the fish populations are likely to be most affected by physical factors.

The 2006 sampling to fill data gaps and the earlier data as summarized above help to fill in the information required for the conceptual models of selenium sources, fate, transport, and ecological risk for the streams and bay. However, some aspects of the Conceptual Models are better understood than others. Following the 2006 data collection, including samples collected this year but not yet available as of this report, the following major portions of the Conceptual Models are fairly well described as a baseline condition for the watershed and bay:

- Swamp of the Frogs groundwater selenium concentrations and sources
- Permitted discharge loadings of selenium (i.e., groundwater treatment and pumping)
- Lower watershed surface water selenium concentrations and seasonal loads to the bay
- Sediment selenium concentrations throughout the watershed and wetlands
- Tissue selenium concentrations throughout the watershed for algae, aquatic plants, aquatic invertebrates, and fish (but less well known for bird eggs).

Several major components of the models are less well described, and further study will be important to better understand the baseline conditions in the watershed and bay. They include the following:

- Mass loadings and transfer of selenium among all compartments of the model, including seasonally-variable biological sequestration (simple mass balance estimates)
- Newport Bay surface sediment distributions, stratigraphy, and seasonal mass loading of selenium to the sediments
- Selenium loss processes in the watershed and bay (e.g., permanent burial in sediments, volatilization)
- Loadings of selenium to surface waters from diffuse groundwater sources and stormflows
- Selenium loading from individual land use categories (i.e., urban runoff, nurseries, open space)
- Selenium loadings from wet and dry atmospheric deposition to the water surfaces (although considered a minor component of the model)
- Bioaccumulation and mass transfer of selenium within the components of the Newport Bay food web (e.g., the relative importance of the planktonic vs. benthic food webs in regulating selenium accumulation and transfer to fish and birds are not known)
- Exposure areas, area use factors, and dietary exposure for birds nesting in the stream channels, wetlands, and bay.

5. DISCUSSION AND CONCLUSIONS

Conclusions applicable to the three main sections of this report are presented in more detail at the end of each section (Sections 2.4, 3.4, and 4.4). In general, the results from field sampling in 2006 were similar to those from earlier years, but the results for water, sediment, and biota expanded our knowledge of selenium concentrations for some geographic areas that had been poorly characterized. The 2006 results verified the hypothesis that the upper areas of the watershed draining upper Peters Canyon Wash and upper San Diego Creek represent regional background values for selenium concentrations. The pattern for water, sediment, and biota was one of low selenium concentrations upstream of the influence from the historic Swamp of the Frogs (where groundwater discharges to the surface) followed by sharply increased concentrations in surface water and other media downstream of the general area of groundwater influence.

Another major conclusion from the 2006 dataset was the trend seen in **Figure 2**. The primary producers that accumulate selenium from the inorganic environment (e.g., algae) and the animals that graze them (e.g., snails) were significantly lower in tissue concentrations of selenium than were the various invertebrates, amphibians, fish, and birds that feed at higher and more variable trophic levels. However, there was not a progressive increase (i.e., no biomagnification) from one trophic level to the next.

The preliminary data on selenium speciation in water suggest that most of the waterborne exposure in the watershed and bay occurs from oxidized selenium (selenate, $Se\ 6^{+}$) (**Table 2**). Chemically reduced selenium (as selenite, $Se\ 4^{+}$) is primarily limited to wetland ponds where organic-rich sediments facilitate the bacterially-mediated conversion of selenium to reduced (and more bioaccumulative) forms.

Water, sediment, and biota from the Upper Newport Bay watershed show a pattern of discrete selenium sources, watershed transformations, bioaccumulation, food-chain transfers, and eventual settlement, dilution, and losses in the bay. The overall pattern is one of elevated groundwater sources of selenium from the area of the historic Swamp of the Frogs followed by downstream displacement, dilution, and dispersion. Most bioaccumulation appears to be downstream of this mid-watershed source area.

The zone where the sharp increase in surface water selenium concentration occurs does not provide significant ecological habitat. The mid-watershed region of strongest groundwater influence (e.g., from Lane Channel, Como Channel, Warner Channel, etc.) is an area of notably poor aquatic habitat quality. The creek in that area is primarily a linear flood control channel with purposefully-minimized habitats resulting from an artifact of flood control maintenance and channel design.

In contrast, the lower creek, wetland ponds, and the upper bay are areas of sediment accumulation, and provide invertebrate, fish, and bird nesting habitats in areas with intermediate waterborne concentrations of selenium. The correspondence between availability of habitat and somewhat elevated selenium peaks in the lower watershed and, consequently, the greatest levels of bioaccumulated selenium are found in that area

(**Figure 5**). However, the wider-ranging birds (**Figure 7**) do not show the same spatial pattern of bioaccumulation that is evident from their potential food items (**Figure 5).**

The 2006 sampling to fill data gaps and the earlier data as summarized above help to fill in the information required for the conceptual models of selenium sources, fate, transport, and ecological risk for the streams and bay. However, some aspects of the conceptual models are better understood than others, as described in Section 3 and previous reports (e.g., CH2M HILL 2006a, 2006c).

Although elevated selenium concentrations are found in the Newport Bay watershed, lower-than-expected concentrations were observed in bird eggs. Factors that may be responsible for lower egg concentrations include restricted diet and foraging areas, possible lack of a high-selenium prey species, number, and patchiness of areas of high selenium, and limited tendency of the watershed to convert inorganic selenium to selenomethionine or other more bioaccumulative organic forms.

Water speciation studies indicate the presence of only very low concentrations of organic selenium compounds in samples, including those with high concentrations of total selenium. Tissue data also suggest that selenium concentrations in bird eggs appear to be lower than might be expected based on the concentrations of total selenium in the water, particularly in certain locations in the watershed.

Dr. Coombs (NWRI 2006) proposed a possible scenario for lower-than-expected selenium concentrations in bird eggs. The research literature on selenium metabolism documents that plants (and bacteria) can produce organic selenium compounds biologically from both selenate and selenite. Tissue selenium concentrations in animals, however, (including at-risk species in the watershed) consist almost exclusively of selenium incorporated non-specifically into proteins as the selenoamino acid selenomethionine (SeMet); because the total protein-methionine pool of the body greatly exceeds the amounts of selenium consumed, this pool is virtually non-saturable. It is also known that SeMet is synthesized only by plants and microorganisms. Thus, the tendency of birds feeding in the watershed to accumulate selenium in tissues is directly related to their consumption of SeMet ultimately from plant and/or microbial sources. The absence of this pathway in the Newport Bay watershed, as a result of either unfavorable growth conditions or the absence of key plant and bacteria species, might explain the relatively low bioconcentration of selenium observed.

This has a number of implications that may apply to the current conditions in Newport Bay watershed:

- The absence of organic selenium compounds in water samples indicates the absence of significant contamination from microbial or plant sources capable of converting selenate/selenite to SeMet.
- The absence of significant amounts of SeMet in the food chain would indicate limited capacity for selenium accumulation in the tissues of animals feeding in the Newport Bay watershed. This is consistent with reported observations of relatively low selenium in bird eggs.

- The Newport Bay watershed may differ from others in which selenium toxicity problems have occurred in terms of the relative absence of species intermediate in the foodweb that can convert selenate/selenite to SeMet and/or accumulate significant amounts of SeMet.

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