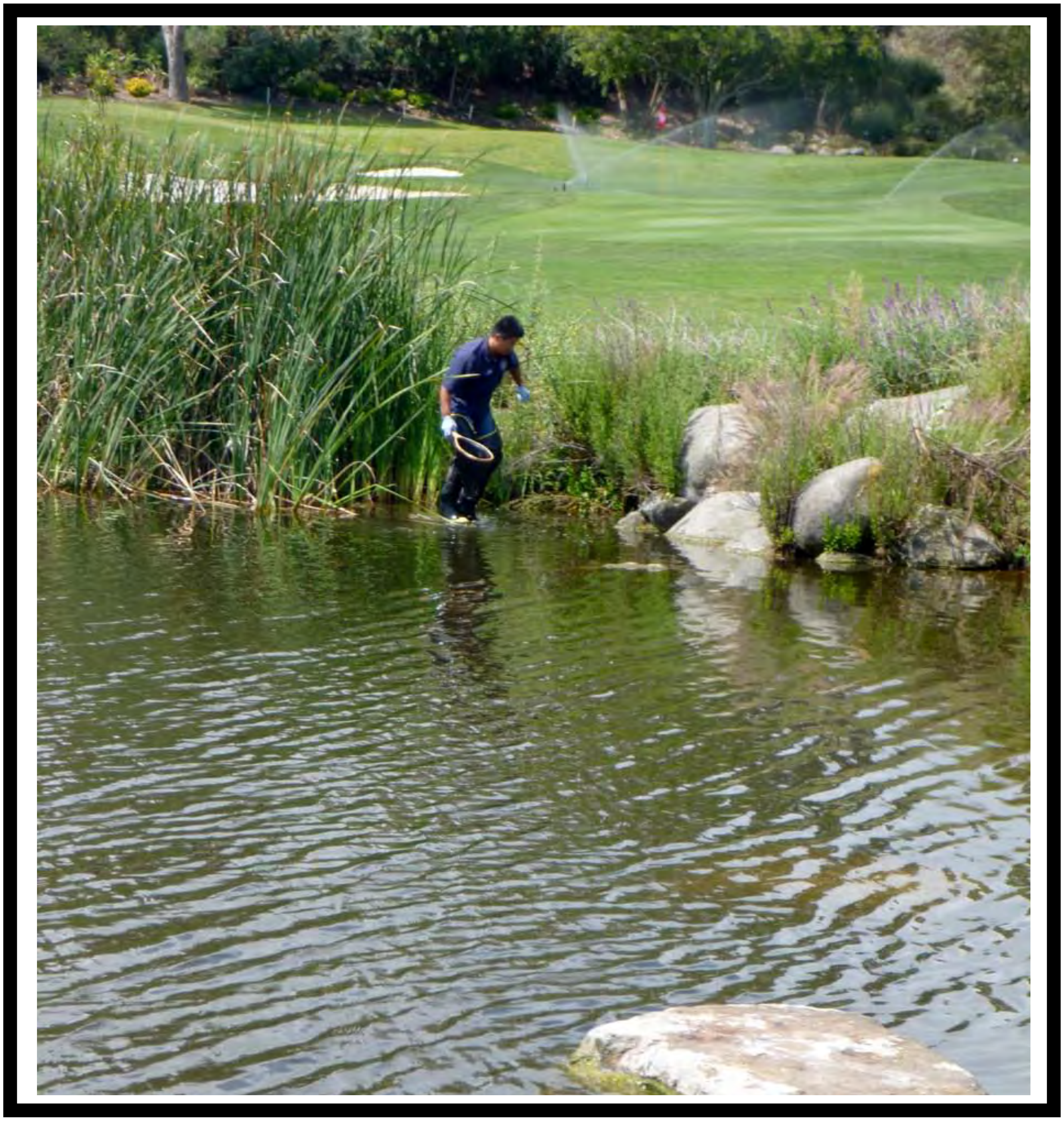
Geology, Hydrology, and Water Quality with a Focus on Selenium Sources and Potential Impacts, Big Canyon Wash Watershed, Newport Beach, California



FINAL REPORT
August 17, 2011

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Santa Ana Regional Water Quality Control Board

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NOTE: This report summarizes and expands on investigations and monitoring conducted over the past 40 years in the Big Canyon Wash watershed by JM Montgomery (1975-1977; 1987), Orange County (1970-2009), Weston Solutions, Inc. (2005-2007), CH2M Hill (2008-2010), and others.

Executive Summary

Big Canyon Wash (BCW) is a small, perennial tributary to Upper Newport Bay (UNB) located in the central portion of coastal Orange County. BCW creek drains a watershed of approximately 2 square miles. The majority of the watershed (approximately 96%) is highly developed with homes, commercial areas, a golf course, cemetery, sports parks, and other urban features. The original drainage patterns in the BCW watershed have been highly modified by development. Groundwater and surface water flow paths are highly influenced by an extensive system of storm drains and channels, which daylight into surface drainages throughout the watershed. BCW creek is composed of three main tributaries: a south branch, a middle branch, and a north branch which is less well defined.

BCW watershed has been divided into three subareas by Regional Board staff based primarily on differences in land use characteristics: BCW Upper, BCW Middle, and BCW Lower. The upper portion of the BCW watershed extends from the drainage divide located west of the San Joaquin Reservoir eastward to MacArthur Boulevard. BCW Upper is contains the 23-acre Big Canyon Reservoir (BCR) and numerous residential developments. The middle portion of the BCW watershed is composed primarily of the Big Canyon Country Club (BCCC). BCW Middle extends from MacArthur Boulevard on the east to Jamboree Road on the west. The lower portion of BCW watershed is dominated by a relatively undeveloped, open space area that forms the Big Canyon Nature Park (BCNP). BCW Lower extends westward from Jamboree Road to the mouth of BCW creek where it discharges into UNB.

Since the mid-1970s, moderate selenium concentrations have been periodically recorded near the mouth of BCW creek where it enters UNB. Selenium is a bioaccumulative compound that has been associated with reproductive impairment in fish and birds. In May 2000, the U.S. Environmental Protection Agency (USEPA) promulgated the California Toxics Rule (CTR), which included water quality objectives for selenium in both fresh and salt water. Selenium concentrations measured in surface waters in the BCW watershed have consistently exceeded the CTR chronic criterion for selenium in freshwater of 5 micrograms per liter (µg/L). Selenium concentrations in sediment and biota collected from the BCW watershed also exceed recommended guidelines for reproductive effects in fish and birds. In 2002, USEPA promulgated Total Maximum Daily Loads (TMDLs) for toxic pollutants (including selenium) for the San Diego Creek and Newport Bay watersheds. The BCW watershed was not explicitly referenced in USEPA's selenium TMDLs, but it is part of the Newport Bay watershed.

The suspected source of the selenium is the underlying Miocene Monterey Formation. The Monterey Formation forms much of the white bluffs visible along the lower northern edge of BCW and extends up through almost the entire length of the watershed. This marine formation is commonly enriched in numerous trace elements that are potentially hazardous to aquatic life, human health, and the environment. These trace elements include chromium, copper, nickel, antimony, selenium, uranium, vanadium, zinc, arsenic, barium, cadmium, and molybdenum.

The changes in canyon hydrology and areas tributary to the BCW watershed as the watershed has urbanized have likely contributed to the mobilization of selenium from the underlying Monterey Formation. Prior to development and urbanization of the BCW watershed, BCW creek functioned as an ephemeral stream, flowing only during and for a short period after, the rainy season. Surface waters now flow year round in BCW creek supporting a variety of beneficial uses including open water (pond), marsh, and riparian habitats that support fish and birds.

The purpose of this report is to summarize the information collected in the BCW watershed over the last 40 years on its geology, hydrogeology, hydrology and water quality, with a focus on selenium. The report includes the findings of the investigation conducted by Regional Board staff and others on June 21, 2010 on selenium cycling and concentrations in different media from several water bodies located in the central and upper portions of the watershed (BCW Middle and BCW Upper).

Review of the information collected to date confirms that leakage from the BCR is the primary source of water to the south or main branch of BCW creek. The middle branch of the creek contains very low selenium concentrations (less than or just above 5 µg/L); additional studies are needed to determine the source of this water and why it is low in selenium. The northern branch of the creek is only expressed on the BCCC golf course. While this branch of BCW creek has relatively high selenium concentrations (>60 µg/L), it contains the lowest flows.

The water, sediment, and biological data collected in the BCW watershed indicate that selenium concentrations in surface waters pose a potential risk to fish and wildlife throughout the watershed, especially in areas where water is ponded and residence times for particulates and organisms are relatively long. Because there is a significant lack of hydrologic data for the BCW watershed, pollutant load estimates and other flow-dependent data can only be considered as preliminary estimates for qualitative purposes. In order to better estimate pollutant loadings and the relative contributions to surface flows from different sources of water, more accurate and seasonal measurements of flows in the BCW watershed are needed. Recommendations for water quality monitoring, future investigations to fill data gaps, and to develop a selenium mitigation and management plan for the BCW watershed are included in this report.

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List of Photographs Taken During the June 21, 2010 Sampling[1]

List of Charts[2]

[1] There are no field photographs for the other sections in this report.
[2] There are no charts for the other sections in this report.

Appendices[3]

[3] There are no appendices for Sections 1.0, 2.0, 5.0, 6.0, or 7.0.

List of Acronyms and Abbreviations

General Acronyms and Abbreviations

ASC	Applied Speciation and Consulting LLC
BCCC	Big Canyon Country Club
BCGC	Big Canyon Country Club Golf Course
BCNP	Big Canyon Creek Nature Park
BCR	Big Canyon Reservoir
BCW	Big Canyon Wash
CH2M Hill	CH2M Hill, Incorporated
CSULA	California State University, Los Angeles
CSULB	California State University, Long Beach
CTR	California Toxics Rule
DFG	California Department of Fish and Game
ESB	Edward S. Babcock & Sons, Inc. Environmental Laboratories
ESRI	Environmental Systems Research Institute
GIS	Geographic Information System
GPS	Global Positioning System
HOA	Home Owners Association
HVNP	Harbor View Nature Park
IIRMES	Institute for Integrated Research in Materials, Environments, and Society California State University, Long Beach
JMM	James M. Montgomery Consulting Engineers
MS	Matrix Spike
MSD	Matrix Spike Duplicate
MTRL	Maximum Tissue Residue Level
NOAA	National Oceanic and Atmospheric Administration
OCPW	Orange County Public Works
PBGR	Pied-billed Grebe
PEL	Probable Effect Level
pH	potential of Hydrogen (a measure of the acidity or alkalinity of a solution)
PIEZ	Piezometer (small diameter well used to measure groundwater elevations)
RPD	Relative Percent Difference
SAP	Sampling and Analysis Plan
SARWQCB	Santa Ana Regional Water Quality Control Board
SCWRP	Southern California Wetlands Recovery Project
SCCWRP	Southern California Coastal Water Research Project
SD	Storm drain/ subdrain
SDC	San Diego Creek
SMW	California State Mussel Watch program
SSO	Site-Specific Objective (a water quality criterion that is based on site-specific data)
SWAMP	Surface Water Ambient Monitoring Program

SWRCB	California State Water Resources Control Board
TEL	Threshold Effect Level
™	Trade Mark
TMDL	Total Maximum Daily Loads
UNB	Upper Newport Bay
URS	URS Corporation
USDOI	U.S. Department of the Interior
USGS	U.S. Geological Survey
Chemical Element Abbreviation/Formula and Names	
Ca	Calcium
Cd	Cadmium
Cl	Chloride
CO_3	carbonate
Cu	Copper
HCO_3	bicarbonate
K	Potassium
Mg	Magnesium
Na	Sodium
Ni	Nickel
Pb	Lead
Se	Selenium
Se IV	selenite (Se^{-4})
Se VI	selenate (Se^{-6})
SO_4	sulfate
TDS	Total Dissolved Solids
Zn	Zinc
Units of Measure	
Ac	Acre
AF	Acre-feet
cfs	Cubic feet per second
cm/s	Centimeter per second (unit of permeability)
dw	Dry weight
gpd	Gallons per day
gpd/ft	Gallon per day per foot (unit of transmissivity)
gpd/ft^2	Gallon per day per square foot (unit of hydraulic conductivity)
gpm	Gallons per minute
K_d	Partitioning Coefficient
lbs/yr	Pounds per year
mi	Mile
mi^2	Square mile
ppb	Parts per billion
ppm	Parts per million
Q	Groundwater flow rate

K	Hydraulic conductivity of an aquifer
i	Groundwater gradient
A	Cross-sectional area of the saturated aquifer
µg/L	Micrograms per liter (equivalent to ppb)
µg/g	Migrograms per gram (equivalent to ppm)

1.0 Introduction and Background

Big Canyon Wash (BCW) is a small, perennial tributary to Upper Newport Bay (UNB) located in the central portion of coastal Orange County (Figure 1-1). BCW creek drains a watershed of approximately 2 square miles (Figure 1-2). The majority of the watershed (approximately 96%) is highly developed with homes, commercial areas, a golf course, cemetery, sports parks, and other urban features (Figure 1-3). The lowermost portion of the watershed, where the creek enters UNB, consists primarily of open space and is minimally developed, except for the canyon bluff areas.

Selenium concentrations measured in surface waters in the BCW watershed (Table 1-1) have consistently exceeded the California Toxics Rule (CTR) chronic criterion for selenium in freshwater of 5 micrograms per liter (µg/L). Selenium concentrations in sediment and biota exceed recommended guidelines for reproductive effects in fish and birds (Tables 1-2 and 1-3). The suspected source of the selenium is the Miocene Monterey Formation, which underlies much of the watershed and forms the pale, steep bluffs that rim the canyon (Figure 1-4). The Monterey Formation is a known source of selenium and metals in California. Some selenium may have also accumulated over time in aquatic sediments, especially in the lakes, ponds, and marshes located in the watershed, either from rising groundwater and/or surface water runoff from surrounding upland areas.

The changes in canyon hydrology and areas tributary to the BCW watershed as the watershed has developed have likely contributed to the mobilization of selenium from the underlying geologic formations. Urban and commercial landscape irrigation, the construction of an 18-hole golf course in the canyon east of Jamboree Road (Big Canyon Country Club, BCCC), a drinking water reservoir (Big Canyon Reservoir, BCR), a large irrigated cemetery facility (Pacific View Memorial Park and Mortuary, PVMP) (Figure 1-3), as well as storm drain and passive subdrain systems that discharge to the canyon, have changed the canyon's flow regime from ephemeral to perennial over the last 50 years. This has resulted in significant changes in habitat and hydrology and has likely contributed to the high selenium concentrations that have been found in the soils and water in the canyon as water from numerous urban sources infiltrates selenium bearing rocks in the subsurface mobilizing selenium into groundwater and surface waters.

Several investigations have been conducted the BCW watershed to determine the extent and ecological effects of selenium and the sources of water that are mobilizing selenium into groundwater and surface waters in the watershed. The purpose of this report is to summarize the information collected in the BCW watershed by others (Orange County, James M. Montgomery, Inc., URS Corporation, Weston Solutions, Inc., CH2M Hill) and for the first time, to report on the findings of the investigation conducted by Regional Board staff and others in June 2010 that included the collection of biota from water bodies on the BCCC golf course, and a small nature park located in the south branch of BCW creek just upstream of the golf course (Harbor View Nature Park, HVNP), as well as the collection and analysis of groundwater samples collected from the vicinity of BCR, also located in the southern, main branch of BCW creek. This report also includes recommendations for future investigations of selenium sources, cycling, and potential impacts in the BCW watershed.

1.1 Big Canyon Wash Watershed Morphology and Geographic Areas of Interest

BCW creek begins at the foot of the western slope of the San Joaquin Hills and extends from the drainage divide in the foothills in the Corona del Mar area westward approximately 2 to 2 ½ miles to UNB (Figure 1-5). BCW creek is composed of three main tributaries: a north branch, a middle branch, and a south branch (Figure 1-5). The south branch extends from BCR at its eastern end, west through the HVNP, before flowing into the BCCC golf course. The middle branch extends from the base of Spyglass Hill into the BCCC golf course, where it is diverted underground before its flows join the south branch just east of the BCCC clubhouse. The north branch, which is less well defined than the south and middle branches of the creek, consists primarily of flow from residential storm drains and the Bonita Canyon Sports Park. This branch of the creek is not expressed east of the golf course. It begins as discharge from a storm drain system, which daylights at the northeastern end of the BCCC golf course. The flows are directed along the northern edge of the BCCC golf course before they eventually join the rest of the creek where it exits the golf course at its western end, just east of Jamboree Road. Residential storm drains from the homes located in and adjacent to the BCCC golf course also add additional flows to BCW creek as it flows through the golf course. The conjoined flows then exit the golf course passing through a large culvert under Jamboree Road directly into the Big Canyon Nature Park (BCNP) before flowing west through the park to UNB.

Because different land uses characterize different portions of the watershed, and for ease of discussion, the BCW watershed has been divided into three subareas by Regional Board staff: BCW Upper, BCW Middle, and BCW Lower.

1.1.1 BCW Upper

The upper portion of the BCW watershed extends from MacArthur Boulevard eastward to the drainage divide located west of the San Joaquin Reservoir (Figure 1-6). BCW Upper includes the Yacht and Port Streets areas, the HVNP, the BCR and the PVMP (located along the southern boundary), and portions of the Bonita Canyon Sports Park (BCSP), which is located along the northern boundary of the watershed (Figure 1-7). The central portion of the watershed extends eastward to Spyglass Hill.

1.1.2 BCW Middle

The middle portion of the BCW watershed is composed primarily of the Big Canyon Creek Country Club (BCCC), which is a development built in the early 1970s that consists of an 18 hole golf course and clubhouse located in the canyon bottom with homes on the canyon cliffs overlooking the golf course (Figure 1-8). The middle portion of BCW extends from Jamboree Road on the west, to MacArthur Boulevard on the east. Residential and commercial developments located south and north of the golf course also drain into the BCCC. BCW creek enters the golf course in three main branches, but exits the golf course as a single drainage just east of Jamboree Road.

1.1.3 BCW Lower

The lowermost portion of BCW extends from Jamboree Road to the mouth of BCW creek where it discharges to UNB (Figure 1-9). The lower portion of BCW watershed is dominated by a relatively undeveloped, open space area that forms the BCNP. There is a small freshwater marsh and pond located in the main channel of BCW creek at its western end, just east of Back Bay Drive (Figure 1-10). The freshwater pond and marsh were created in 1981 as mitigation for a gravity-flow sewer line and access road installed in BCW (NBNF, 2010). The approximately 11 acres of freshwater pond, marsh, and riparian areas located at the western end of the creek were once tidelands. The tidelands were filled with dredge materials from the bay during the 1960's (NBNF, 2010). This acreage is now part of the Upper Newport Bay Ecological Reserve (UNBER), which is managed by the California Department of Fish and Game (DFG). The adjoining 54-acres of the BCNP are owned by the City of Newport Beach. For the purposes of this report, the undeveloped portions of BCW Lower, which include the DFG-owned 11-acre ecological area at its western end and the 54-acres city-owned nature park are referred to jointly as the BCNP. The BCNP has been identified by the Southern California Wetlands Recovery Project as an important resource that is in need of restoration. Privately owned residential areas line the bluffs above the canyon. The Corona del Mar high school and The Bluffs Home Owners' Association (HOA) are located on the north side of the nature park (Figure 1-9). The high school and the eastern half of The Bluffs HOA are included in the BCW Lower drainage subarea.

1.2 History of Selenium Monitoring in the Big Canyon Wash Watershed

Since the mid-1970s, as part of the storm water quality monitoring program for Orange County, moderate selenium concentrations have been periodically recorded near the mouth of BCW creek where it enters UNB (Table 1-1). Selenium is a bioaccumulative compound that has been associated with reproductive impairment in fish and birds. In May 2000, the U.S. Environmental Protection Agency (USEPA) promulgated the California Toxics Rule (CTR), which included water quality objectives for selenium in both fresh and salt water. In 2002, USEPA promulgated Total Maximum Daily Loads (TMDLs) for toxic pollutants (including selenium) for the San Diego Creek and Newport Bay watersheds[1]. Though the BCW watershed was not mentioned in USEPA's selenium TMDLs, the selenium TMDLs are applicable to surface waters in the watershed because BCW creek is tributary to UNB, which was included in USEPA's selenium TMDLs.

In 1987, water quality monitoring for selenium in the BCW watershed was discontinued. In 2005, Orange County resumed monitoring of BCW creek as part of the bioassessment portion of their storm water monitoring program. Beginning in 2006, Weston Solutions, Inc. was contracted to conduct a water quality assessment of the surface waters in the BCNP as part of the restoration planning efforts for the nature

[1] Orange County has since combined the San Diego Creek and Newport Bay watersheds into one watershed simply called the Newport Bay watershed. The Newport Bay watershed includes San Diego Creek, the Santa Ana Delhi Channel, Big Canyon Wash, and other small channels tributary to Newport Bay.

park. Water column samples collected from BCW Lower were found to contain concentrations of selenium that consistently exceeded the CTR chronic criterion for selenium in freshwater of 5 µg/L. In 2008, the Santa Ana Regional Water Quality Control Board (SARWQCB) and the City of Newport Beach funded a study to conduct baseline monitoring in the BCNP to determine if selenium concentrations were bioaccumulating and posing an ecological risk to aquatic life and aquatic-depended wildlife in the BCW watershed. Selenium concentrations in sediment, algae, macroinvertebrates, and fish (nesting birds were not found at that time) exceeded published guidelines for substantial ecological risk (Presser et al., 2004; see Table 1-2).

Since then, several additional investigations have been conducted in the BCW watershed to try and understand the potential sources of selenium and the extent of selenium concentrations in surface waters, sediment, and biota in the watershed. This report summarizes the results of monitoring conducted CH2M Hill in 2008, 2009, and 2010, and monitoring and investigations conducted by Regional Board staff and others in 2010 in the BCW watershed. This report also summarizes earlier water quality information collected in BCW by Weston Solutions in 2006 and 2007, and geologic and hydrologic data collected and/or summarized as part of studies conducted in and around BCR (James M. Montgomery, Inc., 1977 and 1985; URS 2000).

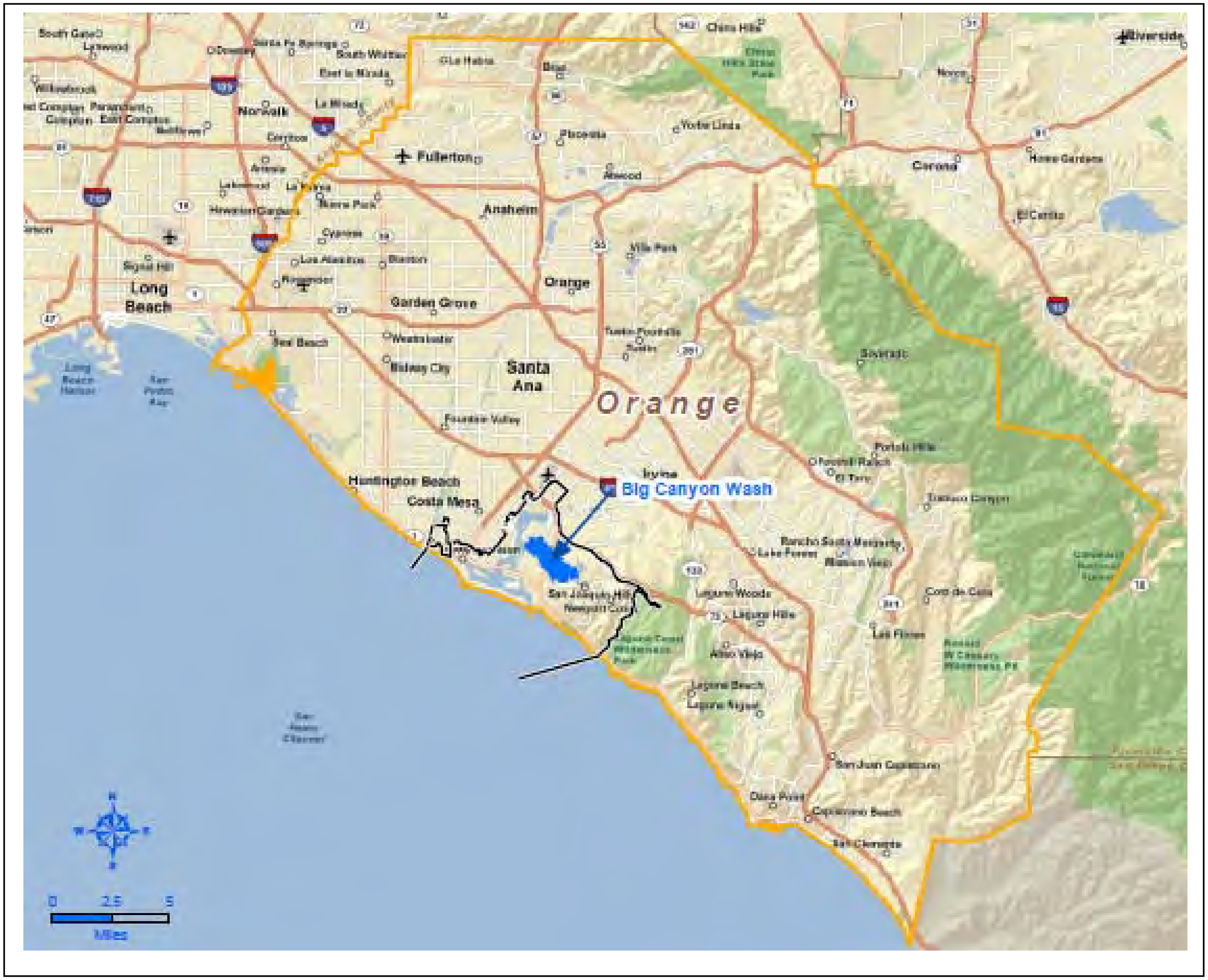

Figure 1-1. Map showing location of Big Canyon Wash watershed. Big Canyon Wash is tributary to Upper Newport Bay and is located in central coastal Orange County, California. (Figure courtesy of the City of Newport Beach).

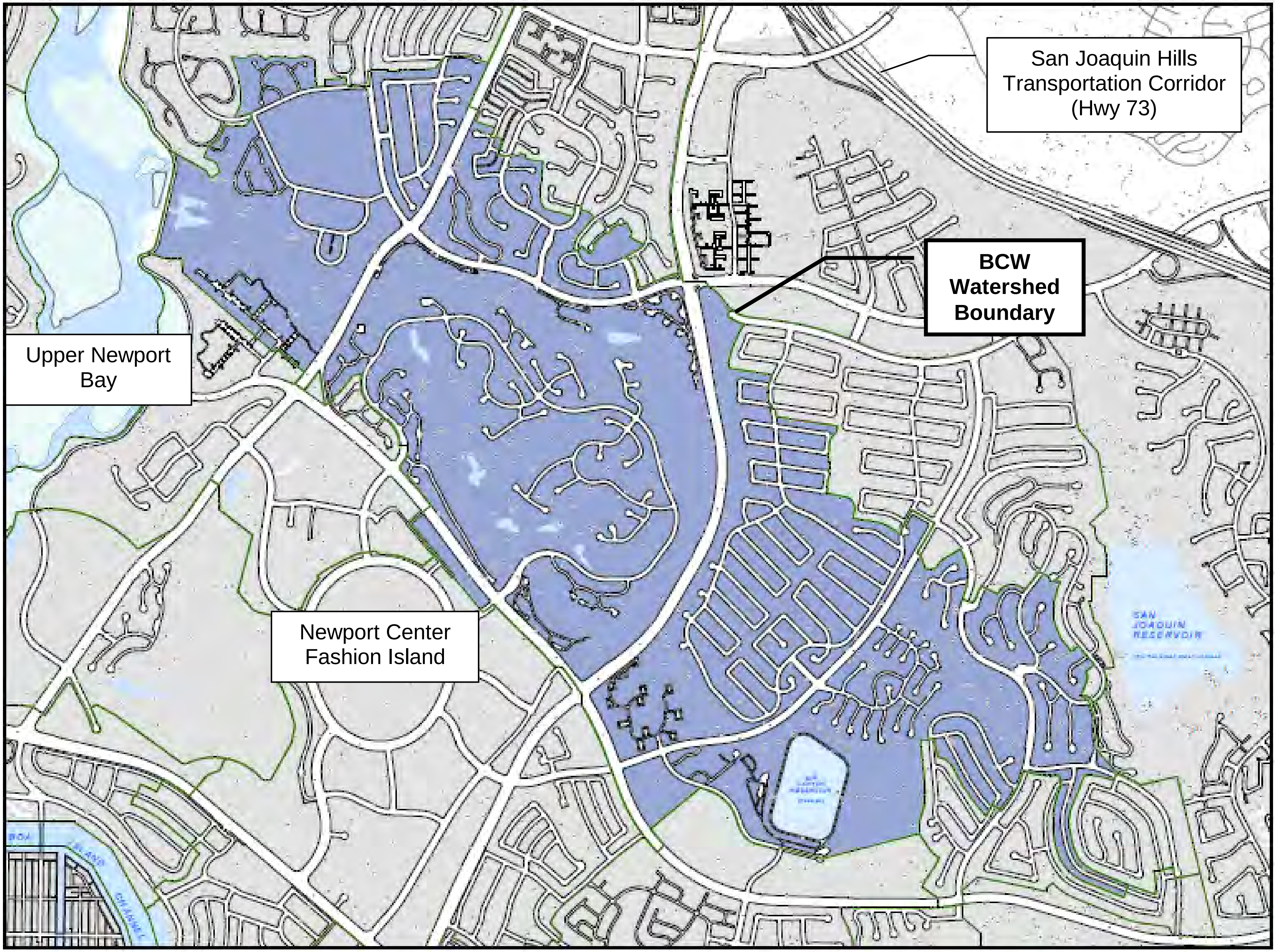

Figure 1-2. Big Canyon Wash drainage area.

Figure 1-3. Geographic areas and features of the Big Canyon Wash watershed and vicinity.

Figure 1-4. Photograph of the bluffs that form the northern edge of Big Canyon Wash. Bluffs along the northern and southern boundaries of BCW are primarily composed of the Miocene Monterey Formation. View is towards the northeast.

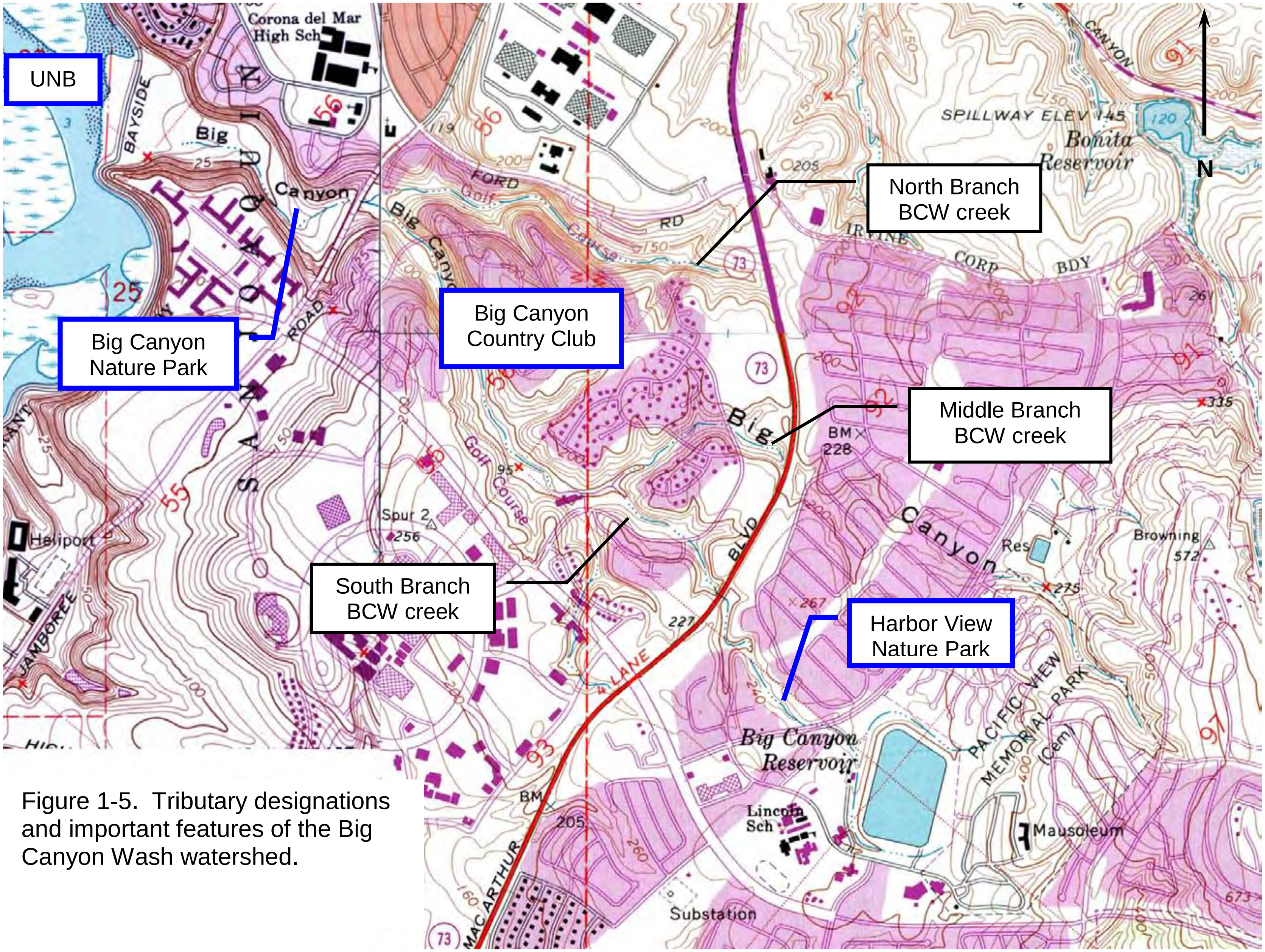

Figure 1-5. Tributary designations and important features of the Big Canyon Wash watershed.

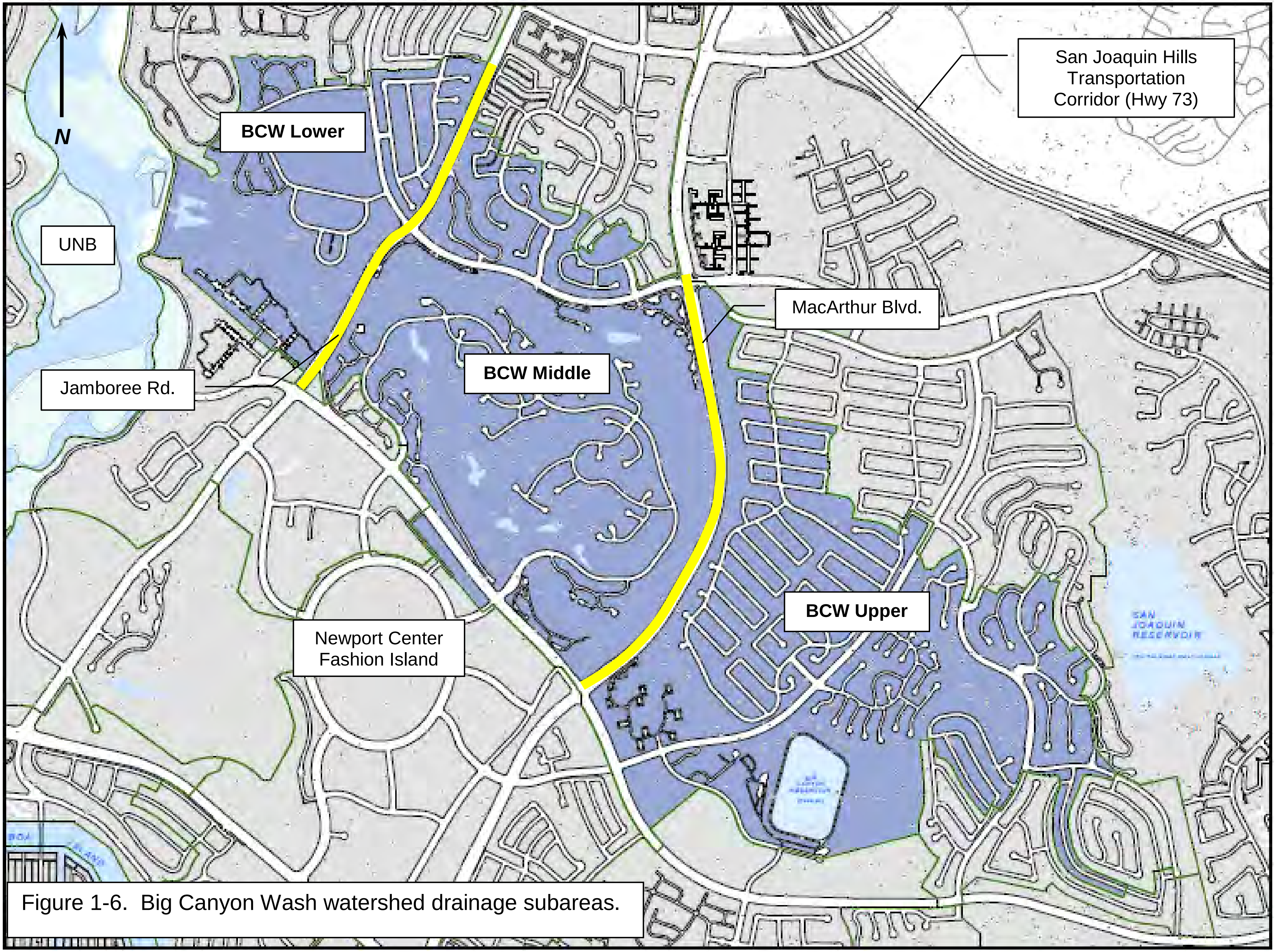

Figure 1-6. Big Canyon Wash watershed drainage subareas.

Figure 1-7. Upper portion of Big Canyon Wash watershed (BCW Upper) with important features noted as follows:

1. Big Canyon Reservoir
2. Pacific View Memorial Park and Mortuary
3. Spy Glass Hill Reservoir
4. Yacht Streets Area (former Broadmoor Tract)
5. Port Streets Area (former Bren Tract)
6. Harbor View Nature Park

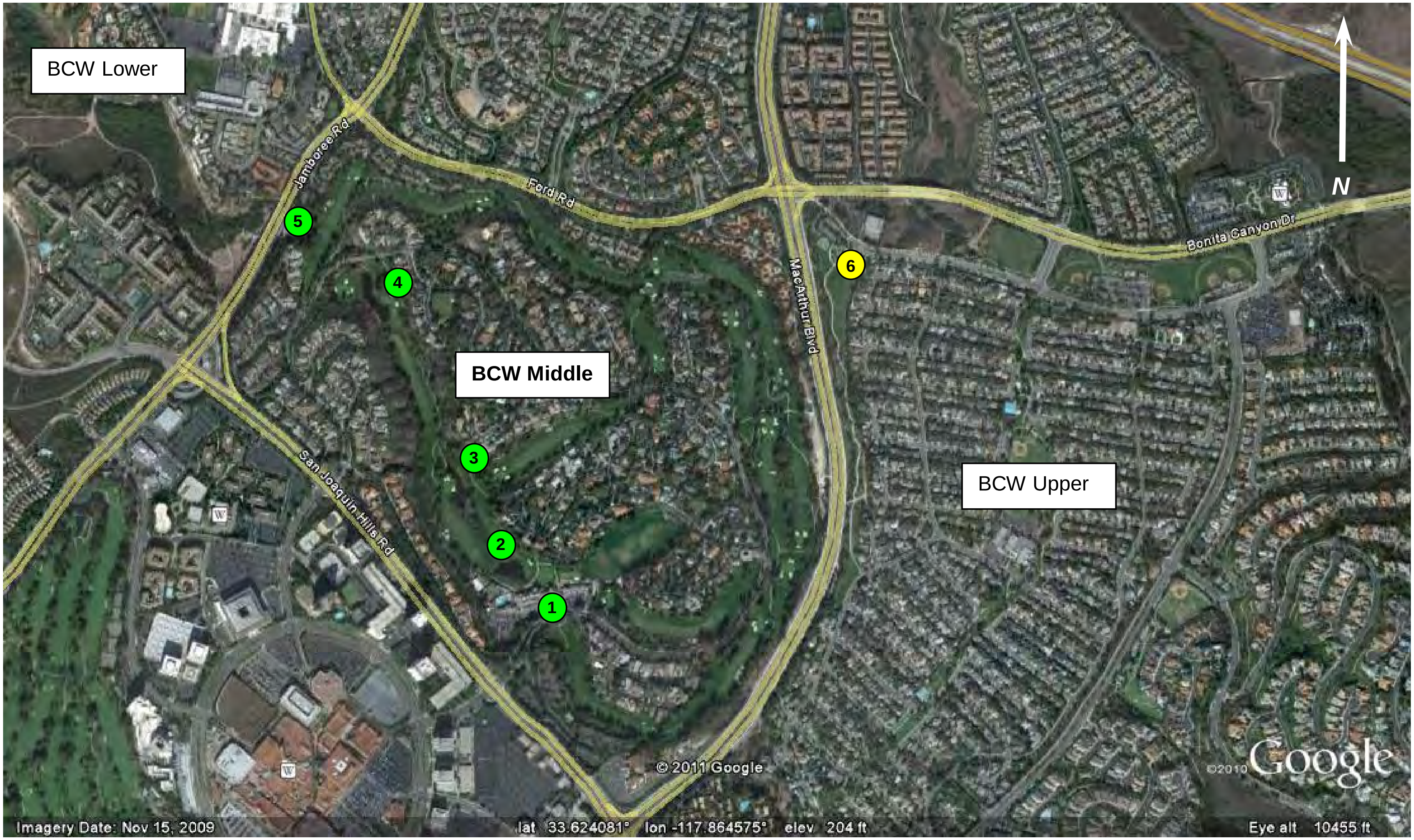

Figure 1-8. Middle portion of Big Canyon Wash watershed (BCW Middle) with important features noted as follows:

1. Big Canyon Country Club (BCCC) Golf Course
2. BCCC Lake 3
3. BCCC Lake 4
4. BCCC Lake 5
5. BCCC Maintenance and BCW creek outlet
6. Bonita Canyon Sports Park (BCW Upper)

Figure 1-9. Lower portion of Big Canyon Wash watershed (BCW Lower) with important features noted as follows:

1. Big Canyon Nature Park (BCNP)
2. BCW creek inflow into BCNP
3. BCNP marsh pond (restoration area)
4. BCNP main channel outlet to UNB
5. BCNP north channel outlet to UNB
6. Corona del Mar High School
7. The Bluffs Home Owners' Association (HOA)

Table 1-1. Selenium (Se) concentrations measured in surface water in Big Canyon Creek under dry and wet weather conditions.

Watershed	Location Desciption	Location ID	Collection Date	Source	Matrix[2]	Se µg/L
Big Canyon Wash	BCW Lower east of Back Bay Drive	BCWG04	06-May-80	Orange County	Surface water[3]	6
Big Canyon Wash	BCW Lower east of Back Bay Drive	BCWG04	06-Oct-80	Orange County	Surface water[3]	3
Big Canyon Wash	BCW Lower east of Back Bay Drive	BCWG04	11-May-81	Orange County	Surface water[3]	21
Big Canyon Wash	BCW Lower east of Back Bay Drive	BCWG04	07-Jun-82	Orange County	Surface water[3]	20
Big Canyon Wash	BCW Lower east of Back Bay Drive	BCWG04	16-Nov-82	Orange County	Surface water[3]	14
Big Canyon Wash	BCW Lower east of Back Bay Drive	BCWG04	01-Nov-83	Orange County	Surface water[3]	15
Big Canyon Wash	BCW Lower east of Back Bay Drive	BCWG04	08-May-84	Orange County	Surface water[3]	34
Big Canyon Wash	BCW Lower east of Back Bay Drive	BCWG04	13-May-87	Orange County	Surface water[3]	30
Big Canyon Wash	BCW Middle, Inflow #2, west of MacArthur Blvd.[1]	BCW sta#1	10-Aug-04	WRC Consulting	Surface water	<60
Big Canyon Wash	BCW Lower west of Jamboree Rd.	BCW sta #2	10-Aug-04	WRC Consulting	Surface water	<60
Big Canyon Wash	BCW Lower above marsh pond	BCW sta #3	10-Aug-04	WRC Consulting	Surface water	<60
Big Canyon Wash	BCW Lower east of Back Bay Drive	BCW sta #4	10-Aug-04	WRC Consulting	Surface water	<60
Big Canyon Wash	BCW Middle, Inflow #2, west of MacArthur Blvd.[1]	BCW sta#1	20-Oct-04	Weston Solutions	Storm water	14.7
Big Canyon Wash	BCW Lower west of Jamboree Rd.	BCW sta #2	20-Oct-04	Weston Solutions	Storm water	17.6
Big Canyon Wash	BCW Lower above marsh pond	BCW sta #3	20-Oct-04	Weston Solutions	Storm water	24.1
Big Canyon Wash	BCW Lower east of Back Bay Drive	BCW sta #4	20-Oct-04	Weston Solutions	Storm water	<2
Big Canyon Wash	BCW Lower east of Back Bay Drive	BCWG04	27-Oct-05	Orange County	Surface water	20
Big Canyon Wash	BCW Lower east of Back Bay Drive	BCWG04	12-Jul-06	Orange County	Surface water	26
Big Canyon Wash	BCW Lower east of Back Bay Drive	BCWG04	04-Oct-06	Orange County	Surface water	37
Big Canyon Wash	BCW Lower east of Back Bay Drive	BCWG04	07-Jun-07	Orange County	Surface water	31
Big Canyon Wash	BCW Lower east of Back Bay Drive	BCWG04	06-Nov-07	Orange County	Surface water	28
Big Canyon Wash	BCW Lower east of Back Bay Drive	BCWG04	21-May-08	Orange County	Surface water	25
Big Canyon Wash	BCW Lower east of Back Bay Drive	BCW sta #4	20-Apr-07	Weston Solutions	Storm water	23.6
Big Canyon Wash	BCW Lower east of Back Bay Drive	BCW sta #4	20-Apr-07	Weston Solutions	Storm water	24.9
Big Canyon Wash	BCW Lower east of Back Bay Drive	BCW sta #4	20-Apr-07	Weston Solutions	Storm water	31.3
Big Canyon Wash	BCW Lower east of Back Bay Drive	BCW sta #4	20-Apr-07	Weston Solutions	Storm water	25.3
Big Canyon Wash	BCW Lower west of Jamboree Rd.	BCW sta #2	20-Apr-07	Weston Solutions	Storm water	18.8
Big Canyon Wash	BCW Lower west of Jamboree Rd.	BCW sta #2	29-May-07	Weston Solutions	Surface water	23.2
Big Canyon Wash	BCW Lower east of Back Bay Drive	BCW sta #4	29-May-07	Weston Solutions	Surface water	20
Big Canyon Wash	BCW Lower west of Jamboree Rd.	BCW sta #2	23-Jan-08	Weston Solutions	Storm water	13
Big Canyon Wash	BCW Middle, Inflow #2, west of MacArthur Blvd.[1]	BCW sta#1	23-Jan-08	Weston Solutions	Storm water	1.1

Table 1-1 (cont'd).

Watershed	Location Desciption	Location ID	Collection Date	Source	Matrix[2]	Se µg/L
Big Canyon Wash	Lower BCW freshwater marsh pond	LBCW-FWMP-A	09-Jun-08	CH2M HILL 2008	Surface water	23.6
Big Canyon Wash	Lower BCW freshwater marsh pond	LBCW-FWMP-B	09-Jun-08	CH2M HILL 2008	Surface water	17.6
Big Canyon Wash	Lower BCW freshwater marsh pond	LBCW-FWMP-C	09-Jun-08	CH2M HILL 2008	Surface water	14.4
Big Canyon Wash	Lower BCW freshwater marsh pond	LBCW-FWMP-D	09-Jun-08	CH2M HILL 2008	Surface water	14.5
Big Canyon Wash	Upper BCW freshwater marsh	UBCW-FWM	09-Jun-08	CH2M HILL 2008	Surface water	21.6
Big Canyon Wash	Upper BCW near Jamboree	UBCW-JAM	09-Jun-08	CH2M HILL 2008	Surface water	21.1

[1] This monitoring station is located in the middle branch of Big Canyon Creek, which has low selenium concentrations. All other monitoring stations are located within the south or main branch of Big Canyon Creek that runs through the south leg of the BCCC golf course and through the BCCNP.
[2] Surface water samples are dry weather samples; storm water samples are wet weather samples. Dry weather is defined as no precipitation 72 hours prior to the sampling event.
[3] Data does not indicate whether samples collected are dry (surface water) or wet (storm water) flows. Precipitation data from the Corona del Mar weather station (located at the Big Canyon Reservoir) used to determine matrix. Sample was classified as surface water if no rainfall had occurred within the last 72 hours.

Table 1-2. Ecological Risk Guidelines for Selenium

Media	Ecological Risk Level (µg/g dw)		
	None	Marginal	Substantive
Freshwater	<2 µg/L	2-5 µg/L	>5 µg/L
Sediment	<2	2-4	>4
Diet (fish & birds)	<3	3-7	>7
Fish Tissue	<4	4-6	>6
Bird Egg Tissue	<6	6-10	>10

(Source: Presser et al., 2004)

Table 1-3. Selenium concentrations in various media collected in Big Canyon Wash.

Media	BCNP[1]	BCCC[2]	HVNP
	Selenium Concentration (µg/g dw)		
Freshwater	23.6 µg/L	11.7 µg/L	58.3 µg/L
Sediment	99.4	11.2	10.0
Algae	35.6	16.4	15.4
Invertebrates	29.5	20.0	NF
Fish	56.5	38.3	23.7
Bird Egg Tissue	NF	37.0	NF

NF = Not Found

[1] Samples were collected from the marsh pond area in the lower part of the BCNP.

[2] Samples collected from the BCCC golf course were collected from Lakes 3 and 5 except bird eggs, which were collected from Lakes 4 and 5. Lakes 3, 4, and 5 are all located on the south side of the golf course within the south branch of BCW creek.

Note: All selenium concentrations are median concentrations with the exception of samples collected from the HVNP.

2.0 Geology and Hydrology of the Big Canyon Wash Watershed

BCW watershed remained largely undeveloped until the late 1960s. BCR was built in 1958 to provide potable water for the growing city of Newport Beach. Residential development began in the Port Streets area in 1969, BCCC and golf course area in 1971, and the Spyglass Hill area in 1977 (Dr. Jack Skinner, personal communication, November 2, 2010). By the early 1980s most of the area was built out. Prior to development of the BCW watershed, BCW creek functioned as an ephemeral stream, only flowing during and for a short period after, the rainy season (Dr. Jack Skinner, personal communication, November 2, 2010).

The hydrologic changes in the BCW watershed and much of the Newport Coast area have resulted in a decline in water quality as a result of contaminants in urban runoff (e.g. residential and commercial pesticides, fertilizers, metals) and storm flows that now flow into the creeks from storm drain systems and sheet flow from pavement, patios, and driveways, and the erosion that often accompanies the increased flows. Many of these contaminants and sediment from erosion ultimately end up in Newport Bay or adjacent coastal waters. Water from urban commercial and residential development (e.g., irrigation, runoff) may also seep into the underlying soils and geologic formations which can result in slope stability problems and mobilization of metals and other compounds from materials in these formations.

Surface waters now flow year round in BCW creek and in many of the Newport Coast drainages as a result of urbanization and the resultant changes in hydrology. The prevalence of water in an urban watershed combined with selenium-bearing geologic formations in the region has resulted in elevated selenium concentrations in water in drainages from BCW southeast along the Newport Coast to Aliso Creek.

2.1 Geology and Hydrogeology of the Big Canyon Wash Watershed

The Miocene (17.5 – 6 million years old) Monterey Formation outcrops along the steep bluffs that form the southeast side of Upper Newport Bay, from Big Canyon Wash south along the eastern edge of the lower bay to the ocean (Figure 2-1). This formation also extends southeastward along the Newport Coast past El Morro Canyon to Aliso Creek (Figure 2-2), which at one time was mined for phosphate (Morton and Miller, 1981). The Monterey Formation is a marine formation rich in organic carbon and is the most widespread petroleum source rock in California (Isaacs et al. 2009). The formation is commonly enriched in numerous trace elements that are potentially hazardous to aquatic life, human health, and the environment. These trace elements include chromium, copper, nickel, antimony, selenium, uranium, vanadium, zinc, arsenic, barium, cadmium, and molybdenum. Of these 12 elements, selenium poses a particular environmental hazard (Isaacs et al. 2009). The Monterey Formation extends up through BCW almost the entire length of the watershed (Figure 2-3) and is likely the source of selenium in the BCW watershed. Moderate to high selenium concentrations in water have also been found in Buck Gully, Muddy Canyon, Los Trancos Canyon, Morning Canyon, and Aliso Creek (Tables 2-1A and 2-1B); portions of these coastal streams are also underlain by the Monterey Formation. In the BCW watershed, some selenium may have also accumulated in aquatic sediments from rising groundwater or runoff from surrounding upland areas, especially in the lakes, ponds, and marshes located in the south branch of BCW creek (HVNP, BCCC golf course, BCNP).

Big Canyon Reservoir is underlain by the Monterey Formation and younger, Quaternary age (350,000 to 450,000 years) marine terrace deposits that overlie the Monterey Formation (URS, 2000). Geologic descriptions of the bedrock beneath the reservoir note that the Monterey formation in that area consists of siltstone with thin interbeds of silty claystone, silty sandstone, and hard cemented sandstones that were intensely fractured and contorted (James M. Montgomery, Inc., [JMM] 1977). A splay of the Pelican Hills fault has been mapped to the eastern edge of the reservoir (URS 2000). A review of historic aerial photographs dating back to 1928 revealed several lineaments that merged with the splay of the Pelican Hills fault crossing the site of the reservoir (URS 2000). The presence of the Pelican Hills fault and associated lineaments are likely responsible for much of the fracturing and contortion of the Monterey formation observed in the boreholes drilled around the reservoir (JMM 1977). Though the late Quaternary Pelican Hills fault is not considered an active fault, URS (2000) concluded that there is potential for co-seismic triggered slip to occur along the fault during a moderate to large earthquake on the nearby Newport-Inglewood fault or the San Joaquin Hills blind thrust. Lineaments and fractures associated with the Pelican Hills fault may act as conduits or barriers to groundwater movement in this area.

There is very little available information on the hydrogeologic characteristics of the subsurface materials in the BCW watershed. There have been however, some fairly extensive studies of groundwater in the vicinity of the BCR. In the mid-1970s, several investigations were conducted to determine the quantity and direction of groundwater flow in the vicinity of the BCR. In order to collect sufficient geologic and hydrologic data, thirteen boreholes were drilled by Converse, Davis and Associates (as directed by JMM) beginning in October 1974. Permeability testing was conducted on samples collected from several of the boreholes including siltstone from the Monterey Formation and sands from the overlying terrace deposits (JMM 1977). Constant head permeability tests were performed in the laboratory on four samples of fine sand from the Quaternary terrace deposits and four samples of clayey siltstone and siltstone from the Monterey Formation[1]. The laboratory tests yielded average permeability

[1] Normally, constant head permeability test are performed on coarser grained materials and falling head permeability tests are performed on finer grained materials. There is no explanation in the JMM 1977 report as to why falling head permeability tests were not performed in the laboratory on the siltstone samples. However, falling head tests were performed in the field in selected boreholes.

values of 1.34 x 10^{-3} centimeters per second (cm/s) or 28.4 gallons per day per square foot (gpd/ft^2) for the terrace sands, and 2.7 x 10^{-8} cm/s (5.7 x 10-4 gpd/ft^2) for the siltstone bedrock (JMM 1977). Laboratory permeability tests are generally performed to determine the permeability of soils that will be reworked and placed as fill materials, such as those used for the BCR embankments and dam. Laboratory permeability tests require the soil sample to be mixed with enough water to prevent particle size segregation while the sample is being placed in the permeameter. The sample is then compacted to the desired density. Therefore, laboratory permeability tests do not provide information on the in situ permeability of the material.

Since it was noted during the drilling of the borings at the reservoir that "where fracture zones are open, the bedrock conducts and transmits significant quantities of groundwater" (JMM 1977), the decision was made to also conducted constant head and falling head tests (slug tests) in the field in four of the boreholes. Measured volumes of water were injected and water levels were recorded to determine the transmissivity[2] and permeability of the fracture zones observed in the bedrock underlying the reservoir. Two of the selected boreholes were located along the eastern edge of the reservoir (H-28 and H-32) and two along the south half of the western edge of the reservoir (H-36 and H-37) (Figure 2-4). Fracture zones ranged in thickness from 3 to 6.5 feet. Permeabilities[3] measured in the fracture zones in the Monterey siltstone ranged from 2.6 x 10^{-3} cm/s (55.1 gpd/ft^2) in the boreholes located on the west side of the reservoir to 3.83 x 10^{-3} cm/s (81.2 gpd/ft^2) in the boreholes on the east side of the reservoir. The highest average transmissivity (406 gpd/ft) was measured in borehole H-28, located on the northeast side of the reservoir; the lowest (206 gpd/ft) was measured in borehole H-37, located at the southwest corner of the reservoir. The permeabilities and transmissivities of the fracture zones measured in the boreholes in the Monterey siltstone indicate that the fractured bedrock underlying the reservoir is likely a better conductor of groundwater than the overlying terrace sands. However, since the consultant did not perform field permeability tests on the terrace sands, a direct comparison of the in situ permeability or transmissivity of the two different geologic units cannot be made.

JMM's investigations of groundwater flow around the BCR (1975-1977) revealed that local groundwater mounds form along the east, south, and southwestern reservoir walls in response to rises in reservoir levels (Figure 2-4). The greatest measured effects were observed along the east wall. The groundwater mounds dissipate with distance from the reservoir and as the reservoir stage declines (JMM 1977). Water levels in the piezometers around the reservoir fluctuate with changes in reservoir surface elevations, though the changes in groundwater

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[2] Transmissivity values represent the quantity of water moving through a strip one foot wide by the estimated thickness of the aquifer.
[3] The aquifer testing (falling head tests or slug tests) performed by JMM actually measured hydraulic conductivity, not permeability. However, Regional Board staff elected to use the same terminology used in the JMM (1977) report for consistency.

elevations are attenuated and generally lag somewhat behind rises or falls in the reservoir surface. JMM estimated groundwater flow rates moving away from the reservoir for several locations (JMM 1977). Flow rates ranged from less than 1 gallon per minute (gpm) along the northwest and northeast sides of the reservoir to about 2.4 gpm along the southeast side of the reservoir (1,440 gallons per day [gpd] or 0.002 cubic foot per second [cfs]). Cumulative underflows from the north half of the reservoir were estimated to be approximately 2.5 gpm (3,600 gpd/0.005 cfs) with approximately 3.3 gpm (4,752 gpd/0.007cfs) flowing from the southern half of the reservoir for a net underflow of 5.8 gpm (8,352 gpd/0.013 cfs) moving out from the reservoir. JMM concluded that though the leakage from the reservoir into the underlying bedrock was relatively small:

> *"…the major source of groundwater moving through the terrace sands and fractured bedrock in the vicinity of the reservoir is the reservoir itself."*

In order to provide a check on JMM's estimates of the amount and rate of water leakage from BCR estimated during the 1970s, Regional Board staff estimated flow rates and directions using 6 months of data from 1987 (January through June)[4], a relatively low rainfall year (5.5 inches cumulative). Regional Board staff selected three piezometers located along the edges of the reservoir: I-41, located at the southeast corner of the reservoir property, H-36, located at the southwestern side of the reservoir, and G-26 located at the northeastern end of the reservoir (Figure 2-5). The average groundwater elevations were calculated for each piezometer and plotted on a map (Figure 2-5). Groundwater flow paths were mapped and the groundwater direction and gradient were estimated. Using data on average fracture zone thickness and in situ permeability (hydraulic conductivity) of the Monterey Formation underlying the reservoir from JMM's 1977 report, groundwater was estimated to flow towards the west-northwest at a rate of roughly 6 gpm[5] (8,640 gpd/0.013 cfs). This estimate is in line with the net

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[4] The average surface water elevation at the reservoir during this time period was 274.9 feet. Flows from the east and west underdrains averaged 1.8 and 4.0 gpm, respectively.

[5] The flow direction between the three piezometers for the 6 month period used was estimated to be towards the west-northwest at a shallow gradient of about 1.5% (a head change of 20.6 feet over a distance of 1350 feet; see Figure 2-5).

The rate of groundwater flow is defined as follows:

$$Q = KiA$$

Where:
Q = Flow rate
K = [average] Hydraulic conductivity: 70.8 gpd/ft^2
i = groundwater gradient (a change in hydraulic head of 20.6 feet over a distance of 1,350 feet): 0.015
A = cross sectional area of the aquifer (estimated by using the average measured thickness of the fracture zones in the bedrock (6 feet) and the distance measured

underflow estimated by JMM (1977). Groundwater flow paths are expected to generally follow surface topography except where altered by subdrains, leaky storm drains, or major fracture/fault zones. Groundwater velocities and elevations were shown to respond to changes in surface water levels within the reservoir itself (JMM 1977, 1985)

All of the above estimates of groundwater flow rates and directions for flow through the Monterey Formation in the vicinity of the BCR (both those made by JMM and Regional Board staff) are extremely rough estimates since they are based on very limited data. At this time, Regional Board staff has not been able to obtain data that may have been collected from the reservoir piezometers and underdrains since 2000. Flow estimates based on more recent data would provide a more accurate portrayal of current conditions in the vicinity of the BCR, since the reservoir was covered by a floating geomembrane liner in 2004, reservoir operations have been changed[6], and the current condition of the reservoir liner is not known. Additional investigations into groundwater flow paths, gradients, and velocities would help to determine the extent of the groundwater aquifer and its contribution to surface flows in the BCW watershed.

In 2000, during their seismic analysis of the BCR, URS found that only nine of the 23 existing piezometers at BCR were being monitored for water levels. Fourteen of the piezometers were considered to be out of service for various reasons. URS recommended the installation of five more piezometers to monitor the phreatic[7] surface in the reservoir embankments and the Quaternary terrace deposits that underlay portions of the reservoir's foundation. Regional Board staff has not yet obtained copies of the borehole logs, piezometer construction logs, or any associated water elevation data. However, the City has confirmed that the five piezometers were installed as recommended by URS (Figure 2-6) and is looking for the original reports and data to share with Regional Board staff.

In the 1960's and early 1970's, a high groundwater table was reported in the residential developments located to the north and west (downgradient) of the BCR. In response, the City of Newport Beach constructed two off-site

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perpendicular to the potentiometric lines across the plane formed by the water table between G-26, I-41, and H-36 (1,350 feet): 8,100 ft^2

Then:

$Q = 70.8\ gpd/ft^2 \times 0.015 \times 8,100\ ft2 = 8,602\ gpd$ or 6 gpm (0.013 cfs)

[6] A floating geomembrane cover was added to the reservoir in 2004 to prevent air borne contaminants from getting into the reservoir water and to reduce algal growth. As a result, the need to drain and clean the reservoir has been reduced. Also, according to City staff the reservoir is now being used primarily for storage (verses direct supply to local users). It is not known how these changes in the operation of the reservoir may affect reservoir levels and leakage from the reservoir into the underlying bedrock.

[7] The phreatic surface is the wetted (saturated) portion of the embankment materials that are in contact with the water in the reservoir. The surface will rise or fall in conjunction with changes in surface water elevations in the reservoir.

groundwater subdrains (URS 2000). The locations of these two drains, known as the Bren Tract and the Seaview (formerly, Broadmoor) drains, are shown on Figure 2-18. These two drains were sampled during the June 2010 water quality sampling event (the Port and Yacht Street HOA drains, respectively; see Section 4.1.2). The Bren and Seaview subdrains discharge into the south branch of BCW creek in the HVNP, located approximately 0.14 miles downstream of the reservoir (R. Stein, City of Newport Beach Assistant City Engineer, email communication dated 4-21-11). The BCR also has two underdrains (east and west underdrains) that were installed to intercept some of the water leaking from the reservoir; flows captured by these underdrains also ultimately discharge into the HVNP.

All of the data and consulting reports used in Section 2.1 of this report are include in Appendix 2.

2.2 Hydrology of Big Canyon Wash Watershed

Big Canyon Wash creek begins at the foot of the western slope of the San Joaquin Hills along the eastern edge of Upper Newport Bay. As discussed in Section 1.1, BCW creek is composed of three main tributaries (Figure 1-5): a south branch which extends from BCR west into the Harbor View Nature Park (HVNP), and then continues through the BCCC golf course into the Big Canyon Nature Park (BCNP); a middle branch which extends from the base of Spyglass Hill into the BCCC golf course, where it joins the south branch just before the BCCC clubhouse; and the north branch which is less well defined and only visible where it enters the northeastern corner of the BCCC golf course. The north branch of the creek flows through the north leg of the BCCC golf course before joining the flows from the south branch of the creek at the western end of the golf course. The conjoined flows then exit the golf course passing through a large culvert under Jamboree Road into the BCNP.

The original drainage patterns in the BCW watershed have been highly modified by development. Groundwater and surface water flow paths are highly influenced by an extensive system of storm drains and channels, which daylight into surface drainages throughout the watershed (Figure 2-7). These storm drains in many cases also direct irrigation runoff and groundwater intercepted by the drains into surface waters in BCW creek.

There is very little flow data available for BCW creek. The primary storm water monitoring station for BCW creek is located in the BCNP (BCW Lower) downstream of the mitigation pond and just east of Back Bay Drive (BCWG04). This location has been monitored by Orange County since 1970 (Figure 2-8). However, there have been no direct measurements of flows at this location by County staff. In 2007, Weston Solutions measured dry and wet weather flows at the upper end of the BCNP where flows enter the park from the BCCC golf course (Station 2) and at the lower end of the main channel of the creek near station BCWG04 (Station 4, see Figure 2-9). In 2009 dry weather flows were monitored at several locations on the BCCC golf course by CH2M Hill. In 2010, dry weather flow monitoring was conducted by Regional Board and Orange County staff at some of the same locations that were monitored by CH2M Hill staff in 2009. However, no flow monitoring was conducted in BCNP during either 2009 or 2010.

Because there is a significant lack of hydrologic data for the BCW watershed, pollutant load estimates and other flow-dependent data can only be considered as preliminary estimates for qualitative purposes. In order to better estimate pollutant loadings and the relative contributions to surface flows from different sources of water, more accurate and seasonal measurements of flows in the BCW watershed are needed.

Each portion of the BCW watershed (BCW Upper, Middle, and Lower) varies somewhat in their hydrological characteristics, primarily as a result of the degree and type of development and hydromodification. A brief discussion of the hydrologic setting and available flow data for each of these sections of the watershed follows.

2.2.1 BCW Upper

BCW Upper is characterized primarily by residential and some commercial development, much of which is underlain by shallow groundwater. BCR and the Pacific View Memorial Park and Mortuary (PVMP) are located along the south edge of BCW Upper and are tributary to the south branch of BCW creek (Figure 2-10). Flows from the BCR underdrains and two subdrains installed in the mid-1970s by the City of Newport Beach to divert rising groundwater from adjacent residential developments (Bren and Seaview subdrains; see Section 2.1) discharge to the HVNP, located in the south branch of BCW creek just downstream of the reservoir, west of San Miguel Road. Within the HVNP, the surface sections of BCW creek are lined with willows and other riparian vegetation and emergent wetland plants such as cattails and bulrush. However, flows are sluggish and locally ponded resulting in warm water temperatures and excessive algae growth, especially in areas not shaded by at least a partial riparian canopy.

In June 2010, flow rates in BCW creek were measured at 0.038 cfs (17 gpm/24,480 gpd) in the upper portion of the HVNP (just west of San Miguel Drive). (See Section 4.1.1 of this report for details on how flow measurements were collected). The combined discharges from the BCR underdrains and Bren and Seaview subdrains have been estimated to be as high or higher than15 gpm (21,600 gpd/0.033 cfs) in the past (JMM 1977; 1985). This implies that surface flows in the south branch of BCW begin at this point and the origin of this water is leakage from the BCR. However, to Regional Board staffs' knowledge, the discharges from these drains have not been recently measured.

From the HVNP, the south branch of BCW creek flows westward and is diverted under MacArthur Boulevard and into the BCCC golf course (BCW Middle) where it daylights once again. The flow volume measured in the south branch of BCW creek where it enters the BCCC golf course (Inflow 1) was more than 5 times higher than those measured in the creek at the HVNP in June 2010. This indicates that additional flows from other sources are entering the south branch between the upstream end of the HVNP and the eastern end of the BCCC golf course. Water may be entering the creek from leaky storm drains or sub drains that discharge groundwater to the creek or rising groundwater may be entering unlined portions of the creek channel.

The middle branch of BCW creek is relatively undeveloped in the upper portion of the canyon between San Miguel and Spyglass Hill roads. The middle branch begins just west of Spyglass Hill. At this time, it is not known whether or not there is any surface expression of flows in this branch of the creek east of San Miguel Road. West of San Miguel Road, the drainage is diverted through an underground pipe until it daylights on the BCCC golf course.

In BCW Upper, the north branch of the creek begins on the BCCC golf course and has no physical expression east of MacArthur Boulevard. The source of the water in this branch of the creek is likely groundwater water infiltration and irrigation water transported by residential storm drains that discharge to the golf course from residences located within BCCC and residential developments located north of Ford Road. Irrigation runoff and/or infiltration from the southern portion of the Bonita Canyon Sports Park located along the northern edge of the watershed may also contribute some flows to the north branch of BCW creek. BCW Upper drains roughly a 545.5 acre (Ac) or 0.85 square mile (mi^2) portion of the BCW watershed.

2.2.2 BCW Middle

The middle section of BCW watershed is dominated by the Big Canyon Country Club (BCCC) residential development and golf course. This privately owned and operated golf course was constructed in BCW in the late sixties/early seventies and opened in 1971. As shown on Figure 2-1, BCW creek daylights along the eastern boundary of the golf course at three locations. Inflow 1 is where the south branch of the creek daylights on the golf course, Inflow 2 is the middle branch, and Inflow 3 is the north branch. The north branch of the creek includes one lake (Lake 6) and the south branch includes four lakes (Lakes 1, 3, 4 and 5). Lakes 1 and 6 are not hydrologically connected to the creek. There is no Lake 2 which was removed in 2004. In addition, numerous storm drains and/or subdrains discharge to the golf course, both from homes located within the BCCC and homes located along its boundaries. BCW Middle drains an area of roughly 517 Ac (0.81 mi^2).

Three of the five lakes (Lakes 3, 4, and 5) and most of the creek and riparian features on the BCCC golf course are supplied by water from BCW creek. Lakes

1 and 6 contain storm water runoff and are supplemented by potable water to maintain lake levels during the dry season (CH2M Hill 2009a). Flows from the middle branch of the creek are diverted underground around residential areas and join flows from the south branch just before the BCCC clubhouse. The conjoined flows then flow through Lakes 3, 4 and 5 located along the south side of the golf course (Figure 2-11).

The north branch of the BCW enters the northeastern end of the BCCC golf course. Low flows run underground and then daylight into a small, fast-moving stream in the golf course about 3,000 to the west of the northeastern boundary of the golf course. The flow is conveyed approximately 1,000 feet to the west where it then joins the flows from the south side of the golf course. Storm flows entering the golf course along the north branch of BCW creek, flow across the fairway into Lake 6, then exit the lake to flow along the fairways to the west where it joins storm flows from the south side of the golf course. The conjoined flows (low flows and storm flows) exit the west central end of the golf course, pass over a large concrete drop structure located near the golf course maintenance buildings, and then flows down a rocky incline into a large culvert under Jamboree Road before flowing under Jamboree and into the BCNP.

Multiple urban storm drains daylight on the BCCC golf course from both within the country club development and from the surrounding residential areas. Many of these drains contain flows year-round, likely as a result of infiltrating groundwater. All together, 16 different inflows, including the three main branches of BCW creek (Inflows 1-3), have been identified on the BCCC golf course (Figure 2-12). Three are located on the north side of the golf course downstream of where the north branch of the creek (Inflow 3) enters the golf course. Two of the drains discharge from the north side of the creek (Inflows 4 and 5) and one from the south side of the creek (Inflow 6). Inflows 4 and 5 were measured and sampled by CH2M Hill staff during their 2009 sampling of the water bodies on the golf course (CH2M Hill, 2009b). Nine discharge points have been identified on the south side of the golf course; one (Inflow 12) enters the middle branch of BCW creek downstream of where the creek discharges into the golf course (Inflow 2), but upstream of where the south (Inflow 1) and middle branches join. Two drains (Inflows 9 and 15) discharge into the golf course from the residential areas located to the south and southwest of the golf course and the remaining six drains (Inflows 8, 10, 11, 13, 14 and 16) discharge from the residential areas located north of the south side of the golf course (Figure 2-12).

None of these discharge points (Inflows 4-16) were measured in June 2010. Most of these small flows are very difficult to sample and measure because they issue from relatively small diameter underground pipes that have very low flows (J. Beardsley, BCCC, personal communication, June 20, 2010).

Figure 2-13 shows the estimated flow path of BCW creek as it flows through the BCCC golf course with respect to the underlying storm drain system. Additional work needs to be done to identify storm drains that contain groundwater that daylight in the surface drainages both on the golf course and in the residential areas located upstream of the golf course.

In 2009, CH2M Hill staff estimated flow rates for several locations on the BCCC golf course including the three main branches of BCW creek and the outflow from the golf course to the BCNP. Table 2-2 shows the locations monitored by CH2M Hill and their estimated flow rates.

In June 2010, Regional Board staff with assistance from Orange County Public Works staff measured flows in all three branches of BCW creek where it enters the eastern end of the BCCC golf course (see Section 4-x for details on how flow measurements were taken), at the flow outlet from Lake 5, and at the drop structure at the western end of the golf course where BCW creek exits the golf course and enters the BCNP below (Figure 2-11). Flows measured in 2010 were higher than those measured by CH2M Hill in 2009. This may have been a result of differences in flow measurement/estimation methods, rainfall amounts the preceding winter[8], or the amount and timing of local landscape irrigation. Table 2-3 shows the locations and flow measurements obtained during the June 2010 monitoring event. Of particular interest in comparing the two different years is that flows in the middle branch of BCW creek were 33% higher than those in the southern branch as measured by CH2M Hill in 2009. The opposite relationship was measured in 2010 by Orange County and Regional Board staff, with flows in the south branch recorded at a rate 36% higher than those measured in the middle branch. This result may be illustrative of the difference in timing and effects of residential irrigation systems upstream of the two different branches of the creek before the flows enter the golf course.

During the June 2010 monitoring, the southern and middle branches of BCW creek at their point of discharge to BCCC golf course contained the largest flows (0.205 cfs and 0.132 cfs, respectively) while the lowest flows were recorded in the north branch (0.004 cfs). The outflow measured at the drop structure located at the western end of the golf course was measured at 0.82 cfs in June 2010. Since the three branches of BCW where they enter the eastern end of the golf course contributed a total of 0.34 cfs in June 2010, an additional 0.48 cfs enters the golf course from residential storm drains, sub drains, golf course and/or residential landscape irrigation, or as rising groundwater directly into the creek (Table 2-3).

2.2.3 BCW Lower

The Big Canyon Nature Park (BCNP) occupies the majority of this portion of the watershed. BCW creek enters the nature park from a culvert that extends from the BCCC golf course outflow under Jamboree Road. BCW creek then flows primarily as a single, meandering channel at the upper end of the nature park;

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[8] The Corona del Mar weather station, located at Big Canyon Reservoir, recorded a total rainfall of 6.87 inches for water year 2008/2009 and 12.72 inches for water year 2009/2010.

however, about two-thirds of the way down the creek, the flow splits and follows two different channels (NBNF, 2010). The southern or main channel includes a freshwater pond and marsh; the northern channel is riparian (Figure 2-14). Both channels discharge into Upper Newport Bay (UNB), immediately west of Back Bay Drive. BCW Lower drains an area of approximately 232.4 Ac (0.36 mi^2).

Seven storm drains discharge to the nature park from the residential areas located on the ridges above the canyon. Five are located along the northern edge of the canyon and three along the southern edge of the canyon (Figure 2-10). Of these 7 drains, one drain flows year-round and has a small catch basin at its base (SD-1). This drain flows into the north channel of the creek and is likely intercepting groundwater. Flow measurements are not yet available for this drain.

In June 2010, the outflow to the nature park from the golf course was measured at 0.82 cfs. The June 2010 sampling event however, was focused on collecting data from the middle and upper portions of the BCW watershed and flow measurements were not made in BCW Lower. However, it is likely that total discharges from the creek to UNB were greater than 1 cfs at that time.

The primary storm water monitoring station for BCW creek is located in the BCNP just downstream of the mitigation pond before the creek enters the bay (BCWG04). This location was monitored by Orange County from 1970 to 1996. However, flows at this location in the creek were only estimated and were not actually measured by County staff. In 2007, Weston Solutions measured flows during dry weather and wet weather at two locations in BCW Lower: the main creek inlet into the nature park at Jamboree Road (Station #2) and the main channel outlet to UNB (Station #4, equivalent to BCWG04) (Figure 2-9). The data from Orange County and from Weston Solutions is discussed below.

2.2.3.1 Orange County Flow Estimates

The Orange County Environmental Management Agency (OCEMA) established a monitoring location in BCW Lower where the flows from the main branch of the creek flow through a mitigation pond and marsh area over a small dam and through a series of pipes under Back Bay Drive. Flows were estimated during sampling events from 1970 to 1996. Flows were estimated as low as 0.25 cfs to as high as 250 cfs in March 1980. Orange County staff has indicated that the flow estimates were based on “best professional judgments”, and there were no measurements taken to validate stream cross-sections or estimated velocities (Bruce Moore, OCPW, electronic mail dated March 30, 2011). Bioassessment monitoring conducted in BCW by Orange County Public Works (OCPW) as part of their storm water monitoring program in 2005-2006 and 2007-2008 did not include flow estimates at the sampling location. Though this sampling location is still labeled as “BCWG04” it is actually located upstream of the sampling location used by Orange County from 1970-1996 (Figure 2-8).

2.2.3.2 Weston Solutions, Inc. Flow Estimates

Monitoring and water quality investigations in support of restoration efforts in the BCNP began in 2004 (Weston Solutions, Inc. 2007). Dry weather monitoring was conducted by WRC Consulting, Inc. on August 10, 2004, at four stations in BCW creek. Station #1 was located in the middle branch of the creek on the upstream side of BCCC golf course (BCW Middle); Station #2 was located just west of Jamboree Road where outflows from the BCCC golf course enter the nature park (BCW Lower); Station #3 was located where the main channel through the BCNP enters the marsh pond mitigation area established in the 1980s (BCW Lower); and Station #4 is located just downstream of the outflow from the mitigation pond, just east of Back Bay Drive (Figure 2-9).

Wet weathering monitoring at the same locations was conducted by Weston Solutions, Inc. on October 20, 2004. Unfortunately, flow rates and volumes were not measured at any of the four stations during either the dry or wet weather events in 2004. Dry weather flow sampling was conducted in the morning following overnight and early morning irrigation (Weston Solutions, Inc. 2007). Flows in BCW creek were estimated to be as low as 0.002 cfs at the upgradient station (Station #1) and as high as 0.67 cfs at the two most down-gradient stations (Stations #3 and #4). There is no indication in the report as to how the flow estimates were derived.

In 2007 however, Weston Solutions, Inc. conducted additional dry and wet weather monitoring at two of the four stations sampled in 2004 (Stations #2 and #4). The wet weather monitoring occurred on April 20, 2007 between 0730 and 1800 hours during a late season storm. The dry weather event took place during a four day period from May 29 through June 1, 2007 (Weston Solutions, Inc. 2007). According to the Weston Solutions, Inc. August 2007 report:

> "Flow measurements were estimated during wet and dry weather by using the Manning geometric equation derived from physical measurements of the channel taken at each sample station prior to the wet weather event. The equation produces an estimated flow rate using the stage of the stream, velocity of the stream, and the surveyed dimensions of the channel. The Manning equation flow measurements were compared to actual flow measurements computed in the field during dry weather conditions using a Marsh-McBimey Model 2000 Portable Flow Meter connected via a cable to an electromagnetic open channel velocity sensor."

2.2.3.2.A April 20, 2007 Wet Weather Flow Estimates

Flows were measured at Station #4 by Weston Solutions beginning at 8:00 AM in the morning on April 20, 2007 with 2.05 inches of cumulative rainfall recorded at the Corona del Mar rain gauge located at Big Canyon Reservoir near the top of the watershed. Only one measurement was made at upgradient Station #2 during the wet weather event. The last discharge measurement was taken at Station #4 at 6:45 PM that evening with 2.32 inches of cumulative rainfall recorded at the Corona del Mar station. A total of only 0.27 inches of rainfall was measured during the 10.75 hour wet weather sampling event[9] and yet flows measured at Station #4 increased by more than 2 cfs (Table 2-4 and Figure 2-16). This seems unlikely, given the small amount of rainfall recorded during the monitoring event. However, it is not known whether irrigation (residential or commercial) occurred prior to or during the wet weather monitoring event, or whether the rainfall recorded at the Corona del Mar station is reflective of the amount and intensity of rainfall that may have occurred at the downstream end of BCW creek.

2.2.3.2.B MAY 29 – JUNE 1, 2007 DRY WEATHER FLOW ESTIMATES

Beginning on May 29, 2007, Weston Solutions measured flows at the same two locations in the BCNP that were measured during the April 20, 2007 wet weather event. Two measurements were made at Station #2 at the upper end of the nature park on May 29 and five measurements were made at Station #4 at the lower end of the nature park from May 29 through June 1, 2007 (Table 2-5). Flows at Station #2 nearly doubled from the first measurement taken at 8:30 AM to when the second measurement taken at 10:00 AM. The highest flow measured at Station #4 was recorded on May 29 at 10:50 AM. By 12:30 PM the flow rate at Station #4 had dropped by almost 0.2 cfs (Table 2-5 and Figure 2-17). Flows recorded at Station #4 on the morning of May 30, 31, and June 1, 2007, did not vary and likely represent true base flow in BCW creek at that time. Though the data are limited, it appears likely that flow rates measured on May 29 at both Stations #1 and #4 were influenced by local and/or upstream landscape irrigation, as was surmised during the 2004 dry weather monitoring event. However, continuous monitoring data are needed to determine when, and to what degree, local irrigation is contributing to surface flows in the BCNP and elsewhere in the watershed.

2.3 Potential Sources of Water in the Big Canyon Wash Watershed

As discussed previously, the urbanization of the BCW watershed that began in the late 1950s with the construction of the BCR has resulted in a change in hydrology from ephemeral, seasonal flows to perennial flow in the creek. Anecdotal information indicates that conditions were still relatively dry into the 1970s when the BCCC golf course was constructed; dewatering was not required during construction as a shallow groundwater table did not exist in the area at that time (Jeff Beardsley, golf course superintendent, BCCC, personal communication, August 4, 2008). That is no longer the case however, and rising groundwater has been observed on the BCCC golf course during the rainy season.

Groundwater seeps have been observed on the steep slopes along the east side of San Miguel Drive (Dr. Jack Skinner, personal communication, November 2, 2010). A shallow, perched groundwater table now appears to underlie at least portions of the area between San Miguel Road, Ford Road, and MacArthur

[9] During the period of time (10.75 hours) that the sampling was conducted: 8:00 AM until 6:45 PM

Boulevard. However, the extent of the aquifer and its characteristics have not yet been investigated. The aquifer is likely maintained by a combination of local precipitation, golf course and urban landscape irrigation, leakage from the BCR and possibly, leaking water lines. Measurements of selenium concentrations in groundwater in the vicinity of BCR (see Section 4.3.1) confirm that the shallow groundwater table contains high concentrations of selenium. Selenium is likely mobilized from the subsurface geologic materials in the vadose zone or the aquifer itself by this infiltrating water. High selenium groundwater then enters surface waters through seeps, leaky storm drains, passive subdrains, or other types of drainage systems and subsurface conduits in the area. Selenium concentrations in groundwater and surface waters in the BCW watershed are therefore likely due to a combination of the underlying geologic materials, and the hydrologic changes that have occurred in the watershed during the last 40 to 50 years.

Several potential sources of water in the BCW watershed have been identified and are briefly discussed below.

<u>2.3.1 Big Canyon Country Club Golf Course</u>

The BCCC golf course is located upstream of the BCNP between Jamboree Road and MacArthur Boulevard in the middle portion of the BCW watershed (BCW Middle; Figure 2-1). This privately owned and operated golf course was constructed in BCW in the late sixties/early seventies and opened in 1971. Most of the water bodies on the golf course are supplied by water from BCC. Lakes 3, 4 and 5 are supplied with water from Big Canyon Creek, primarily from the combined south and middle branches. Lakes 1 and 6 contain storm water runoff and are supplemented by potable water to maintain lake levels during the dry season (CH2M Hill, 2009a). The riparian areas along the northern and southern portions of the golf course, and the emergent wetlands vegetation along Lakes 5 and 6 are mitigation areas that were required for a dredge and fill project that resulted in the removal of Lake 2 in 2006. BCW creek is a blue-line stream[10] (Figure 1-5).

The golf course uses approximately 210 acre-foot per year (AF/yr) for irrigation. Approximately 60% of the water is reclaimed water from the Orange County Water District (OCWD) Green Acres project and 40% is potable water (J. Beardsley, BCCC, personal communication, May 19, 2008). Residential landscape irrigation inputs from within and around the golf course also contribute to stream flows. As discussed previously, multiple urban storm drains discharge to the golf course and stream flows increase by almost ½ cfs from the eastern end of the golf course where the three branches of BCW creek enter the course to the western end of the golf course where stream flows are diverted under Jamboree Road and discharged into the BCNP. In addition, none of the golf

[10] "Blue-line stream" means that a stream appears as a broken or solid blue line (or a purple line) on a USGS topographic map. Blue line streams may be either perennial or intermittent.

course lakes are lined, providing another potential source of infiltration from the golf course into the underlying shallow aquifer.

2.3.2 Big Canyon Reservoir

Big Canyon Reservoir is a 23-acre drinking water facility that was constructed in 1958 in Upper BCW as a drinking water reservoir and has a capacity of 195 million gallons (George Murdock, City of Newport Beach, personal communication, May 15, 2008). The reservoir was designed by James M. Montgomery, Inc. (JMM) and was formed by cutting the side of a hillslope (URS 2000). The reservoir is owned and operated by the City of Newport Beach Utilities Department and is fully covered to prevent water loss from evaporation and contamination from airborne pollutants (Figure 2-15). Though the reservoir is asphalt-lined and underlain by a five-foot deep clay layer, it leaks. The water table at the base of the reservoir dam is around eight (8) feet below grade (George Murdock, City of Newport Beach, personal communication, May 15, 2008).

As discussed in more detail in Section 2.1, the two underdrains installed at the BCR to divert leakage from the east and west embankments discharge flows to a storm drain channel located along the west side of the reservoir. This water then flows though a concrete channel into a culvert and then into the HVNP in the south branch of BCW creek. Though no flow measurements were collected at the underdrain discharge points at BCR in June 2010, flow data collected from the 1970s through 1999 indicated that the east underdrain system discharges about 2 to 5 gpm (2,883 gpd/0.0044 cfs to 7,200 gpd/0.111 cfs), while the west underdrain discharges about 5 gpm under normal reservoir operating conditions (URS 2000). Total discharge from the reservoir underdrains to surface waters averages 7 to 10 gpm (10,080 to14,400 gpd or 0.015 to 0.02 cfs).

In the late 1960s and early 1970s, shallow groundwater was reported in the residential areas located to the north and west (downstream) of the BCR (URS 2000). In response, the City constructed two off-site subdrain systems to lower the water table in the affected developments (Figure 2-18). The two drains (Bren and Seaview drains) discharge to the City's storm water system, which in turn discharges to surface waters in the HVNP (R. Stein, City of Newport Beach, email dated April 21, 2011). JMM was engaged by the City of Newport Beach to investigate the rising groundwater in the vicinity of the BCR, including the levels and quality of groundwater flowing in the area of the reservoir and the two newly constructed subdrains.

In 1975 JMM designed and installed a system to measure flows in the off-site Bren drain. JMM staff measured cumulative discharge from the Bren drain for the period of March through September 1977 (Table 2-6). The average discharge on a daily basis was 3.27 gpm (4,713 gpd or 0.0073 cfs) with a total estimated discharge of approximately 881,136 gallons for this time period (187 days). The JMM report (1977) indicates that after September 29, 1975, City staff took over the drain monitoring; however, City staff only collected single measurements from the Bren drain on a monthly or semi-monthly basis, instead of making cumulative measurements as JMM staff did. The JMM report includes data collected by City staff for the time period from July 1976 through March 1977 (Table 2-6).

From 1980 to 1984 the City continued to monitor discharges from the Bren drain, but discharges from the Seaview drain were not measured because of chronic maintenance problems associated with the drain pump (JMM 1985). No actual discharge data for the Bren drain was included in the 1985 JMM report. The report did note that two complaints of highly saline groundwater were submitted by local residents to the City sometime during 1984/1985, but the report does not mention if any actions were taken by the City to either repair or replace the Seaview drain pump (JMM 1985).

JMM also collected hydrologic, hydrogeologic, and water quality data from the vicinity of BCR from November 1974 to June 1977 (JMM 1977). The results of the study indicated that BCR was the primary source of the rising groundwater in the area (see discussion under Section 2.1). Groundwater recharge from rainfall was found to be of minor significance to the overall groundwater supply in the area and irrigation at the adjacent and upstream Pacific View Memorial Park and Mortuary also did not result in any significant recharge to the shallow groundwater[11]. While these studies were of short duration and occurred more than 30 years ago, geochemical data collected in June 2010 support the conclusions of the 1977 JMM report and point to the BCR as a major source of water to the south branch of BCW creek.

Ground water movement in the area of the reservoir is generally towards the west and northwest, though leakage from the reservoir results in groundwater mounds forming around the reservoir with the highest groundwater levels found on the southeastern side of the reservoir (JMM 1977; 1985). The net leakage from the reservoir into the subsurface was not determined by JMM, but based on the information in their 1977 report, it is probably on the order of at least 4.0 gpm (5,760 gpd or 0.009 cfs) to 6 gpm (8,640 gpd/0.80 cfs; see Section 2.1). Total leakage from the reservoir, including leakage captured by the underdrains and leakage directly into the subsurface from the reservoir may be on the order of 10 to 16 gpm (14,400 - 23,040 gpd/1.34 - 2.14 cfs).

At this time, Regional Board staff has only received some limited monitoring data and consultant reports for the piezometers and underdrains at the BCR. The data provided by the City only covers portions of the time period from 1975 up through 2000; no post-2000 data has yet been provided to Regional Board staff. Regional Board staff has also not received any discharge data for the nearby residential subdrains (Bren and Seaview subdrains), other than that provided in

[11] However, the PVMP has doubled in size since the mid-1970s so the irrigation contributions from this source should be reassessed.

the 1985 JMM report. Additional monitoring of water level fluctuations in the BCR piezometers and underdrain system, as well as the adjacent residential subdrains, should be conducted in order to determine current groundwater leakage, flow rates, and discharges to surface waters in this area of the BCW watershed.

2.3.3 Spyglass Hill Reservoir

This small reservoir is located at the extreme upstream end of the middle branch of BCC (BCW Upper) under the Spyglass Reservoir park at the end of Muir Beach Circle (Figure 2-18). The reservoir is owned and operated by the City of Newport Beach Utilities Department and is a 1.5 million gallon concrete drinking water reservoir that was built in the 1970's to supply the surrounding community (http://www.newportbeachca.gov/index.aspx?page=234). The underground reservoir is 101 feet in diameter and 27 feet deep and is supported by large concrete columns and a thick concrete roof. At this time, City staff has not indicated whether or not there is any subsurface leakage from this reservoir. If the reservoir does leak, it may be one of the sources of water that surfaces in the middle branch of BCC. Selenium concentrations in the surface waters in the middle branch of BCC are anomalously low compared to surface waters in the north and south branches. The reason for this is not known, but the upper portion of this branch of the creek may be underlain by a different geologic formation than the other branches of the creek (Figure 2-3).

2.3.4 Pacific View Memorial Park and Mortuary

Pacific View Memorial Park cemetery and mortuary (Figure 2-1 and 2-5) opened in 1958. The 45-acre facility includes private garden estates, sloping lawns, and abundant landscaping with associated irrigation. Two fountains and two artificial streams on the grounds constantly recycle water so there is no infiltration from those systems (Cathy Wadsworth, office manager, Pacific View Memorial Park and Mortuary, personal communication, May 19, 2008); however, the amount and frequency of landscape irrigation that occurs at the site is not known at this time.

As part of their investigation into the source of shallow groundwater in the vicinity of the BCR, JMM conducted an evaluation of precipitation, irrigation, and consumptive use at the cemetery from January 1974 to September 1975 (JMM, 1977). The study determined that the irrigation at the cemetery did not result in any significant recharge to the shallow water table in the vicinity of the BCR. However, because the cemetery is almost double the size studied by Montgomery (23.5 acres), another similar evaluation should be considered to determine if the cemetery irrigation is still an insignificant source of groundwater recharge and selenium mobilization in the area. The highest nitrate concentration measured in a groundwater collected during the June 2010 study was from piezometer I-41, which is located directly downgradient of the Pacific View Memorial Park and Mortuary (see Section 4.3.1).

2.3.5 Residential and Commercial Landscape Irrigation
Approximately 96 percent of the BCW watershed has been developed for urban use with homes, schools, sports parks, green belts, and commercial facilities. Much of the urban area is heavily landscaped and irrigated providing another potential source of infiltrating water to the watershed. Increases in flow rates in the three branches of BCW creek where they discharge into the BCCC golf course have been observed by BCCC staff in the morning when upstream residential automatic irrigation systems are likely running (J Beardsley, BCCC, personal communication, May 19, 2008). During their 2004 monitoring in the BCNP, Weston Solutions, Inc. staff observed that overnight and early morning irrigation were influencing flows in BCW creek. Analysis of flow data collected during the dry season in 2007 by Weston Solutions, Inc. (see Section 2-2.3.2.B) also indicates that flows were likely influenced by local landscape irrigation. In addition, differences in flow volumes measured in 2009 (CH2M Hill) and 2010 (Regional Board and Orange County staff) in the south and middle branches of BCW creek where they daylight on the golf course may reflect the influence of upstream irrigation at the time the measurements were made (see Section 2.2.2). Though the magnitude of the contribution of this source to surface and groundwater flows in BCW watershed is not yet known, it appears that is likely an important source of water in this area.

2.3.6 Leaking Water Lines and Storm Drains
City of Newport Beach staff (R. Stein, personal communication) have also suggested that some of the water lines (both irrigation and drinking water) in the BCW watershed may be leaking and contributing to the shallow groundwater aquifer in the area Dr. Barry Hibbs, a hydrogeologist with California State University, Los Angeles (CSULA), found during his investigations of sources of water in the San Diego Creek watershed (2008) that some of the water that was infiltrating into the shallow groundwater in the vicinity of the Santa Ana Delhi Channel was from a leaking water line owned by the Irvine Ranch Water District (IRWD). He reported this to IRWD and the line was subsequently repaired. Tools such as isotope analyses and point measurements of flow volumes and/or water pressure in areas where leaking water lines may be suspected could be used to help locate and repair or replace them. Further investigation of this potential source of water in the BCW watershed should be conducted.

Much of the BCW watershed is underlain by an extensive system of storm drains. Leaking storm drains can act as conduits, intercepting groundwater and transporting it into surface waters. Joints and cracks in storm drains can provide entry to shallow groundwater, intercepting groundwater flows and diverting it more quickly to surface waters, changing both the subsurface and surface water hydrology. This can result in the short circuiting of any natural attenuation of pollutants in the groundwater that might otherwise occur as it passes through subsurface soils or the hyporheic zone[12] within the creek channel. Storm drains

[12] The hyporheic zone is a region beneath and lateral to a stream bed, where there is mixing of shallow groundwater and surface water. The hyporheic zone is a very active location of

in all three subareas of the BCW watershed (BCW Upper, Middle, and Lower) have been observed to discharge flows year-round, indicating that these drains are likely intercepting groundwater.

2.3.7 Local Precipitation

The Corona del Mar rain gauge is located on the south side of Big Canyon Reservoir (BCR) and is the main weather station for the BCW watershed (Figure 2-19). Monthly precipitation totals are available for this station from water year[13] 1969-1970 to water year 2009-2010. According to the data collected as of June 2010, the average precipitation for the BCW area is 12.27 inches per year, with a maximum annual rainfall amount of 31.88 inches received during the 1997-1998 El Nino water year and a minimum of 2.94 inches received during the 2006-2007 water year (Figure 2-20). During their investigation of the high water table in the vicinity of BCR, JMM (1977) also assessed the potential contributions to the shallow groundwater from local precipitation. They concluded that groundwater recharge from rainfall was of minor significance to the overall groundwater supply in the area. However, the average rainfall received in the area for the period of the JMM study (1974 and 1975) was slightly less than the average (less than 12 inches) and did not include any El Nino type events[14]. While local precipitation is certainly a periodic source of water to the shallow perched aquifer in the BCW watershed, the highly urbanized nature of the watershed likely results in limited infiltration with rapid surface runoff, limiting its overall influence on the shallow aquifer.

Though there is very limited data on selenium concentrations for the period of the rainfall record (usually only one sample was collected annually, and the early data is not always reliable), a comparison of the average yearly selenium concentrations to the rainfall record appears to show that selenium concentrations are generally higher in low rainfall years, and lower in high rainfall years (Figure 2-21). If this pattern is true, it supports the hypothesis that other sources of water (such as irrigation and reservoir leakage) have a greater influence on selenium mobilization in the watershed than local precipitation.

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biogeochemical transformation of nutrients and other dissolved solutes such as selenium and metals.

[13] A “water year” is defined as the time period beginning from July 1 of the preceding year to June 30 of the following year.

[14] A total of 13.41 inches of rainfall was recorded in 1974 and 9.67 inches in 1975 at the Corona del Mar weather station.

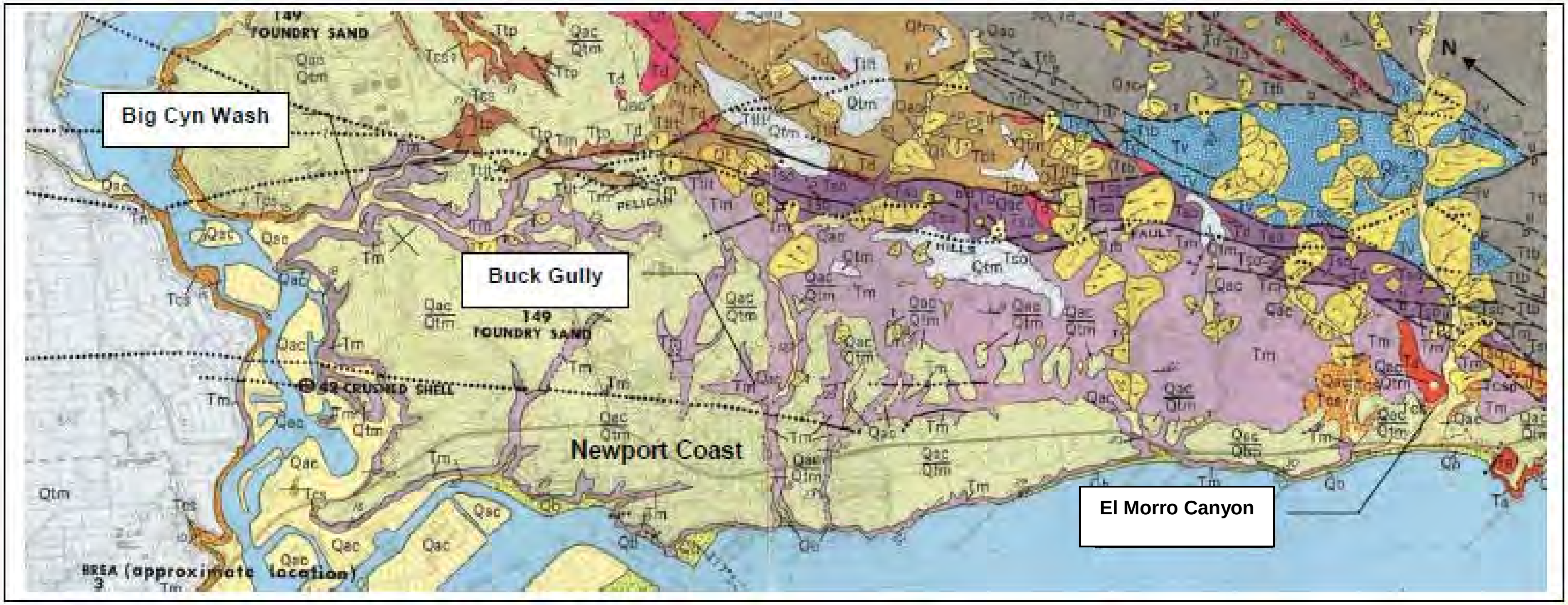


Figure 2-1. Geologic map showing the extent of the Monterey Formation (light purple unit labeled Tm) along the Newport Coast. (Source: Morton and Miller, 1981.)

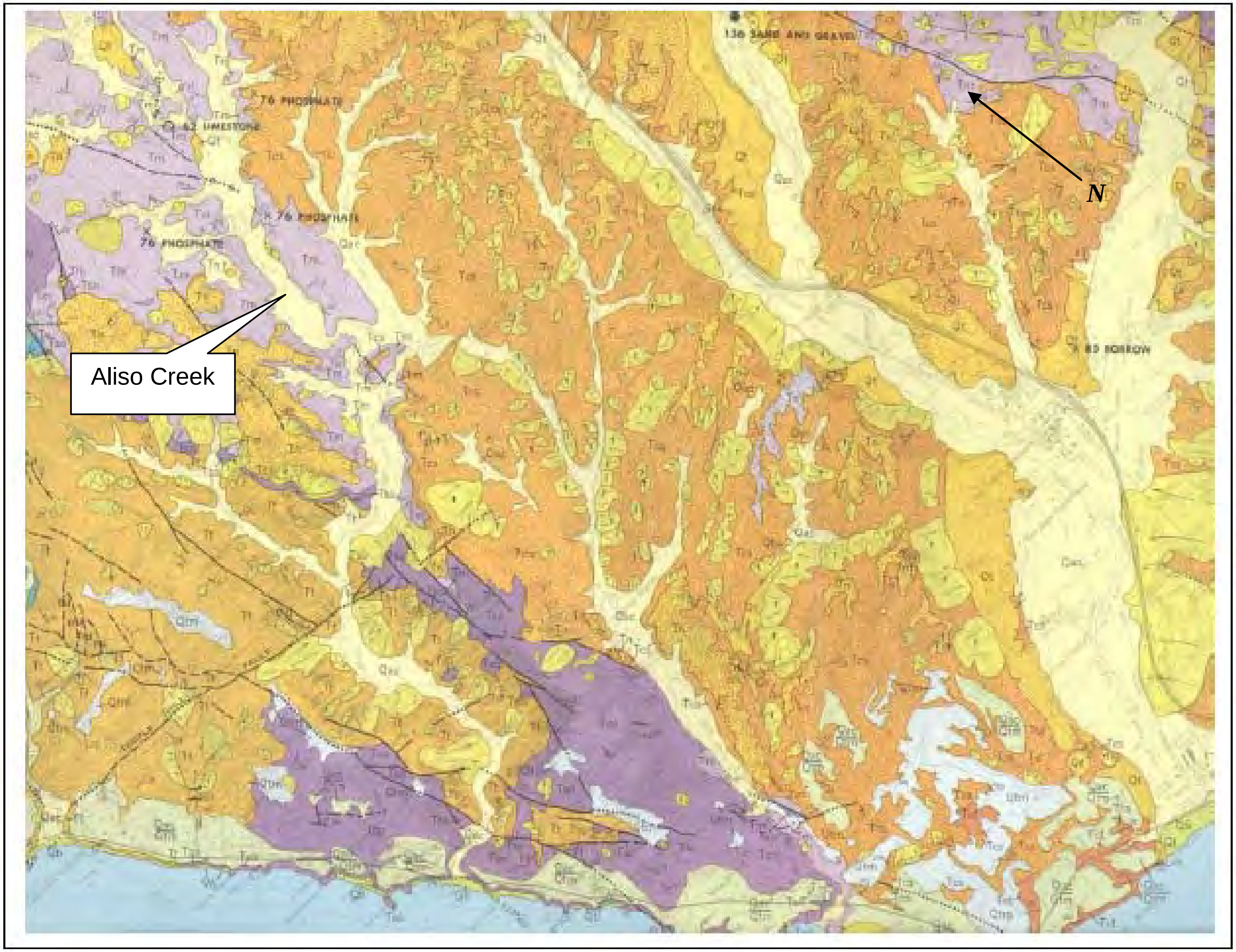


Figure 2-2. Geologic map showing the extent of the Monterey Formation (light purple unit labeled Tm) in the Aliso Creek watershed. Note the presence of several old phosphate mines in the middle portion of the watershed. The Monterey Formation also underlies the San Onofre Brecia Formation shown in the southern portion of Aliso Creek (darker purple unit labeled Tso). (Source: Morton and Miller, 1981).

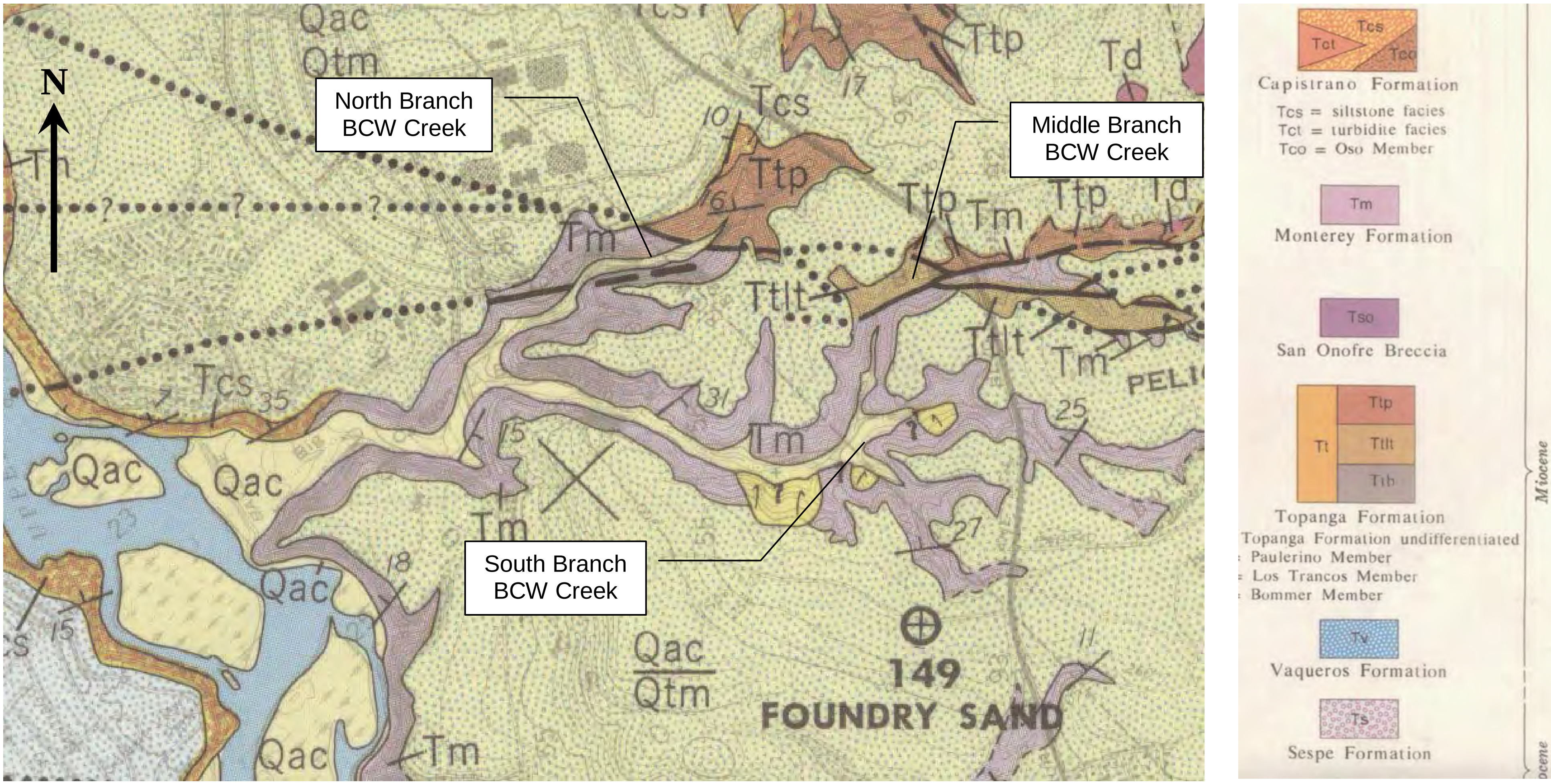


Figure 2-3. Geologic map of the Big Canyon Wash watershed (from Morton and Miller, 1981)
[NOTE: Legend is not complete.]

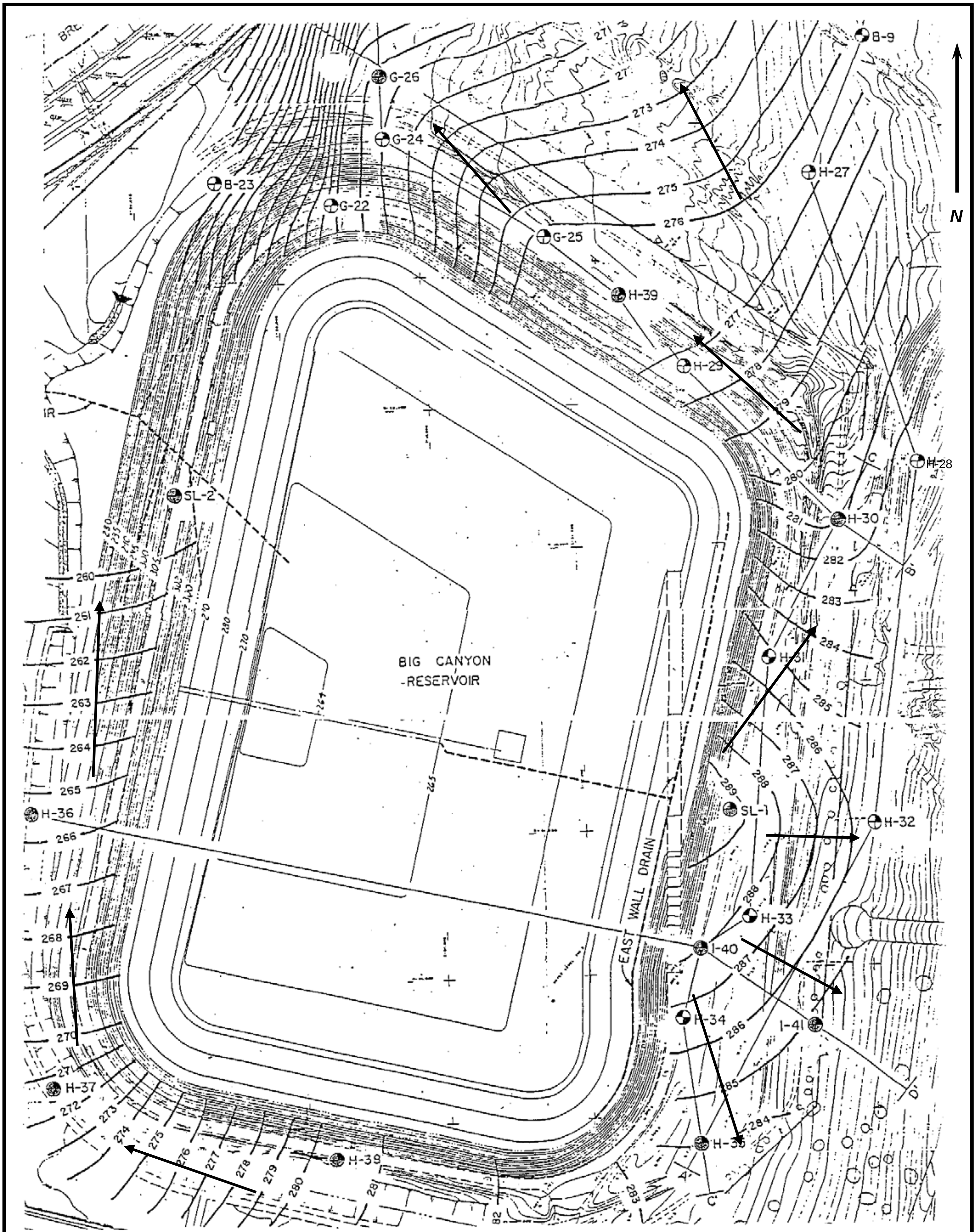


Figure 2-4. Map showing original reservoir piezometers and August 1975 groundwater elevation contours. Arrows indicate direction of groundwater flow around the reservoir. (Adapted from JMM 1977).

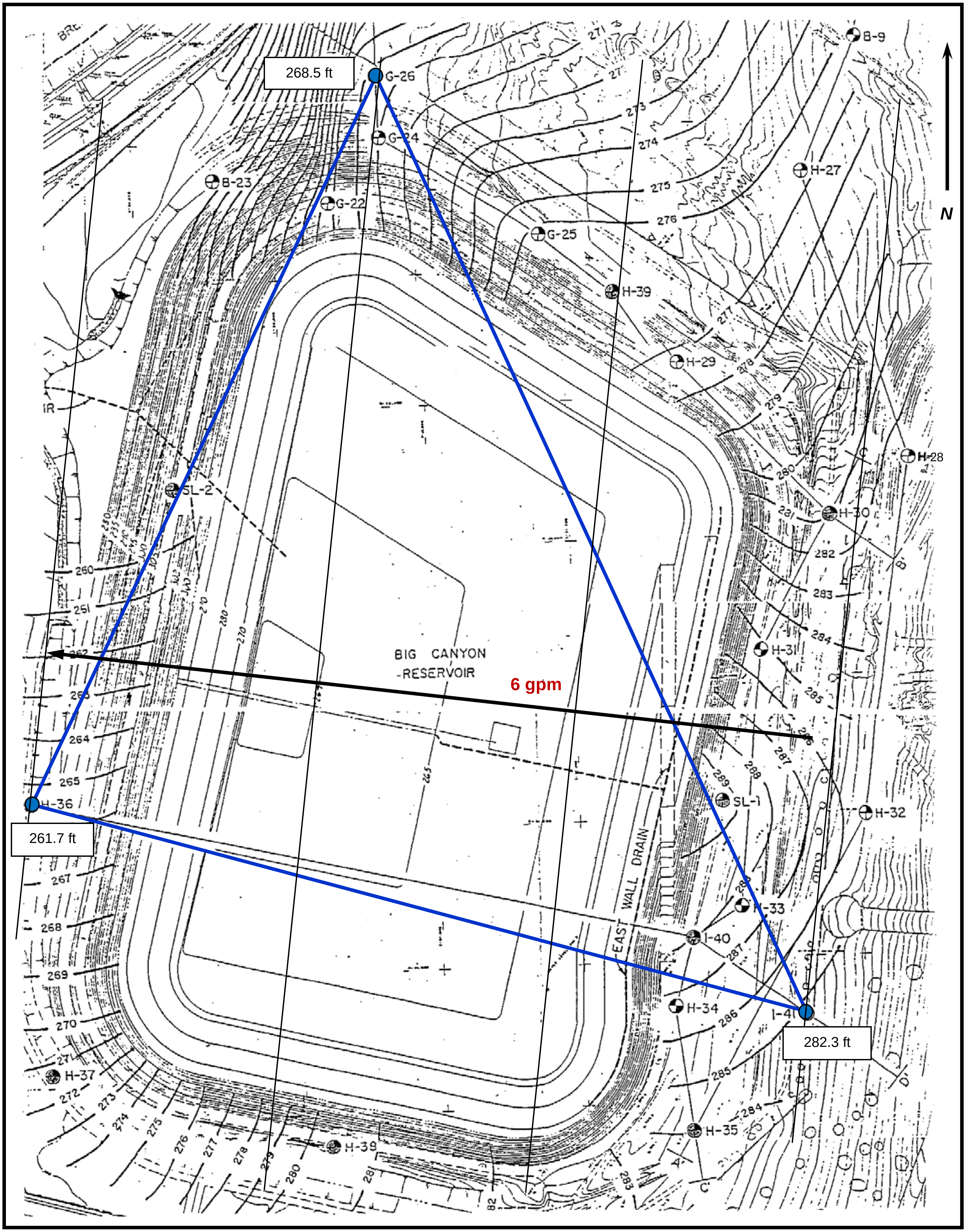


Figure 2-5. Direction, gradient, and estimated rate of flow of groundwater beneath the BCR based on groundwater elevation data from 1987 and the average permeability of fracture zones in the Monterey Formation as estimated by JMM (1977).

Figure 2-6. Map showing locations of existing piezometers and underdrains (vault) at the Big Canyon Reservoir.

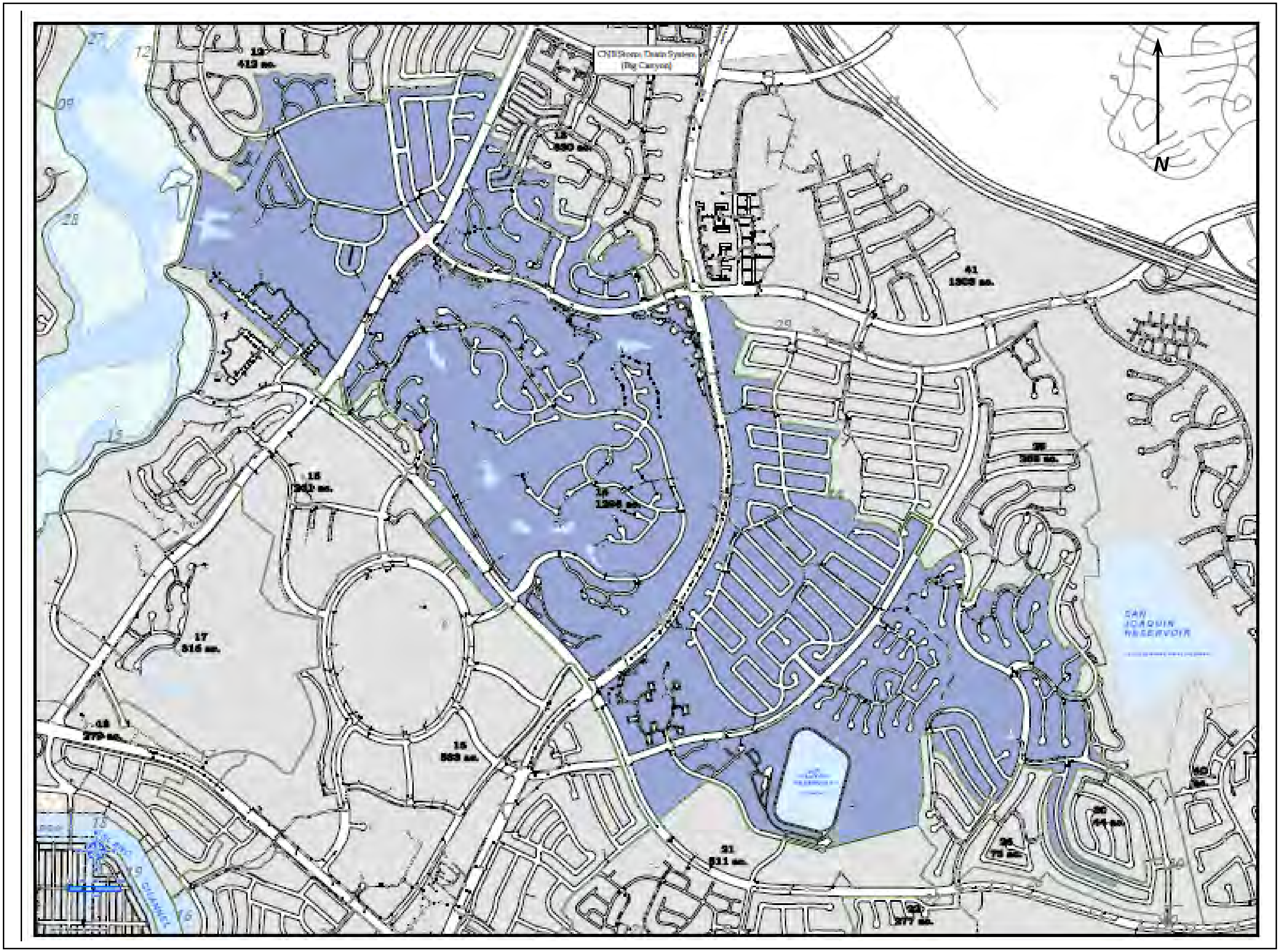


Figure 2-7. Storm drain system map of Big Canyon Wash watershed (map courtesy of City of Newport Beach).

Figure 2-8. Water quality monitoring locations in the Big Canyon Nature Park established by Orange County staff for their storm water monitoring program (toxicity testing was also conducted on the water samples collected from the upstream location from 2005 through 2008).

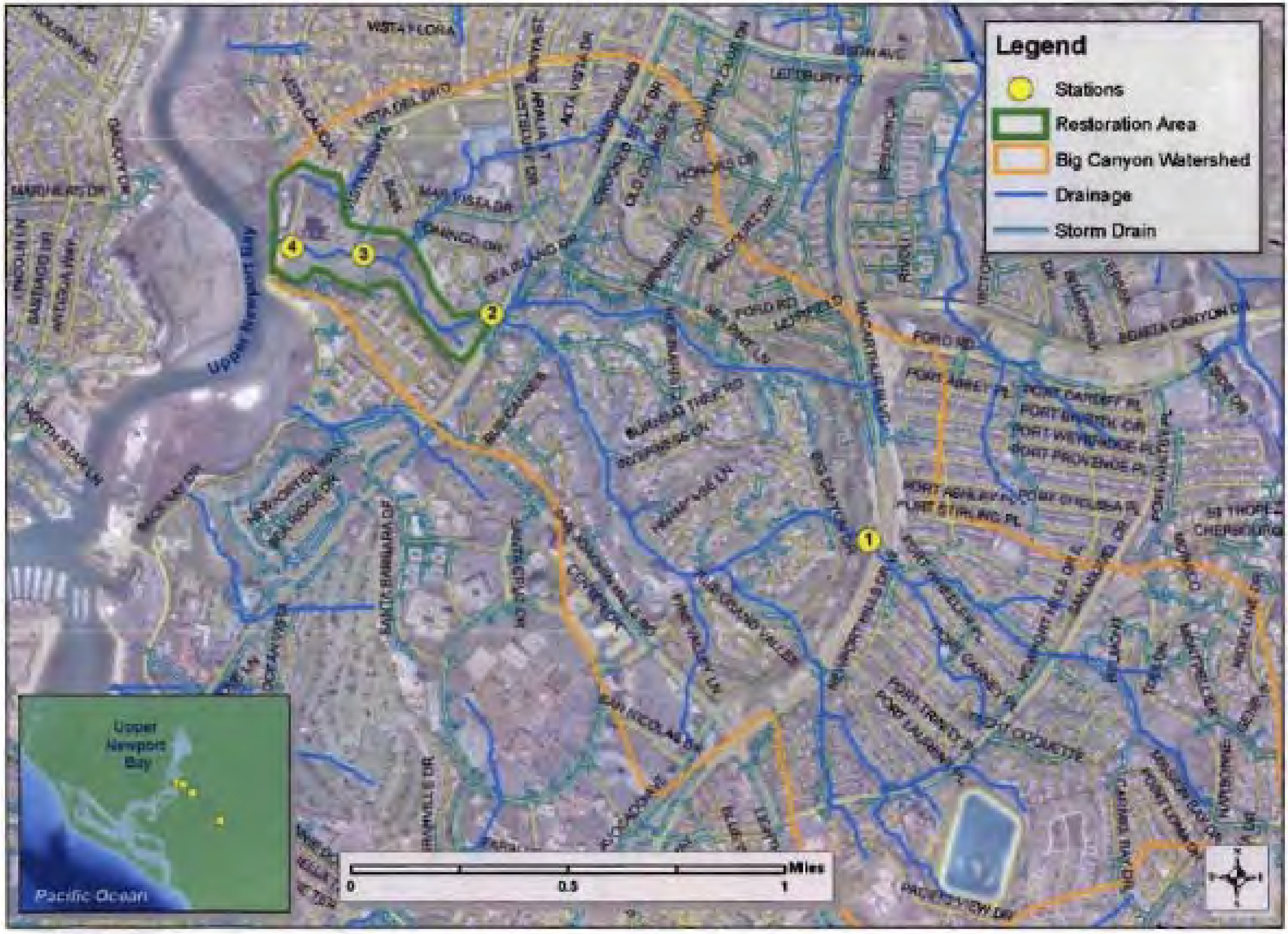


Figure 2-9. Monitoring stations used by Weston Solutions for dry and wet weather monitoring in BCW.

Station 1: Inflow #2 (middle branch of Big Canyon Wash creek) where it enters the BCCC golf course.

Station 2: BCW creek entrance into BCNP.

Station 3: Main BCW creek just upstream of the marsh pond DFG mitigation area in the BCNP.

Station 4: BCW creek main outlet from marsh pond to UNB (equivalent to Orange County station BCWG04).

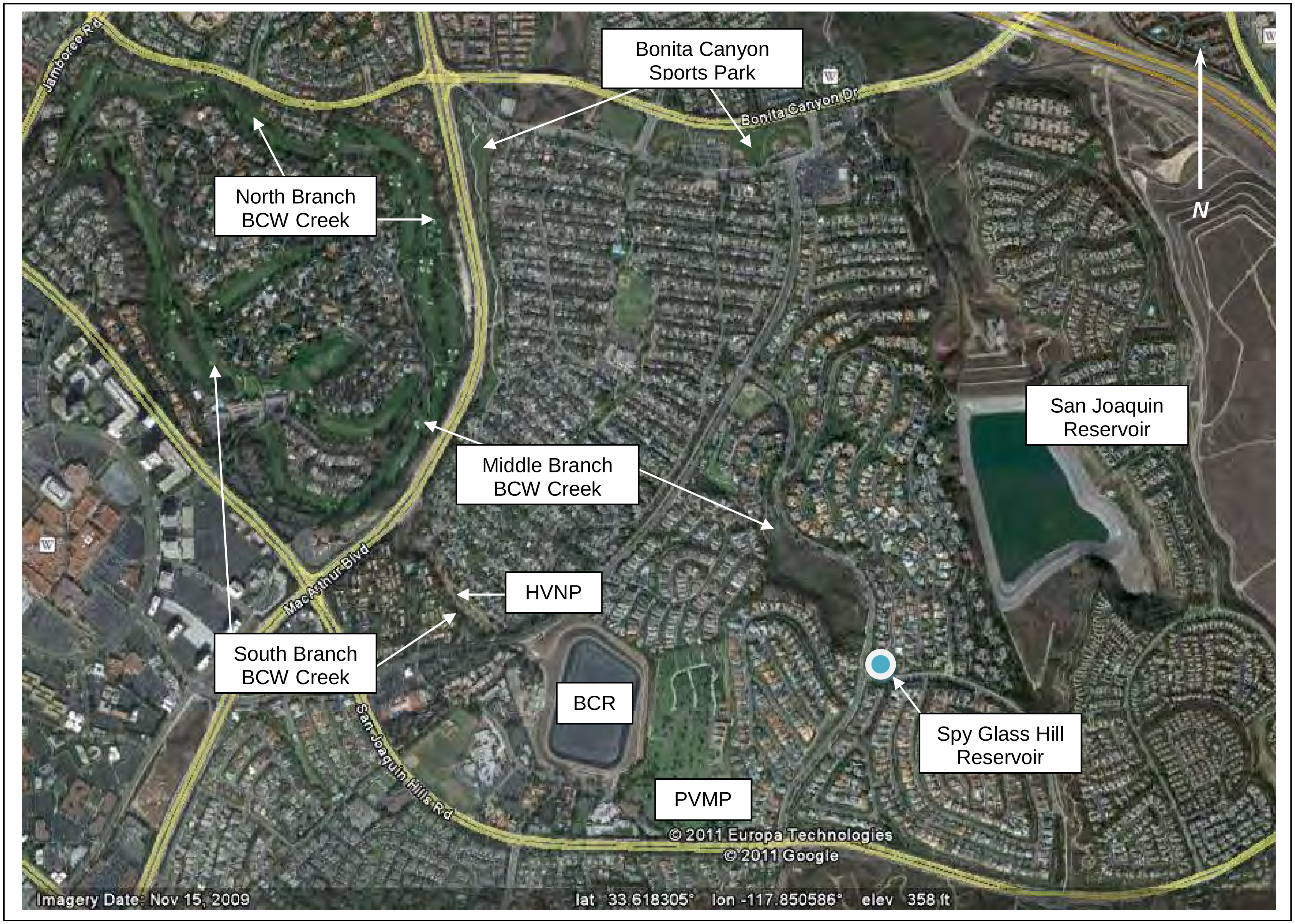


Figure 2-10. Hydrologic and geographic features of BCW Upper. The San Joaquin Reservoir is is not hydrologically connected to the BCW watershed.

Figure 2-11. Big Canyon Country Club golf course surface hydrology showing stream areas and lakes (BCW Middle).

Sample Locations: Inflow Lake Riparian Outflow Blueline Stream Storm Drain

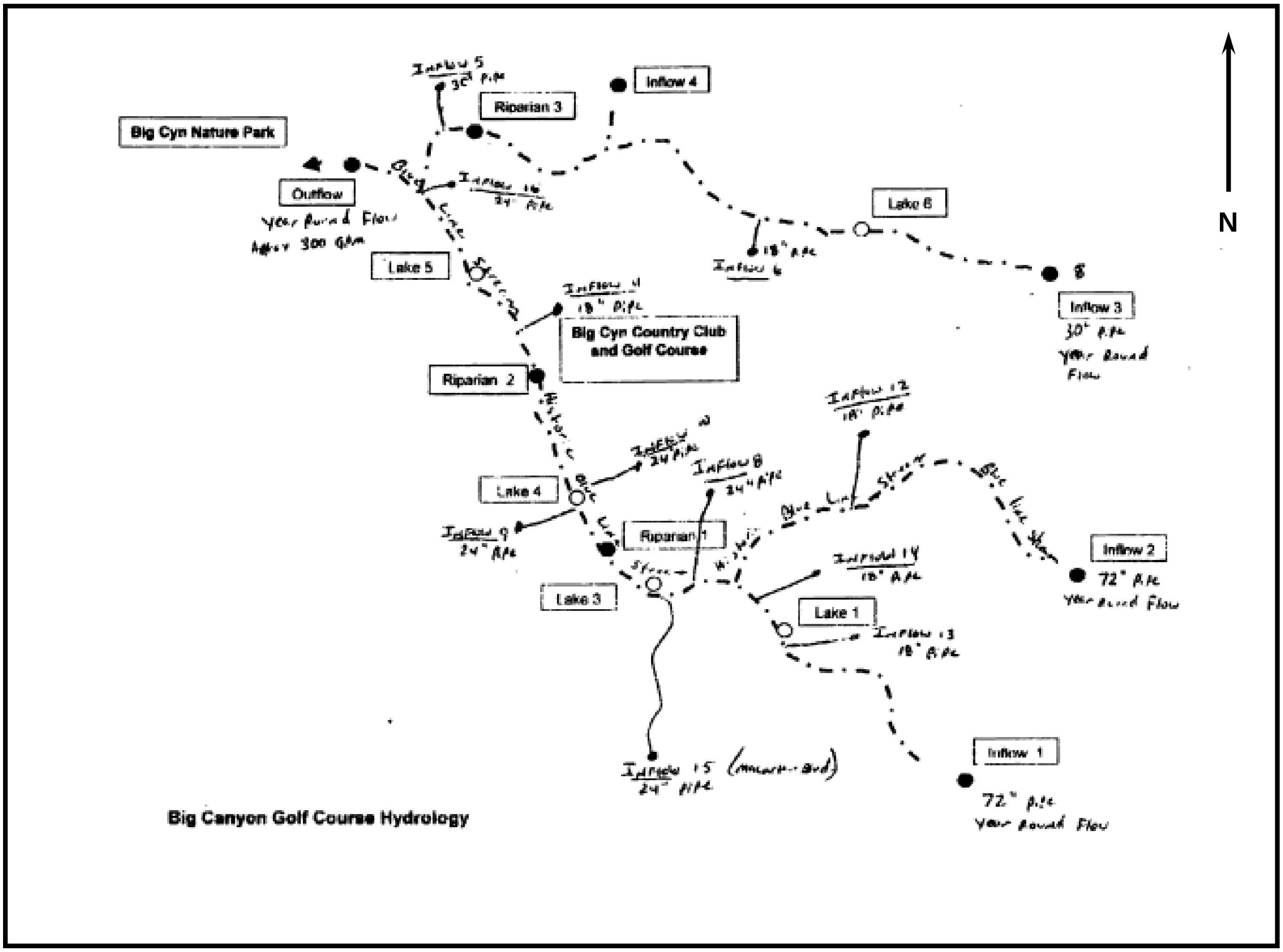


Figure 2-12. Drawing showing estimated route of surface flows and sources of inflows to Big Canyon Creek on the Big Canyon Country Club golf course (courtesy of Jeff Beardsley, golf course maintenance superintendent).

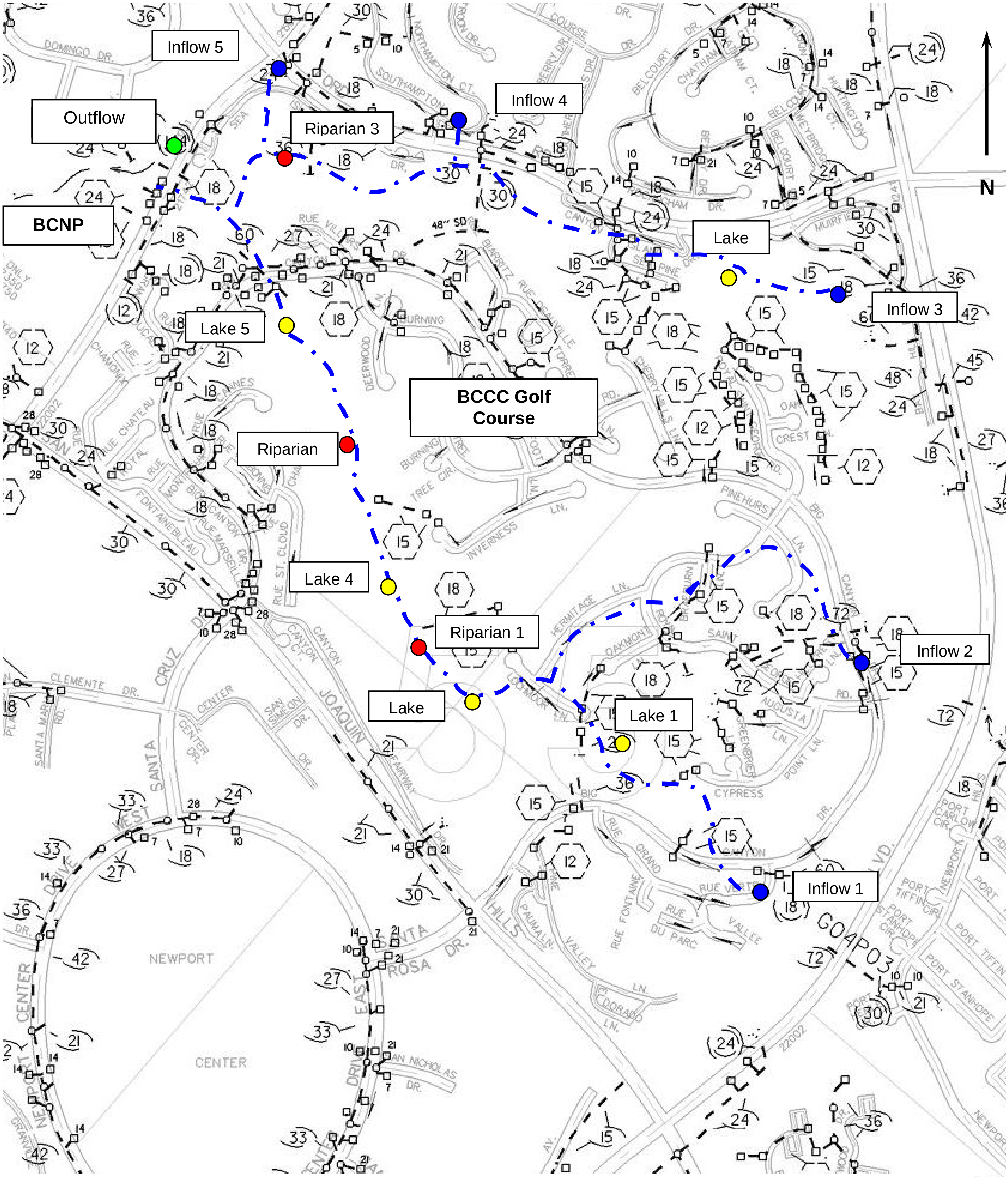


Figure 2-13. Big Canyon Country Club golf course hydrology and storm drain system.

Locations: Inflow Lake Riparian Outflow

NOTE: Stream course hydrology overlay is a rough approximation.

Figure 2-14. Important hydrologic features in the BCNP (BCW Lower).

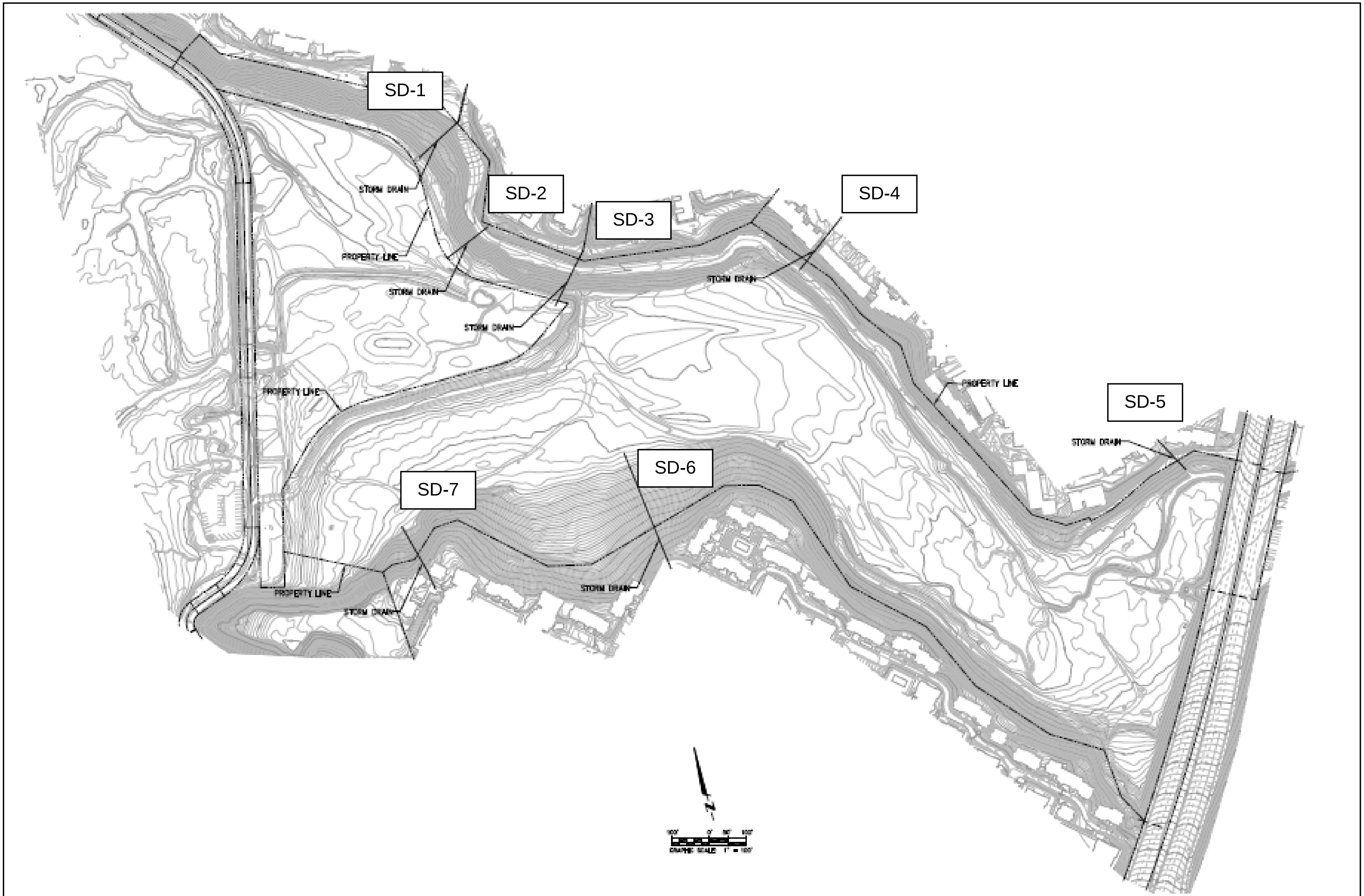


Figure 2-15. Location of storm drains that discharge into the BCNP (BCW Lower).

Figure 2-16. April 20, 2007 Wet Weather Event in Big Canyon Wash: Precipitation verses Discharge at Station #4 (Weston Solutions, Inc. report dated August 2007)

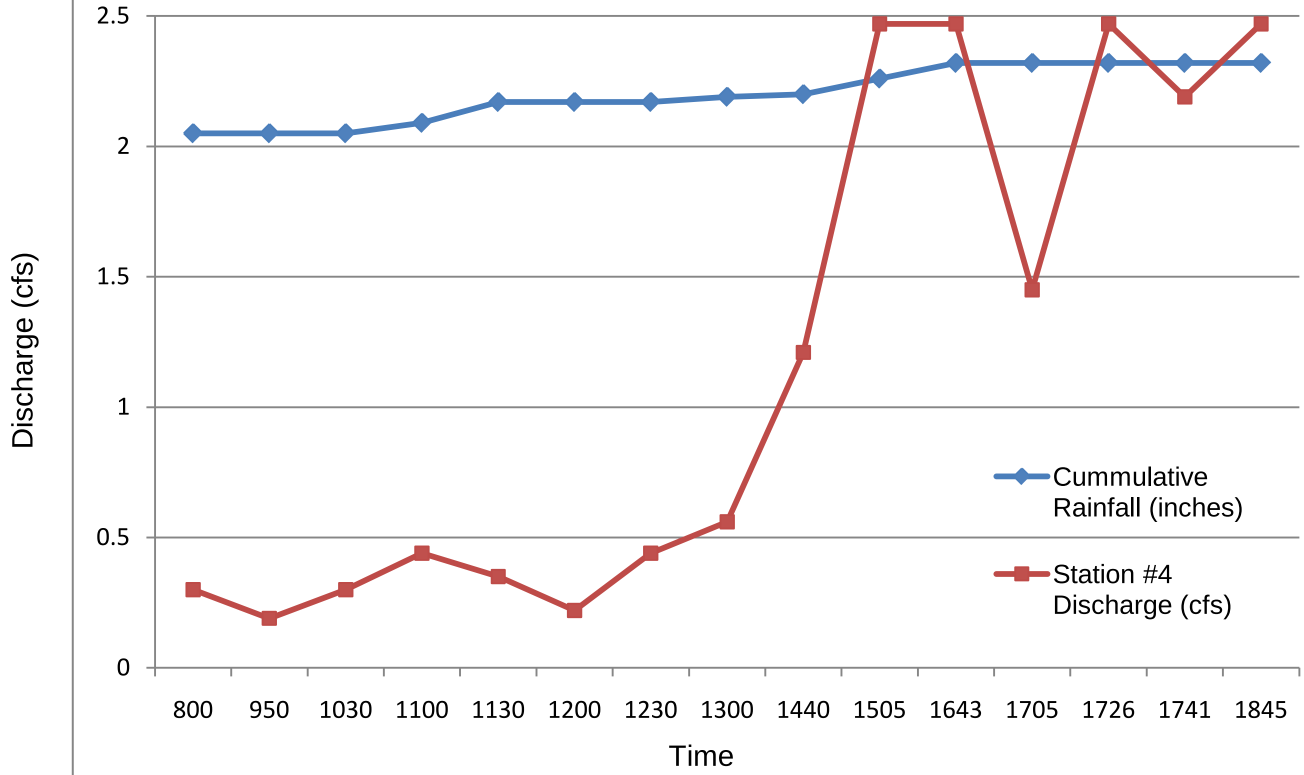
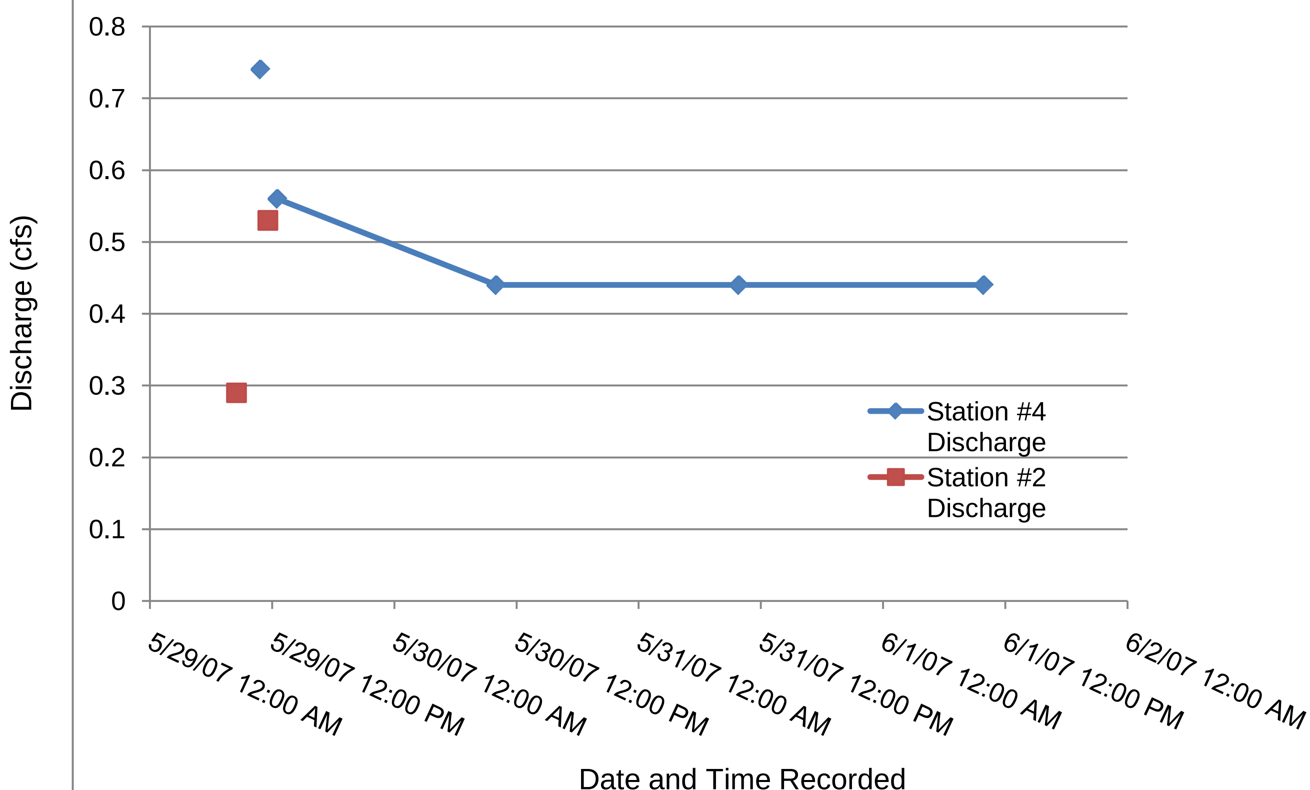


Figure 2-17. Dry Weather Flows Measured in the BCNP from May 29 - June 1, 2007 (Weston Solutions, Inc. report dated August 2007)



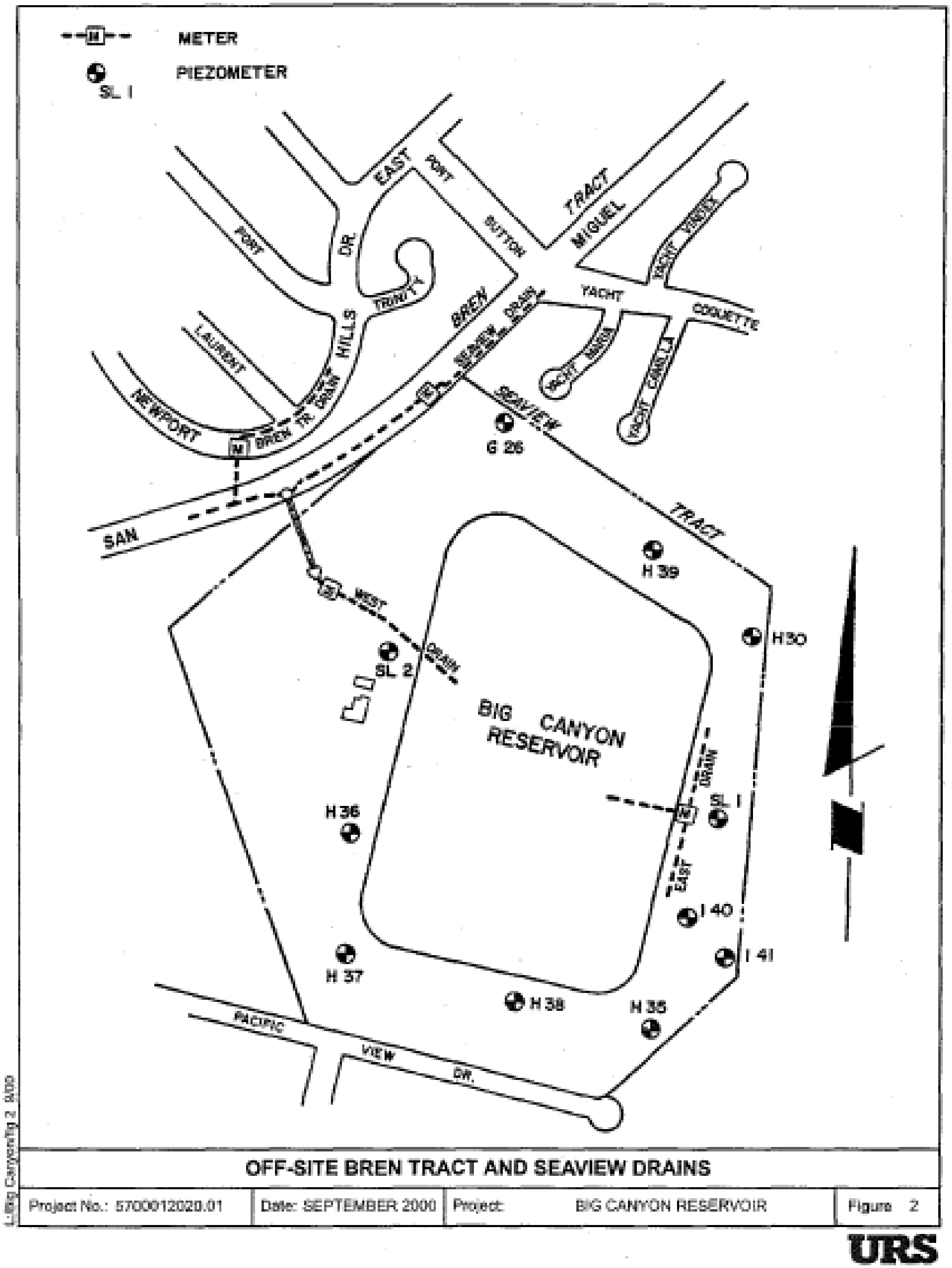


Figure 2-18. Map showing location of the Bren and Seaview subdrains installed in the 1970s to divert groundwater away from residential areas. Both drains discharge to the HVNP.

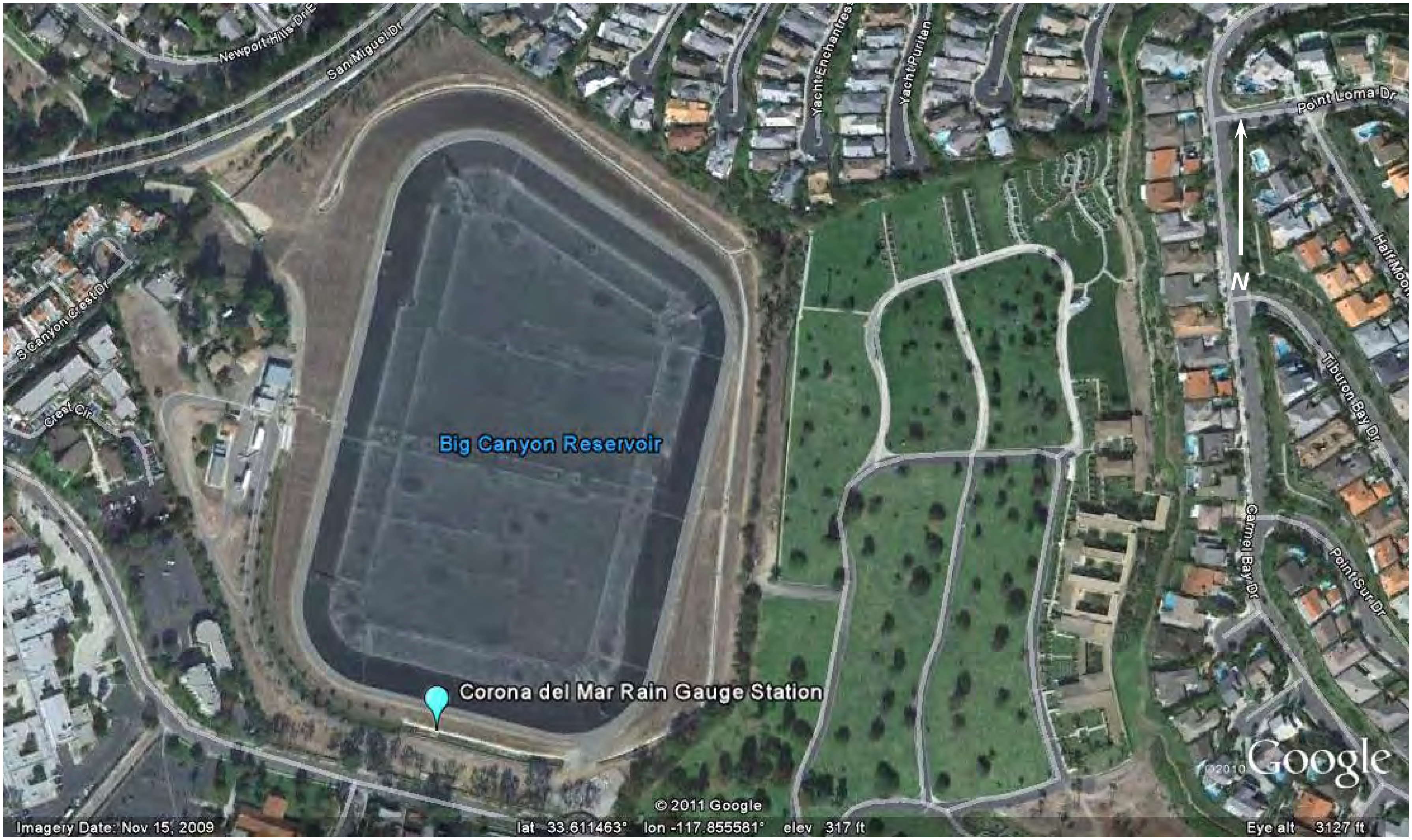


Figure 2-19. Approximate location of the Corona del Mar rain gauge station.

Figure 2-20. Rainfall measured at the Corona del Mar rain gauge station from July 1969 to June 2010.

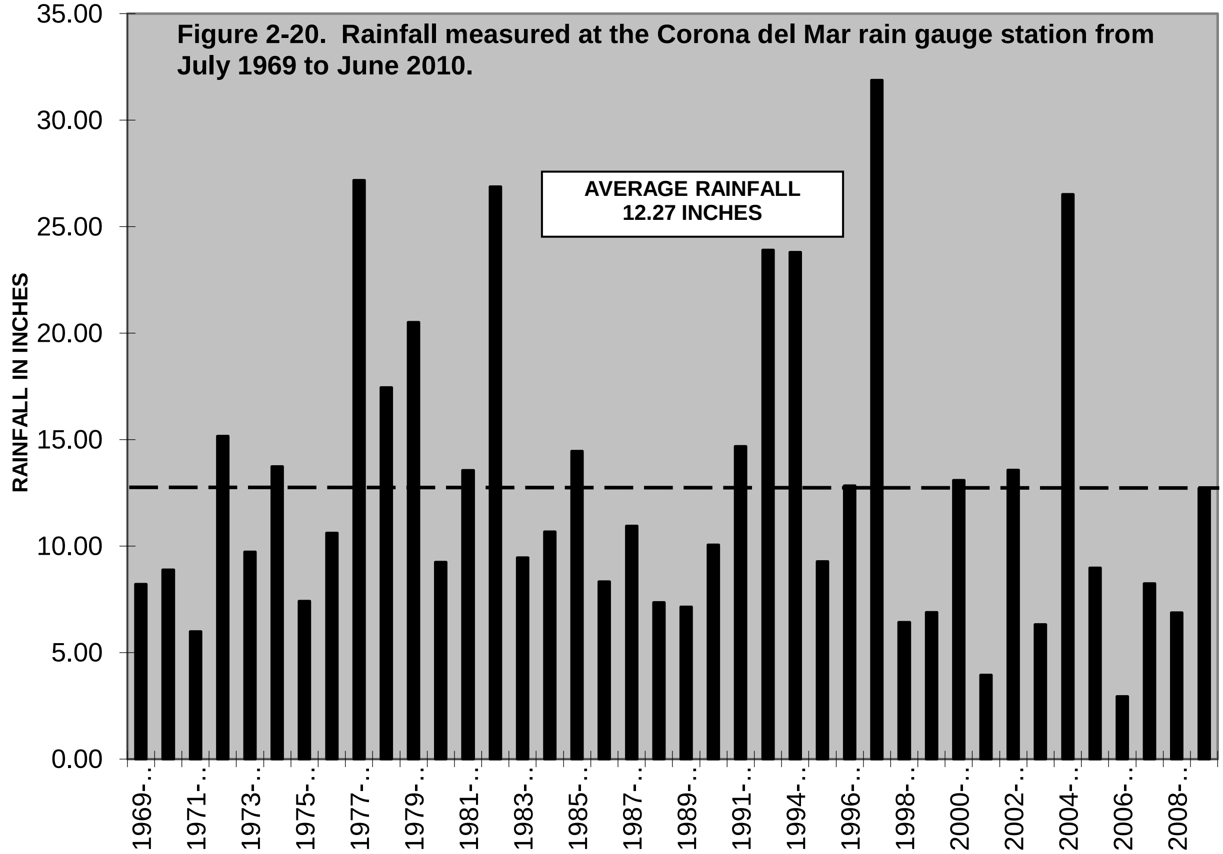


Figure 2-21. Selenium concentration verses precipitation. (Precipitation measurements are from the Corona del Mar rain gauge station and selenium concentrations measured at BCWG04.)

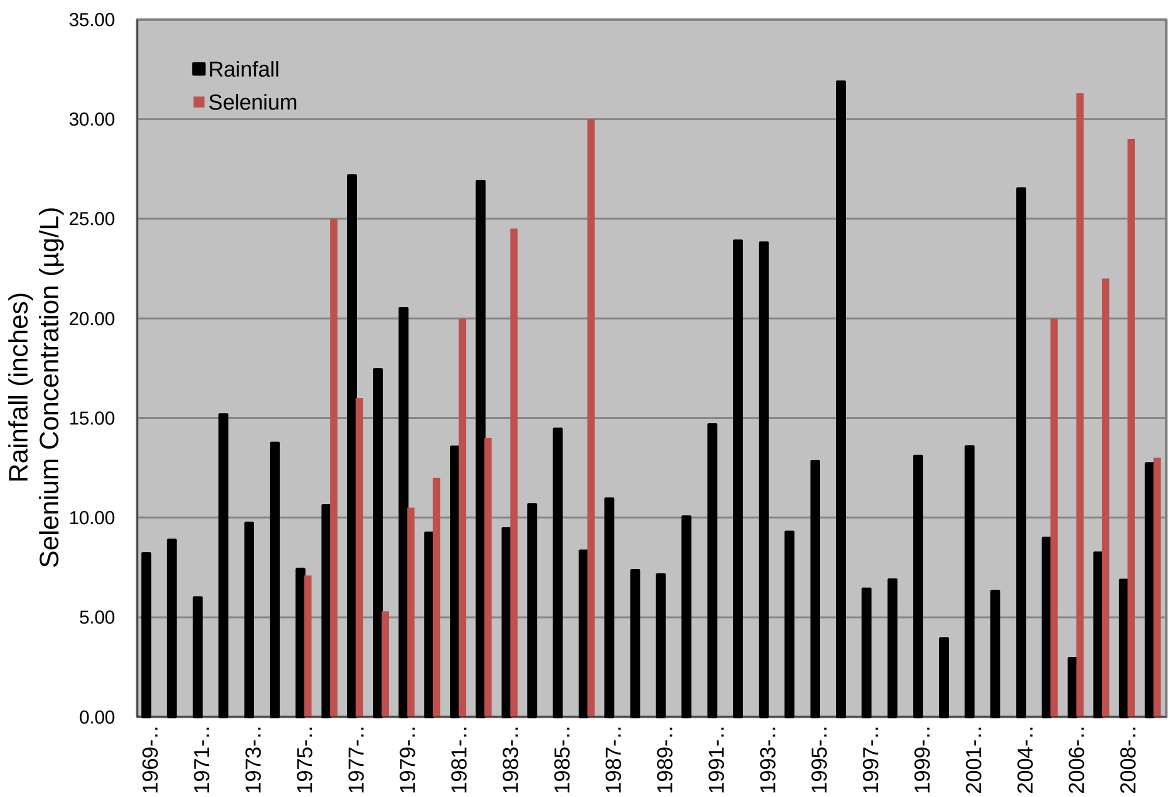


Table 2-1A. Selenium Data - Newport Coast Creeks

Station ID	Alternate Station ID	Station Location	Date Sampled	Sample Matrix	Weather Event	Results	
						Se Total (µg/L)	Se Diss. (µg/L)
BGO	BGO	Buck Gully Offshore	9/28/2005	Saltwater	Dry	0.415	2.09
BGO	BGO	Buck Gully Offshore	9/28/2005	Saltwater	Dry	0.928	2.02
BGO	BGO	Buck Gully Offshore	10/17/2005	Freshwater	Wet	37.4	39.7
BGO	BGO	Buck Gully Offshore	10/17/2005	Freshwater	Wet	37.9	38.9
LCB	BG1	Buck Gully above weir	9/28/2005	Freshwater	Dry	65.8	58.4
LCB	BG1	Buck Gully above weir	9/28/2005	Freshwater	Dry	69.3	64.3
LCB	BG1	Buck Gully above weir	10/17/2005	Freshwater	Wet	46	47
LCB	BG1	Buck Gully above weir	2/13/2006	Freshwater	Wet	83.3	80
LCB	BG1	Buck Gully above weir	2/19/2005	Freshwater	Wet	61.3	64.9
LCB	BG1	Buck Gully above weir	2/27/2006	Freshwater	Wet	14	16
ECH	BG2	Buck Gully 20 yds dnstrm of 3 SDs	9/28/2005	Freshwater	Dry	95	96.1
PPY	BG3	Buck Gully storm drain(?)	9/28/2005	Freshwater	Dry	109	99.6
PPY	BG3	Buck Gully storm drain(?)	10/17/2005	Freshwater	Wet	4.58	4.65
PPY	BG3	Buck Gully storm drain(?)	2/13/2006	Freshwater	Wet	110	117
PPY	BG3	Buck Gully storm drain(?)	2/19/2005	Freshwater	Wet	90.8	85.7
PPY	BG3	Buck Gully storm drain(?)	2/27/2006	Freshwater	Wet	21.7	21.3
SGR	BG4	Buck Gully/Spy Glass Hill corg. pipe	9/28/2005	Freshwater	Dry	79.7	72.4
SGR	BG4	Buck Gully/Spy Glass Hill corg. pipe	2/13/2006	Freshwater	Wet	86.2	81.6
SJC	BG5	Buck Gully pool below waterfall	9/28/2005	Freshwater	Dry	6.7	21.5
BGC	BG6	Buck Gully	9/28/2005	Freshwater	Dry	12.1	5.42
BGU	BG7	Buck Gully - storm drain	9/28/2005	Freshwater	Dry	9.81	10
BGU	BG7	Buck Gully - storm drain	10/17/2005	Freshwater	Wet	2.12	1.89
BGU	BG7	Buck Gully - storm drain	2/13/2006	Freshwater	Wet	7.94	7.67
BGU	BG7	Buck Gully - storm drain	2/19/2005	Freshwater	Wet	3.46	3.74
BGU	BG7	Buck Gully - storm drain	2/27/2006	Freshwater	Wet	0.94	1.28
EMD	EMD	El Morro Canyon downstream	10/17/2005	Freshwater	Wet	6.17	6.19
EMD	EMD	El Morro Canyon downstream	2/13/2006	Freshwater	Wet	6.21	6.04
EMD	EMD	El Morro Canyon downstream	2/19/2005	Freshwater	Wet	1.82	4.93
EMD	EMD	El Morro Canyon downstream	2/19/2005	Freshwater	Wet	4.65	4.69
EMD	EMD	El Morro Canyon downstream	2/27/2006	Freshwater	Wet	7.17	7.42
EMO	EMO	El Morro Cyn Offshore	9/28/2005	Saltwater	Dry	ND	ND
EMO	EMO	El Morro Cyn Offshore	10/17/2005	Saltwater	Wet	0.118	0.077
EMO	EMO	El Morro Cyn Offshore	10/17/2005	Saltwater	Wet	0.111	0.075
EMU	EMU	El Morro Canyon upstream	9/28/2005	Freshwater	Dry	9.36	9.67

Table 2-1A. Selenium Data - Newport Coast Creeks (cont'd).

Station ID	Alternate Station ID	Station Location	Date Sampled	Sample Matrix	Weather Event	Results	
						Se Total (µg/L)	Se Diss. (µg/L)
EMU	EMU	El Morro Canyon upstream	2/13/2006	Freshwater	Wet	2.49	2.29
EMU	EMU	El Morro Canyon upstream	2/13/2006	Freshwater	Wet	2.05	1.83
LTD	LTD	Los Trancos Canyon downstream	10/17/2005	Freshwater	Wet	15	14.5
LTU	LTU	Los Trancos Canyon upstream	9/28/2005	Freshwater	Dry	154	142
MCC	MCC	Muddy Canyon	9/28/2005	Freshwater	Dry	20	19.7
MCC	MCC	Muddy Canyon	10/17/2005	Freshwater	Wet	4.81	4.52
MCD	MCD	Morning Cyn Creek	9/28/2005	Freshwater	Dry	105	109
MCD	MCD	Morning Cyn Creek	10/16/2005	Freshwater	Wet	17.1	19.3
MCD	MCD	Morning Cyn Creek	2/19/2005	Freshwater	Wet	47.8	49.4
MCD	MCD	Morning Cyn Creek	2/27/2006	Freshwater	Wet	22.3	24.8
MCD	MCD	Morning Cyn Creek	2/27/2006	Freshwater	Wet	22.1	24.7
MCU	MCU	Morning Cyn Ck NE	9/28/2005	Freshwater	Dry	50.5	48.7
MCU	MCU	Morning Cyn Ck NE	10/16/2005	Freshwater	Wet	21.5	24.7
MCU	MCU	Morning Cyn Ck NE	2/19/2005	Freshwater	Wet	5.48	5.8
MCU	MCU	Morning Cyn Ck NE	2/27/2006	Freshwater	Wet	3.84	3.96
PP1	PP1	Pelican Point Creek	9/28/2005	Freshwater	Dry	18.6	16.9
PP1	Pelican 1	Pelican Point Creek	10/16/2005	Freshwater	Wet	4.28	1.81
PP1	Pelican 1	Pelican Point Creek	2/19/2005	Freshwater	Wet	10.2	10.4
PP1	Pelican 1	Pelican Point Creek	2/27/2006	Freshwater	Wet	2.55	2.59
PPD	PPD	Pelican Point Creek downstream	2/27/2006	Freshwater	Wet	4.34	4.98
PPU	PPU	Pelican Point Creek upstream	2/27/2006	Freshwater	Wet	10	11.1
PPM	PPM	Pelican Point Ck Middle	9/28/2005	Freshwater	Dry	22.5	23.1
PPM	PPM	Pelican Point Ck Middle	10/16/2005	Freshwater	Wet	5.87	5.9
PPM	PPM	Pelican Point Ck Middle	2/19/2005	Freshwater	Wet	9.02	9.53
PPM	PPM	Pelican Point Ck Middle	2/27/2006	Freshwater	Wet	15.1	15.1
PPW	PPW	Pelican Point Waterfall Ck	10/16/2005	Freshwater	Wet	2.11	0.8
PPW	PPW	Pelican Point Waterfall Ck	2/19/2005	Freshwater	Wet	3.34	3.02
PPW	PPW	Pelican Point Waterfall Ck	2/27/2006	Freshwater	Wet	2.24	2.04

Data is from the Newport Coast Flow and Water Quality Assessment report prepared for the City of Newport Beach by Weston Solutions, Inc. (2007).
Highlighted cells indicate that concentration exceeds the CTR freshwater criterion for total recoverable selenium of 5 µg/L.

Table 2-1B. Selenium Concentrations Measured in Dry Weather Flows in Buck Gully and Aliso Creek.

BUCK GULLY			**ALISO CREEK WET CAT INSTREAM WETLAND†**			
Station*	Date	Se (ug/L)	Station	Date	Se (ug/L)	
BGH01	10/27/05	73			Inflow	Outflow
BGH01	10/4/06	61	Wet CAT[1]	11/18/04	36.6	29.9
BGH01	6/7/07	26	Wet CAT	12/16/04	43.9	39.4
BGH01	11/6/07	24	Wet CAT[2]	1/20/05	52	44.6
BGH01	5/13/08	18	Wet CAT	3/09/05	52.4	42.7

* Buck Gully Wash at Little Corona Beach (Source: OCRDMD 2008 Annual Storm Water Report)
† Aliso Creek Wetland Capture and Treatment (Wet CAT) network BMP (Source: SCCWRP 2005, Technical Report 461): [1]pre-BMP samples [2] post-BMP samples

Table 2-2. Surface flow rates estimated by CH2M Hill staff in May 2009 on the BCCC golf course (BCW Middle).

Location	**Flow Rate (cfs)**	**Flow Rate (gpd)**
BCW Middle		
Inflow 1 (south branch BCW creek)	0.082	52,998
Inflow 2 (middle branch BCW creek)	0.121	78,204
Inflow 3 (north branch BCW creek)	0.032	20,682
Inflow 4+ (storm drain discharge into north branch BCW creek)	0.016	10,341
Inflow 5 only (storm drain discharge into north branch BCW creek)	0.01	6,463
Outflow (to BCNP; *BCW Lower*)	0.3	193,895

Table 2-3. Flow rates estimated during the June 2010 monitoring event by Orange County and Regional Board staff.

Location	**Flow Rate (cfs)**	**Flow Rate (gpd)**
BCW Upper		
HVNP (south branch BCW creek)	0.038	24,560
BCW Middle		
Inflow 1 (south branch BCW creek)	0.205	132,495
Inflow 2 (middle branch BCW creek)	0.132	85,314
Inflow 3 (north branch BCW creek)	0.004	2,585
Lake 5 outlet	0.530	342,548
Cummulative inflows from BCW creek	0.341	220,394
Outflow (to BCNP; *BCW Lower*)	0.819	529,333
Unmeasured inflows to BCCC golf course	0.478	308,939

Table 2-4. April 20, 2007 Rain Event and BCW Creek Flow Measurements, BCNP

		Station #2	Station #4		CDM
Date	**Time**	**Discharge (cfs)**	**Discharge (cfs)**	**Stream Stage**	**Cummulative Rainfall (inches)**
4/20/2007	800		0.3		2.05
4/20/2007	950		0.19		2.05
4/20/2007	1030		0.3		2.05
4/20/2007	1100		0.44		2.09
4/20/2007	1130		0.35		2.17
4/20/2007	1200		0.22		2.17
4/20/2007	1230		0.44		2.17
4/20/2007	1300		0.56	Rise	2.19
4/20/2007	1440		1.21		2.2
4/20/2007	1505	0.59	2.47	Peak	2.26
4/20/2007	1643		2.47		2.32
4/20/2007	1705		1.45		2.32
4/20/2007	1726		2.47		2.32
4/20/2007	1741		2.19		2.32
4/20/2007	1845		2.47	Fall	2.32
Total Gain		**NA**	**>2**		**0.27**

Notes: Flow data is from Weston Solutions, Inc. (2007)

CDM = Corona Del Mar rain gauge located at Big Canyon Reservior

Sta#2 = located at culvert at Jamboree Road where BCW creek enters the BCNP from the BCCC golf course
Sta #4 = located near mouth of Big Canyon Wash creek main channel outlet to UNB, at Back Bay Drive (BCWG04)

NA - not enough data to analyze

Table 2-5. May 29 – June 1, 2007 Dry Weather Flow Measurements, BCNP

	Discharge (cfs)	
Date and Time Recorded	**Station #2**	**Station #4**
5/29/07 8:30	0.29	
5/29/2007 10:50		0.74
5/29/2007 11:35	0.53	
5/29/2007 12:30		0.56
5/30/2007 10:00		0.44
5/31/2007 9:50		0.44
6/1/2007 9:54		0.44

Notes:

Flow data is from Weston Solutions, Inc. (2007)

Sta#2 = located at culvert at Jamboree Road where BCW creek enters the BCNP from the BCCC golf course
Sta #4 = located near mouth of Big Canyon Wash creek main channel outlet to UNB, at Back Bay Drive (BCWG04)

Table 2-6. Bren Tract Drain Discharge Data

Date	Discharge (GPM)	Date	Discharge (GPM)
3/21 - 4/2/75	3.38	8/21 - 8/25/75	3.92
4/2 - 4/3/75	2.98	8/25 - 8/29/75	4.18
4/7 - 4/18/75	4.03	8/29 - 9/2/75	4.20
4/18 - 5/5/75	2.55	9/2 - 9/5/75	4.23
5/5 - 5/16/75	2.89	9/5 - 9/12/75	4.11
5/16 - 5/30/75	0.83	9/12 - 9/19/75	4.27
5/30 - 6/13/75	2.88	9/19 - 9/25/75[a]	3.86
6/13 - 6/23/75	2.90	- -	
6/23 - 6/27/75	3.06	7/26/1976	0.02
6/27 - 6/30/75	3.33	9/20/1976	0.30
6/30 - 7/3/75	3.27	10/8/1976	1.10
7/3 - 7/7/75	3.31	10/22/1976	0.40
7/7 - 7/11/75	3.49	11/12/1976	0.40
7/11 - 7/18/75	3.53	11/29/1976	1.80
7/18 - 7/25/75	3.73	12/13/1976	1.80
7/25 - 8/1/75	3.65	12/27/1976	1.70
8/1 - 8/4/75	3.74	1/13/1977	3.00
8/4 - 8/8/75	4.07	1/31/1977	2.40
8/8 - 8/12/75	3.79	2/7/1977	2.00
8/12 - 8/15/75	3.82	2/25/1977	2.10
8/15 - 8/21/75	4.10	3/13/1977	1.60

[a] After 9/29/75, all drain measurements were taken by City of Newport Beach staff. JMM (1975) measurements are cummulative measurements of discharge for the period indicated. City measurements (1976-77) are single point in time measurements made on the date listed.

3.0 Previous Water Quality Investigations in the Big Canyon Wash Watershed

Water quality data has been collected from BCW watershed since the mid-1970s by Orange County as part of their storm water monitoring programs. In 2005-2006 and 2008-2009, Orange County also included BCW creek as one of their Urban Stream Bioassessment Sites and conducted both toxicity testing and chemical analysis on dry season water samples collected from a site in the BCNP. In 2006-2007, Weston Solutions, Inc. collected water samples for chemical analysis and toxicity testing as part of the effort to develop a plan to restore the BCNP. Information from the County's bioassessment reports and Weston Solutions are discussed briefly below and toxicity data from these reports are included in Appendix 3A.

In addition to the above sampling and testing, three years of sampling and data analysis focusing on selenium have now been conducted in the BCW watershed. The locations sampled in BCW watershed from 2008-2010 are shown in Figure 3-1. The first focused data collection effort took place in 2008 as a means to collect baseline data as part of the effort to restore the BCNP. Sampling efforts in 2009 included additional sampling of water, sediment, and biota in the BCNP and the collection of water column and suspended particulate samples for analysis of selenium and other constituents in BCW creek as it passes through the BCCC golf course, located directly upstream of the BCNP. In May and June of 2010, as part of the NSMP monitoring program for the Newport Bay watershed, CH2M Hill collected fish from the pond in the lower part of the BCNP and collected bird eggs from the BCCC golf course for analysis of selenium and trace metals. The June 2010 sampling conducted by Regional Board staff and others discussed in Section 4.0 of this report expanded on and provided complementary data to CH2M Hill's 2009 and 2010 sampling in the BCCC golf course. Copies of CH2M Hill's technical reports can be found in Appendix 3B.

3.1 BCW Watershed Water Column Toxicity Testing

Both Orange County and Weston Solutions collected water samples from BCW creek in the BCNP (BCW Lower) and submitted them for chemical analyses and toxicity testing. Weston Solutions submitted both wet (4/20/07) and dry (5/29/07) weather water column samples for toxicity testing collected from Stations 2 and 4 (see Figure 2-9 for station locations). The wet weather sample was subjected to acute toxicity testing using the 96-hour survival test for the amphipod *Hyalalla azteca*. The dry weather sample was subjected to chronic toxicity testing using the cladoceran (water flea) *Ceriodaphnia dubia* 7-day test for both survival and reproduction. While toxicity was noted in both the dry and wet weather samples, the chronic reproduction test performed on Ceriodaphnia displayed the greatest toxicity (Tables 3-1 and 3-2). Orange County conducted toxicity testing in BCW creek in the BCNP from 2005 to 2008 (see Figure 2-8 for the location in the nature park where County staff collected their water samples from 2005 through

2008). The chronic toxicity test results for the County's samples also indicated reproductive toxicity for Ceriodaphnia (Table 3-3). Copies of Weston Solutions, Inc. and Orange County's toxicity data are included in Appendix 3A.

Metals and pyrethroids (cis- and trans-permethrin) have been found to be toxic to Ceriodaphnia (PAN Exotoxicity database, http://www.pesticideinfo.org/Search_Ecotoxicity.jsp). Sutula et al. (2008) found elevated concentrations of bifenthrin and permethrin, two synthetic pyrethroid compounds, and cadmium and nickel in sediments in the riparian and marsh areas in the lower portion of the BCNP. Weston Solutions (2007) found concentrations of bifenthrin in wet weather water flows and prallethrin in dry weather flows in the nature park in 2006. The Sutula et al. (2008) study of urban wetlands concluded that the sediment toxicity observed in all 10 of the wetland sites studied (including BCNP) was likely due to pyrethroid pesticides, but that without fractionation and confirmation studies, the contaminant(s) responsible for the toxicity observed could not be conclusively identified.

While selenium is known for its adverse reproductive effects in fish and birds, there has been little scientific research conducted on selenium effects in invertebrates. Though some research has indicted that excessive selenium may impact sensitive invertebrates (Janz et al., 2010), the sensitivity of Ceriodaphnia to selenium concentrations has not been well documented, especially with regards to adverse effects. Additive effects may also be a contributing factor to reproductive toxicity in Ceriodaphnia, but there is no clear guidance on how to accurately represent synergistic effects, which may vary from site to site or over time.

3.2 2008 CH2M Hill Selenium Baseline Sampling: BCNP

In 2008, the Regional Board and the City of Newport Beach jointly funded an effort to collect baseline water, sediment, and biological data on selenium and trace metals concentrations in the BCNP in order to assess current water quality conditions and potential impacts on restoration efforts. Water, sediment, algae, invertebrates, fish, and frogs were collected from several areas within the BCNP. No nesting birds were found in the BCNP so no bird eggs were collected.

Selenium concentrations measured in all media collected were greater than their applicable water quality criteria or biological effects guidelines (Table 3-4). The freshwater marsh pond located at the western end of BCNP, just east of UNB, was the site of the highest selenium concentrations measured in sediment and fish tissue samples collected from the nature park. Selenium concentrations measured in mussels collected from the saltwater marsh at the mouth of BCW (Figure 3-2) exceeded the biological effects guidelines for selenium in bird diet, but the selenium concentrations in the mussels were much lower than selenium concentrations measured in invertebrates (dragonfly larvae and crayfish) collected from the freshwater areas of the nature park. Birds foraging in the freshwater portions of the nature park appear to be at greater risk from adverse effects of selenium than those that collect most of their food items from the adjacent saltwater marshes. (A copy of CH2M Hill's report for the sampling they conducted in 2008 in the BCCNP is included in Appendix 3B.)

Selenium concentrations measured in sediment and biota collected from the BCNP were compared to selenium concentrations measured in similar samples collected from the San Diego Creek (SDC) watershed (Table 3-5). Although total selenium concentrations measured in water samples collected from BCW creek were similar to selenium concentrations measured in water samples collected from SDC, selenium concentrations in other media were found to be 5 (macroinvertebrates) to 100 (sediment) times higher in the samples collected from BCW (Table 3-5). The percentage of the most bioaccumulative form of inorganic selenium, selenite (Se IV), measured in BCW creek was double that measured in SDC and the partitioning coefficient, or K_d – a measure of how efficiently a system may bioaccumulate selenium – calculated for BCW creek was 10 times higher than the K_d calculated for SDC. These factors indicate that the water bodies in BCW are more efficient at cycling and retaining selenium than SDC, likely because flows in BCW are more lentic in nature and residence times are greater for particulates and organisms, allowing more time for selenium to enter and accumulate in the food web.

Based on the results of this investigation, Regional Board staff recommended that additional monitoring data be collected from the water bodies in the BCNP and areas upstream of the park to try to determine the source(s) of the water and selenium entering the nature park.

3.3 2009 CH2M Hill Selenium Source Tracking Sampling: BCNP and BCCC Golf Course

Samples were collected on May 8, 2009, by CH2M Hill staff in the BCNP and in water bodies located on the BCCC golf course, located directly upstream of the nature park, to characterize waterborne selenium, selenium speciation, and trace metals throughout this portion of the BCW watershed. Selenium concentrations measured in the biota collected in the BCNP were still above their applicable criteria and were only slightly lower than those measured in 2008. No nesting birds were found in the nature park or on the golf course grounds, so no bird eggs were collected.

On the BCCC golf course, water samples and some suspended particulate samples were collected from the creeks and lakes on the golf course and at the flow outlet structure where BCW creek exits the golf course and flows under Jamboree Road and into the BCNP (Figure 3-3). Total selenium concentrations measured in all of but one of the water samples collected from the water bodies on the BCCC golf course exceeded the CTR chronic freshwater criterion for selenium of 5 µg/L (Table 3-6). The selenium concentration measured in the water sample collected from the middle branch of BCW creek (Inflow 2) was just below the CTR chronic criterion.

As can be seen in Table 3-6, the relative percentages of selenite and organic selenium increased down-gradient as water flowed through the lakes and riparian areas along the south side of the golf course, indicating an increased potential for bioaccumulation of selenium in these areas. However, sufficient funds were not available in 2009 to collect sediment and tissue samples from the water bodies on the BCCC golf course for selenium analysis. A copy of CH2M Hill's report for the sampling they conducted in 2009 in the BCNP and BCCC golf course is included in Appendix 3B.

3.4 2010 CH2M Hill Selenium Tissue Sampling: BCNP and BCCC Golf Course

The objective of the sampling conducted by CH2M Hill in 2010 was to conduct additional fish and bird egg tissue monitoring for selenium to add to baseline data for the Newport Bay watershed and to assist in the development of selenium TMDLs/SSOs. The sampling and analyses were funded by the NSMP. Twenty (20) primarily fish tissue composite samples and thirty (30) individual bird egg samples were collected in the Newport Bay watershed from SDC (including the Irvine Ranch Water District and University of California, Irvine wetlands), Peters Canyon Wash, Upper Newport Bay (bird eggs only), and BCW creek in May and June, 2010.

In BCW, three (3) composite samples of mosquitofish were collected from the marsh pond in the lower portion of the BCNP on May 20, 2010; no bird eggs were found in the nature park. Two (2) pied-billed grebe bird eggs were collected from nests located on the BCCC golf course near two of the golf course lakes (designated Lakes 4 and 5; see Figure 3-3) on June 14, 2010, but no other samples (water, sediment, fish, etc.) were collected from the BCCC golf course by CH2M Hill at that time.

Selenium concentrations measured in the whole body mosquitofish tissue composites collected from the BCNP ranged from 57.4 to 63.4 µg Se/g dry weight (dw), similar to tissue concentrations measured in samples collected from the same area in 2008 and 2009. Selenium concentrations in the pied-billed grebe eggs ranged from 33 µg Se/g dw (in the egg found near Lake 4) to 41 µg Se/g dw (in the egg located near Lake 5). These are the first bird eggs collected from the BCW watershed; however, given the concentrations of selenium measured in other media (e.g., sediment, algae, invertebrates, fish tissue) collected from this watershed, the relatively high concentrations of selenium measured in these two eggs[1] is not unexpected. A copy of CH2M Hill's report for their 2010 sampling effort is included in Appendix 3B.

[1] Regional Board staffs' proposed site-specific objective (SSO) for selenium in bird egg tissue for the Newport Bay watershed, which includes BCW, is 8.0 µg Se/g dw.

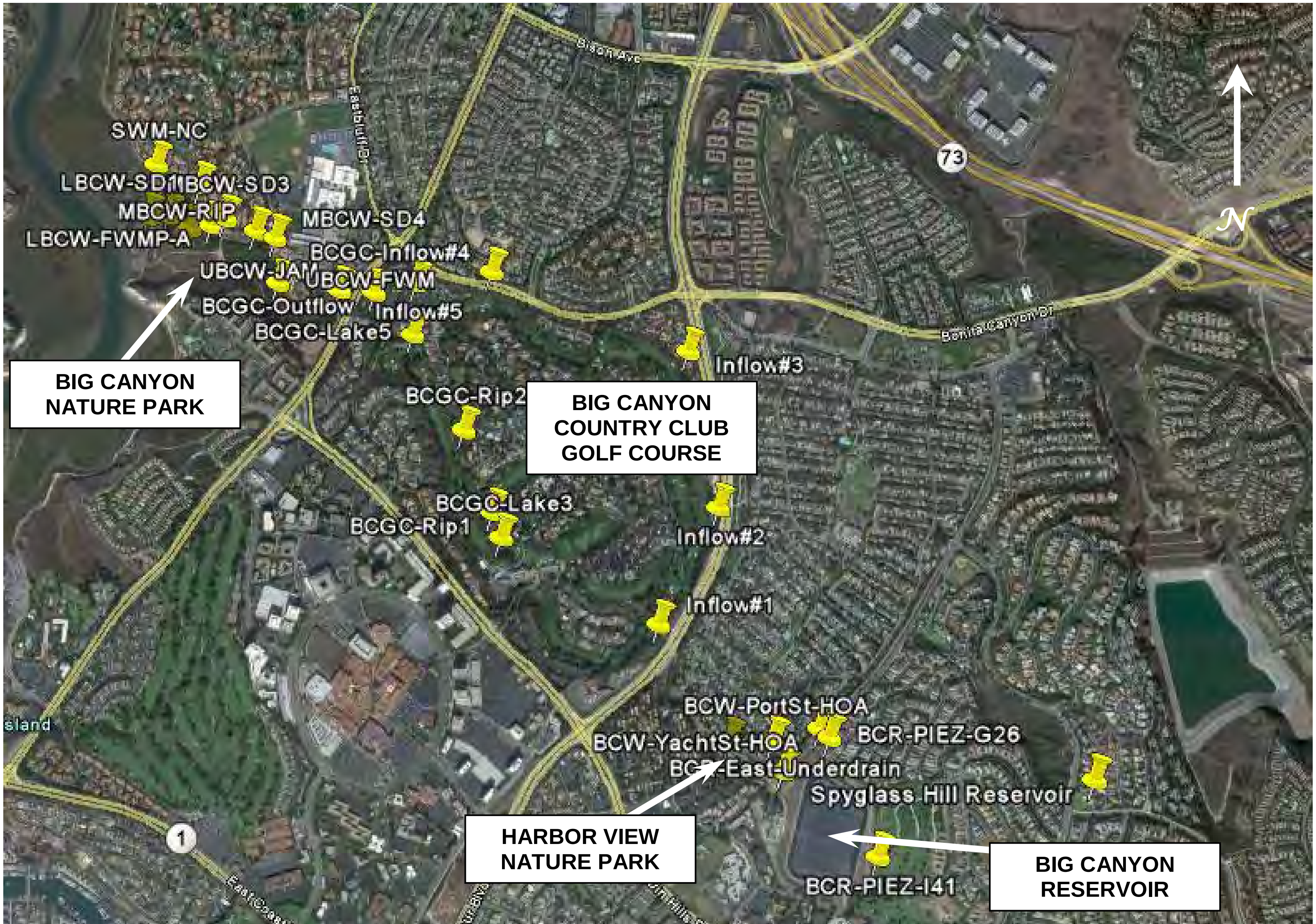


Figure 3-1. Important features and areas investigated for selenium concentrations in the Big Canyon Creek watershed, 2008-2010. (Note: At a minimum, water samples have been collected from all of the sample sites shown with the exception of water from within the Big Canyon and Spyglass Hill Reservoirs.)

Figure 3-2. Selenium concentrations measured in various media in water bodies in the Big Canyon Nature Park (data collected by CH2MHill in 2008).


Inflow 5
Inflow 4
Riparian 3
Big Cyn Nature Park
Outflow
Lake 6
Lake 5
Inflow 3
NB BCW
Big Cyn Country Club
and Golf Course
Riparian 2
Lake 4
Riparian 1
Inflow 2
MB BCW
Lake 3
Lake 1
Inflow 1
SB BCW
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Table 3-1. Acute Toxicity Test Results for Wet Weather Samples, BWC Creek (Weston Solutions, Inc., 2007)

Organism and Test	Sample ID	% Control Survival	% Survival Relative to Control	TUa
Hyalella azteca - 96 hour	Station #2	100	82.5	0.73
	Station #4		87.5	0.65

Table 3-2. Chronic Toxicity Test Results for Dry Weather Samples BCW Creek (Weston Solutions, Inc., 2007)

Organism and Test	Sample ID	NOEC %	LOEC %	EC_{50} (%)	TUc
Ceriodaphnia dubia - 7 day survival	Station #2	100	>100	>100	1
Ceriodaphnia dubia - 7 day reproduction		12.5	25	39	8
Ceriodaphnia dubia - 7 day survival	Station #4	50	100	>100	2
Ceriodaphnia dubia - 7 day reproduction		25	50	62	4

NOTES:

Station #4 is equivalent to Orange County's station BCWG04 that was used for monitoring BCW creek from 1970-1996. It is located near Back Bay Drive (see Figures 2-8 and 2-9).

LC50 - The lethal concentration (LC) of a substance killing 50 percent of exposed organisms within a specific time interval.

NOEC - No Observed Effect Concentration: The highest concentration of an effluent or a toxicant in a chronic bioassay that did not cause adverse effect statistically different from the control. Also known as the NOEL, No Observed Effect Level.

LOEC - Lowest Observed Effect Concentration: The lowest toxicant concentration of an effluent or a toxicant in a chronic bioassay that caused an adverse effect statistically different from the control. Also known as the LOEL, Lowest Observed Effect Level.

TU = Toxic Units: A measure of toxicity in effluent or water as determined by acute or chronic toxicity testing. The higher the TU, the greater the toxicity of the sample.

TUa = Toxic Unit Acute: a conversion of the LC50 into Toxic Units (Tua = 100/LC50). If the percent survival (S) of the control organism is greater than 99%, the TUa is reported as zero, which is the lowest TUa value possible.

TUc = Toxic Unit Chronic: A conversion of the NOEL or NOEC into Toxic Units (Tuc = 100/NOEC). The lowest TUc possible is 1, which means no toxicity.

Table 3-3. Orange County Toxicity Data for Dry Weather Monitoring in BCW Creek

Station Code	Date/Time Sample Collected	Acute Hyallela Azteca Survival (96-Hour)		Selenastrum Algae Growth		Ceriodaphnia Dubia (7-Day)					Fathead Minnow (7-Day)				
						Survival			Reproduction		Survival			Growth	
		TUa	LC50	TUc	NOEC	TUa	TUc	NOEC	TUc	NOEC	TUa	TUc	NOEC	TUc	NOEC
BCWG04	10/27/05	0.69	>100	1	100	0.59	1	100	>2	<50	0.51	1	100	1	100
BCWG04	7/12/06	0.41	>100	1	100	1.00	1	100	2	50	0.41	1	100	1	100
BCWG04	10/4/06 11:55	0.00	>100	1	100	0.00	1	100	2	50	0.00	1	100	1	100
BCWG04	6/7/07 8:20	0.00	>100	2	50	0.00	1	100	2	50	0.00	1	100	1	100
BCWG04	11/6/07 8:27	1.06	94	1	100	0.00	1	100	1	100	0.13	1	100	1	100
BCWG04	5/21/08 8:30	1.12	89	1	100	0.00	1	100	1	100	0.00	1	100	>2	<50
BCWG04	9/30/08 14:15	3.89	26	1	100	0.00	1	100	>2	<50	0.14	>2	<50	1	100

NOTES:

The BCWG04 monitoring station, used for bioassessment monitoring from 2005-2008, is located just upstream of the mitigation pond area in the lower portion of BCNP (see Figure 2-8).

LC50 - Lethal concentration of a substance killing 50 percent of exposed organisms within a specific time interval.

NOEC - No Observed Effect Concentration: The highest concentration of an effluent or a toxicant in a chronic bioassay that did not cause adverse effect statistically different from the control. Also known as the NOEL, No Observed Effect Level.

TU = Toxic Units: A measure of toxicity in effluent or water as determined by acute or chronic toxicity testing. The higher the TU, the greater the toxicity of the sample.

Tua = Toxic Unit Acute: a conversion of the LC50 into Toxic Units (Tua = 100/LC50). If the percent survival (S) of the control organism is greater than 99%, the TUa is reported as zero, which is the lowest TUa value possible.

Tuc = Toxic Unit Chronic: A conversion of the NOEL or NOEC into Toxic Units (Tuc = 100/NOEC). The lowest TUc possible is 1, which means no toxicity.

Table 3-4. Water quality criteria and biological effects guidelines for selenium.

CTR Criteria for Selenium

Freshwater		Saltwater	
Criterion Maximum Concentration (CMC) *[Acute Criterion]*	Criterion Continuous Concentration (CCC) *[Chronic Criterion]*	Criterion Maximum Concentration (CMC) *[Acute Criterion]*	Criterion Continuous Concentration (CCC) *[Chronic Criterion]*
µg/L			
Reserved[3]	5.0[1]	290	71[2]

[1] Expressed as total recoverable selenium
[2] Expressed as total dissolved selenium
[3] Per USFWS recommendation, USEPA agreed to reserve the acute freshwater aquatic life criterion in the final CTR for determination at a later date.

GUIDELINES FOR ASSESSING RISK TO AQUATIC LIFE AND AQUATIC-DEPENDENT WILDLIFE
ECOLOGICAL RISK THRESHOLDS FOR SELENIUM[1]

	None	Marginal	Substantive
Freshwater (µg/L)	<2	2–5	>5
Sediment (mg/kg)	<2	2–4	>4
Diet (mg/kg)	<3	3–7	>7
Fish (mg/kg diet) (whole body)	<4	4–6	>6
Avian eggs (mg/kg)	<6	6–10	>10

Note: sediment and tissue guidelines are dry weight values
[1] Presser et al., 2004

Table 3-5. Comparison of median selenium concentrations in surface waters and biota in BCW and SDC.

MEDIA	**SAN DIEGO CREEK BASIN 2**	**BIG CANYON NATURE PARK**
Water	15 µg Se/L	19 µg Se/L
Sediment	0.5 µg Se/g dry weight	54 µg Se/g dry weight
Algae	0.64 µg Se/g dry weight	35 µg Se/g dry weight
Macroinvertebrates	7 µg Se/g dry weight	32 µg Se/g dry weight
Fish	7 µg Se/g dry weight	57 µg Se/g dry weight
Percent Selenite (SeIV)	**<12%**	**>28%**
Partitioning Coefficient (Kd)*	**159**	**1637**

*Estimated from selenium concentrations in algae and bed sediment

Table 3-6. CH2M Hill selenium species concentrations and relative percentages, BCCC Golf Course, May 8, 2009

Location	Site	Total Se	Dissolved Se	Selenate (SeVI)	Selenite (SeIV)	Organic Se	Se VI	Se IV	Org Se
		(µg/L)					(%)		
North side of golf course	Inflow 3	64.5	62.9	63.5	0.91	ND	98.55	1.45	ND
	Inflow 4+	24.3	23.1	22	1.78	ND	92.29	7.71	ND
	Inflow 4 only*								
	Inflow 5+	28.7	28.7	21.2	3.58	ND	87.53	12.47	ND
	Inflow 5 only*	41.3							
South side of golf course	Inflow 1	41.7	39.8	29.7	7.4	0.25	80.78	18.59	0.63
	Inflow 2	4.74	4.52	4.12	0.37	ND	91.81	8.19	ND
	Lake 3	21.8	20.2	13.5	3.74	2.19	70.64	18.51	10.84
	Riparian 1	20.7	19.8	11.8	3.6	1.54	74.04	18.18	7.78
	Lake 4	15.9	14.3	6.24	5.02	0.73	59.79	35.10	5.10
	Riparian 2	15.4	14	6.56	5.07	0.32	61.50	36.21	2.29
	Lake 5	14.1	13.3	5.3	5.39	0.67	54.44	40.53	5.04
Outflow	Outflow	14.6	14.1	6.41	5.16	0.65	58.79	36.60	4.61

* Estimated by subtraction; Inflow 4 yielded negative results so estimates were not possible.

4.0 2010 Regional Board Team Selenium Source Tracking Investigation, BCCC Golf Course and BCR

In June 2010, Regional Board staff attained funding to collect additional water column samples, as well as sediment and biological samples, from the water bodies on the BCCC golf course and from several locations upstream of the golf course in and around BCR (including groundwater samples). This study expanded on the work conducted by CH2M Hill in 2009 and provided complementary data to CH2M Hill's 2010 sampling and analysis of bird eggs collected from the BCCC golf course.

The goals of this project were to:

1. Assess potential sources of selenium and flows upstream of the BCCC golf course.
2. Determine where and how selenium conversions are occurring upstream of the golf course.
3. Compare selenium concentrations and loads in the main tributaries of BCW creek that enter and exit the BCCC golf course to the concentrations measured in 2009 by CH2M Hill.
4. Determine selenium cycling and potential impacts to aquatic life in the golf course ponds and the HVNP.
5. Provide data to help build a conceptual model for selenium for the BCW watershed.
6. Determine if preliminary estimates of potential sources of water and selenium (e.g., leakage from BCR, irrigation, leaking potable water lines) can be made based on general chemical parameters (i.e., use of Piper diagrams or Stiff plots).
7. Provide additional information that can be used in assessing potential selenium source controls and treatment options.
8. Collect data to aid in designing a long-term selenium monitoring and management program for the BCW watershed.
9. Provide additional data that can be used to refine the Newport Bay watershed biodynamic model for the BCW watershed.

4.1 Sampling and Analytical Methods

On June 21, 2010, surface water, groundwater, particulates, sediment, algae, and biota (fish, invertebrates, and frogs) were collected from surface waters in the BCCC golf course and the HVNP, and groundwater samples were collected from various areas around the BCR to determine potential sources of selenium, selenium cycling, and selenium concentrations in, and potential impacts to, aquatic life. Regional Board staff was assisted by staff of the City of Newport Beach, County of Orange, California Department of Fish and Game (DFG), and California State University, Long Beach (Regional Board Team). The sampling and analysis plan (SAP) used for the project is included as Appendix 4A. The sample locations are shown on Figure 4-1. The Regional Board Team collected a total of six (6) groundwater samples from piezometers, underdrains, or subdrains located in and around BCR and seven (7) surface water samples from water bodies on the BCCC golf course and in the HVNP. Three (3) sediment samples, four (4) particulate samples, three (3) composite algae samples, two (2) composite crayfish samples, three (3) composite whole body mosquitofish samples, and one (1) composite whole body African-clawed frog sample were collected from two of the lakes on the BCCC golf course (Lakes 3 and 5) and at the upper (eastern) end of the HVNP.

4.1.1 Surface Water Flow Measurements and Field Data Collection

The Regional Board Team was divided into three sampling teams: one team to collect groundwater samples (Groundwater Team); one to measure and collect surface water samples from the three main branches of BCW creek (Inflows 1, 2, and 3) where they daylight on the golf course and from the golf course outflow structure located just east of Jamboree Road (Surface Water Team); and one to collect water, particulates, sediment, algae, and tissue samples from BCCC golf course Lakes 3 and 5 and the HVNP (Multi-media Team). The Surface Water Team also measured flows at the outlet from BCCC Lake 5. The outlet for Lake 3 was not accessible for flow measurements due to abundant vegetative growth (cattails) and the outlet design (small drain with a grill cover).

Only one Geographical Positioning System (GPS) unit was available for the sampling event (a Garmin GPS 76 hand held unit); this unit was used by the Surface Water and Multi-media Teams to record the locations sampled on the BCCC golf course and in the HVNP. The accuracy of the Garmin unit is 10^{-5} degrees. The groundwater sampling locations were estimated using Google™ Earth.

Temperature, pH, conductivity, and dissolved oxygen were measured at each sampling location in the field. In addition, turbidity was also measured at the groundwater sampling locations. Field parameters were measured at the surface water sampling locations using a YSI-6600 sonde and at the groundwater sampling locations using a Horiba U-10 water quality checker. The field data sheets are included in Apppendix 4B and information on the YSI-6600 and Horiba U-10 water quality probes are included in Appendix 4C.

Depth to groundwater was measured in the two piezometers located along the northwestern (G-26) and southeastern (I-41) margins of the BCR using an electronic water level well sounder and recorded on the field data sheets (Appendix 4B).

Flow measurements were taken by Orange County staff at the HVNP, at Inflows 1, 2, and 3 on the BCCC golf course, the outlet from BCCC Lake 5, and the outlet structure from the BCCC golf course where the conjoined flows from BCW creek exit the golf course. Flows were measured using the Flow Tracker Handheld Acoustic Doppler Velocimeter (Photograph 4-1). A cross sectional area was selected for measurement for each channel and divided into numerous subsections. The discharge was measured in each subsection using the velocity-area method (the discharge measurement is calculated by measuring the width, depth, and velocity of each subsection). For areas with low flows, sand bags were used to channel and concentrate the flow so it could be measured (Photograph 4-2). Since the flow velocity in natural channels generally pulsates, the velocity for each subsection was measured for at least 40 seconds to better represent the average velocity at that point. The flows at Inflow 3 (north branch of BCW creek) were too low to be measured using the velocimeter and were estimated by Orange County staff. Information on the Flow Tracker velocimeter is included in Appendix 4D.

Flow data and field parameters measured for this project are shown in Table 4-1.

4.1.2 Groundwater Sample Collection

Grab samples were collected from two, 2 inch diameter groundwater piezometers located at the northwestern and southeastern ends of BCR (BCR-PIEZ-G26 and BCR-PIEZ-I41, respectively; Figure 4-2) The depth to groundwater was measured in piezometer G-26 at 8.5 feet and in piezometer I-41 at 31.5 feet. The total depth and construction design of the groundwater piezometers is not known at this time and the Groundwater Team did not have the equipment to purge the piezometers. Therefore, the first sample was discarded and a second sample taken to provide some circulation and inflow into the piezometer.

Groundwater samples were collected from the piezometers using a clear plastic (polyethylene) sanitized bailer (Photographs 4-3 and 4-4). The groundwater samples could not be transferred directly from the bailer into the sample bottles so the sample in the bailer was poured into a clean, sanitized plastic bucket, and then into the sample bottles. The sample pulled from piezometer G-26 was cloudy with suspended silt particles, indicating either that the well was shallow in depth or partially silted up. The turbidity of the sample did not affect the analytical results for the constituents of concern (selenium and trace metals) because the sample was filtered in the laboratory prior to analysis. No silt was observed in the sample pulled from piezometer I-41.

Grab samples were collected from the east and west underdrains at BCR (Photograph 4-5). A groundwater sample was collected from the discharge pipe for the sump pump for the BCR-WEST-Underdrain. The sample from the BCR-EAST-Underdrain was collected directly from the 8 inch diameter pipe which discharges directly from the underdrain. This drain is gravity-flow, not pumped. Grab samples from the Yacht and Port Street Home Owners Association (HOA) subdrains[1] were collected using a clean plastic bucket lowered into the drain via the manhole (Photograph 4-6).

All groundwater samples were transferred to clean, labeled plastic bottles and placed in a cooler on ice for shipment to the analytical laboratory[2]. Groundwater samples were submitted to E.S. Babcock and Sons, Inc. Environmental Laboratories (ESB) for

[1] These two subdrains are refered to as the Seaview (Yacht St HOA) and Bren (Port St HOA) subdrains. At the time of the sampling, the names of the subdrains were not known and they were labeled based on their geographic locations.

[2] Sample container types and preservatives (if needed) as well as analytical methods used can be found in the SAP in Appendix 4A.

analysis of cations, anions, hydroxide, bicarbonate, carbonate, total dissolved solids, and trace metals. Groundwater samples were also submitted to Applied Speciation and Consulting LLC (ASC) for selenium analyses[3]. All groundwater samples were filtered in the laboratory prior to analysis. Two groundwater samples (BCR-PIEZ-I41 and BCR-West-Underdrain) were also submitted to ASC for selenium speciation analyses. Analytical methods, sample containers, preservatives and holding times are listed in Table 5 in the SAP (Appendix 4A). Chain-of-custody forms for the groundwater samples are included in Appendix 4E.

4.1.3 Surface Water and Particulate Sample Collection

Surface water samples were collected from the HVNP (located in the south branch of BCW creek upstream of the BCCC golf course; Photograph 4-7), and the south, middle, and north branches of BCW creek where they flow into the BCCC golf course (Inflows 1, 2, and 3, respectively) (Photographs 4-8, 4-9, and 4-10). Surface water samples were also collected from BCCC golf course Lakes 3 and 5 (Photographs 4-11, 4-12, and 4-13), and the golf course outflow structure (Photograph 4-14), where flows are funneled through a culvert under Jamboree Road and into the BCNP. Surface water sample locations are shown on Figure 4-3.

All surface water samples were grab samples. Surface water samples were submitted to ESB for analysis of cations, anions, hydroxide, bicarbonate, carbonate, total dissolved solids, and trace metals. All surface water samples were also submitted to ASC for total and dissolved selenium analyses. Five (5) of the six (6) surface water samples collected were also submitted to ASC for analysis of selenium species.

In order to obtain sufficient material for collection and analysis of particulates, two liter samples of surface water were collected from the HVNP, BCCC golf course Lakes 3 and 5, and the outflow to the BCNP. Particulates were filtered from these samples in the ASC laboratory. The filtrate was dried and analyzed for total selenium, cadmium, copper, lead, nickel, zinc, and total suspended solids.

Analytical methods, sample containers, preservatives and holding times for surface water and particulates are listed in Table 5 in the SAP, which can be found in Appendix 4A of this report. Chain-of-custody forms for the surface water and particulate samples can be found in Appendix 4E.

4.1.4 Sediment, Algae, and Tissue Sample Collection

Sediment, algae, and tissue samples were collected from the BCCC golf course Lakes 3 and 5 and from the HVNP. Sediment and algae samples were not collected from the outflow area due to a lack of sufficient material to sample. The outflow area is a terraced concrete and rip-rap lined channel which drops down from the golf course to

[3] Traditional EPA Method 200.8 does not work well for selenium; the method tends to overestimate the amount of selenium in the sample because of interference from other, as of yet, undetermined constituents. ASC uses a Dynamic Reaction Cell to help reduce this interference and to provide a more accurate assessment of the amount of total selenium in the sample. In addition, ASC has the ability to analyze samples for selenium species, which ESB is not able to do at this time.

flow into a culvert that passes beneath Jamboree Road into the BCNP (Photograph 4-14).

Samples from each location and for each media were composited, placed in clean, sterilized glass jars with plastic lids and stored on ice for transport to the analytical laboratory. For sediment, the upper two centimeters of material was collected from several locations in each water body with a plastic scoop, then composited before placing into glass jars.

Green filamentous algae samples were collected from BCCC golf course Lakes 3 and 5 and the HVNP. Crayfish (*Procambarus* species), Western mosquitofish (*Gambusia affinis*), and African clawed frogs (*Xenopus laevis*) were collected from the targeted water bodies using small, fine mesh dip nets. Two small composite samples of crayfish (Photograph 4-15) were collected from Lake 5. Mosquitofish (Photograph 4-15) were collected from BCCC golf course Lakes 3 and 5, and the HVNP; African clawed frogs (Photograph 4-16) were collected from Lake 3. Crayfish could not be found in Lake 3, likely as a result of its depth and steep sides. African clawed frogs were likely present in Lake 5 but were not observed during sampling. African clawed frogs however, were abundant in Lake 3; tadpoles, juveniles, and adult frogs were observed.

In addition, two pied-billed grebe (*Podilymbus podiceps*) bird eggs were collected from separate nests (one from a nest located adjacent to Lake 4, another from a nest found near Lake 5) on the BCCC golf course on June 14, 2010 by CH2M Hill just prior to the sampling conducted on June 21 by the Regional Board Team. Bird embryos were visually inspected for deformities by CH2M Hill staff and then the embryos and remaining tissues were submitted to CRG Laboratories for analysis of selenium and trace metals. No deformities were observed in the two pied-billed grebe (PBGR) eggs collected from the golf course.

Sediment, algae, and fish/frog tissue samples collected as part of this study were analyzed for selenium and trace metals (Cd, Cu, Ni, Pb, and Zn) only (the samples were not analyzed for nitrate) at the Institute for Integrated Research in Materials, Environments, and Society (IIRMES) laboratory located at California State University, Long Beach (CSULB). Analytical methods, sample containers, preservatives, and holding times are listed in Table 5 in the SAP (Appendix 4A). Chain-of-custody forms for the sediment, algae, and tissue samples are included in Appendix 4E.

4.2 Summary of Laboratory Quality Assurance/Quality Control

This summarizes the quality assurance procedures followed by the contract laboratories for this project, which included the analyses of water, sediment, algae, and tissue samples. The complete quality assurance report on the analytical results for the BCW watershed June 21, 2010 sampling event is included in Appendix 4F. The quality control samples were compared to the quality assurance procedures listed in the SAP (Appendix 4A). These procedures are Surface Water Ambient Monitoring Program (SWAMP) quality assurance criteria. The quality control procedures were communicated to ESB the main contract laboratory for this project via electronic mail two weeks prior to the start of sampling though the final SAP was not completed until June 18, 2010.

ESB subcontracted ASC for the selenium speciation analyses and IIRMES for collection and analysis of sediment, algae, and tissue samples.

Samples were collected from surface water and groundwater in the BCW watershed on June 21, 2010. Nineteen (19) aqueous samples were sent to ESB for cations, anions, total and dissolved organic carbon, total dissolved solids, and dissolved trace metals (cadmium (Cd), copper (Cu), lead (Pb), nickel (Ni), and zinc (Zn)) analyses. Fourteen (14) aqueous samples were sent to ASC for total and dissolved selenium (8 samples), dissolved selenium (14 samples) and selenium speciation (10 samples) analyses. Four (4) of the surface water samples were filtered and the particulates (filtrate solids) were analyzed for total selenium and trace metals (Cd, Cu, Pb, Ni, and Zn) concentrations by ASC. Finally, three (3) sediment, three (3) algae, and ten (10) tissue samples (crayfish, mosquitofish, and African-clawed frogs) were sent to IIRMES for analysis of total selenium and trace metals (Cd, Cu, Pb, Ni, and Zn), as well as percent solids.

Based on the project objectives listed in the SAP, the measurement quality objectives that are critical for this project are accuracy, precision, and completeness.

4.2.1 SWAMP Completeness

The SWAMP completeness requirement of 90% was met.

4.2.2 SWAMP QA Procedures Compliance

The SWAMP quality assurance procedures stipulated for this project were not completely followed:

- The target reporting limits used by ESB were higher than the SWAMP recommended reporting limits. However, the analytes in the samples were found in sufficiently high concentrations that "non-detect" data was kept to a minimum. Lead, carbonate, and hydroxide were the only analytes found in the aqueous samples that were below the laboratory's reporting limit.

- Matrix spike duplicates (MSDs) were not conducted for the metals, total dissolved solids, and cation analyses performed by ESB. In addition, the matrix spike (MS) recovery for zinc was low in one of the batches analyzed by ESB.

- The high detected concentrations of zinc in the preparation blanks used by for ASC indicate that the aqueous sample results will be biased high due to possible zinc contamination.

- IIRMES did not perform the matrix spike and matrix spike duplicates for the sediment analyses. Instead, the laboratory blank spike duplicates were analyzed to measure precision. These blank spike duplicates had recoveries and relative percent difference (RPD) that fell within the required SWAMP criteria.

4.2.3 Quality Assurance Assessment

Data that should not be used for the project's intended purpose because it did not meet all of the precision criteria:

- Zinc data from the analyses performed by ASC on the aqueous samples by ASC: the detections in the preparation blanks indicate that this data is biased high and did not meet the accuracy criteria.

Data that should be used with caution because it met most of the quality assurance criteria though it had poor precision[4]:

- Cations, total alkalinity, hydroxide, carbonate, bicarbonate, total organic carbon, dissolved organic carbon, and dissolved metals analyses performed on the aqueous samples by ESB.
- The sediment data from the IIRMES laboratory lacked MS and MSD for the analyses and did not meet the precision criteria.

Data that may be used for the project's intended purpose because it met all of the quality assurance criteria:

- Except for zinc, all of the trace metals data for the aqueous samples.
- The total dissolved solids data from the analyses performed by ESB.
- The selenium analyses, including selenium speciation analyses, performed by ASC.
- The total suspended solids data from the analyses performed by ASC.
- The analyses performed on the particulate samples by ASC (selenium and trace metals).
- All of the chemical analyses (selenium, trace metals, and percent solids) performed by IIRMES on the algae and tissue samples.

4.3 Results

As discussed previously, in 2009, CH2M Hill collected water and particulate samples from Lakes 3, 4 and 5 on the BCCC golf course. No sediment, algae, or tissue samples were collected at that time. The Regional Board Team collected water, particulates, sediment, algae, and biota from Lakes 3 and 5 on the BCCC golf course and from the HVNP located in the south branch of BCW creek, upstream and east of the golf course on June 21, 2010 (Figure 4-1). Surface water samples were also collected from the three branches of BCW creek where they enter the golf course (Inflows 1, 2, and 3) and the outflow structure where surface waters exit the golf course via a culvert that extends under Jamboree Road and enters the BCNP (Figure 4-1). Due to limited funds and resources, the Regional Board Team was not able to sample the two riparian areas (1 and 2) and Inflows 4 and 5 located along the north side of the BCCC golf course that were sampled in 2009 by CH2M Hill (see Figure 3-3). Groundwater samples were collected from subdrains, underdrains, and piezometers located in and around BCR.

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[4] E.g., it can be used for preliminary assessment purposes or to design future monitoring, but not for comparison to water quality criteria for compliance purposes.

Most samples were analyzed for several hydrogeochemical indicator constituents (see discussion in Section 5.0), nitrate, selenium (total and/or dissolved), selenium species, and trace metals (cadmium (Cd), copper (Cu), lead (Pb), nickel (Ni), and zinc (Zn)). Several parameters were also measured in the field including flow volumes (for surface waters), pH, temperature, specific conductance, dissolved oxygen, and depth and turbidity (groundwater samples only; see Table 4-1).

4.3.1 Selenium, Trace Metals, and Nitrate in Groundwater

Selenium concentrations measured in samples collected from the BCR piezometers and underdrains ranged from around 44 to 80 µg/L (Figure 4-2 and Table 4-2). The highest selenium concentrations measured in either groundwater or surface water samples were collected from the Yacht Street HOA and Port Street HOA subdrains (149 and 143 µg Se/L, respectively). The water from these two drains also had the highest measured specific conductance, total dissolved solids, sodium, and chloride of the groundwater and surface water samples collected. BCR piezometer I-41 had the lowest pH (6.97) and highest nitrate concentration (3.4 mg/L) measured, which may reflect irrigation infiltration from the adjacent and up-gradient PVMP cemetery (Figure 4-2). With the exception of lead, trace metal (Cd, Cu, Ni, Zn) concentrations measured in groundwater samples were higher than those measured in the surface water samples (Table 4-2). For lead except for the surface water sample collected from the HVNP, concentrations measured in groundwater samples were similar to surface water samples. The highest lead concentration measured (0.556 µg/L) was from the surface water sample collected from the HVNP.

Selenate comprised greater than 85% of the selenium in the groundwater samples submitted for selenium speciation analyses (BCR piezometer I-41 and west underdrain), with all other selenium species being below detection limits (Table 4-3).

4.3.2 Selenium, Trace Metals, and Nitrate in Surface Water

As shown on Figure 4-3 and in Table 4-3, the highest selenium concentration measured in the three main branches of BCW creek was the surface water sample collected from the north branch of the creek (Inflow 3), while the lowest concentration was measured in the sample collected from the middle branch of the creek (Inflow 2). The highest selenium concentration measured in surface water samples collected from the south (main) branch of BCW creek was collected from the HVNP (Figure 4-3). Selenium concentrations measured in samples collected from the three main branches of BCW creek where they discharge into the BCCC golf course (Inflows 1, 2, and 3) were slightly higher but similar to those measured by CH2M Hill in 2009 (see Figure 3-3). However, selenium concentrations measured in samples collected from the golf course lakes and the outfall structure were slightly lower though similar to those measured in 2009. This may be simply a reflection of the precedent rainfall patterns and time of year the samples were collected (May 2009 verses June 2010), the influence of residential and/or golf course irrigation at the time of sampling, or the inherent variability in selenium concentrations in surface waters in the watershed.

While all surface water samples collected from BCW creek on June 21, 2010 exceeded the CTR chronic criterion for selenium of 5 µg/L, the sample from the middle branch of the creek (Inflow 2) barely exceeded the criterion in 2010 and was measured at just below the criterion in 2009 (4.74 µg Se/L).

Selenium speciation analyses was performed on all of the surface water samples collected on June 21, 2010 except for the sample collected from Inflow 2 where it enters the golf course. Inflow 2 (middle branch of BCW creek) has the lowest selenium concentration measured in samples collected from the surface waters in the watershed. Selenium species were analyzed for samples collected from Inflow 2 by CH2M Hill in 2009; only selenate and selenite were at detectable concentrations and the percent selenite was very low, only around 8%. Flows from the middle branch of the creek join with the flows from the south branch (Inflow 1) before entering Lake 3, located just west of the BCCC clubhouse (Figure 4-3).

Selenium speciation analytical results for the samples collected on June 21, 2010 are shown in Table 4-3. As can be seen in Figure 4-4, the percent of inorganic selenite (Se IV) of the total selenium measured in the surface water samples collected is lowest at the upstream end of the south branch of BCW creek in the HVNP (<3%) and highest at the western end of the BCCC golf course (42-43%) in Lake 5 and the outflow structure where flows exit the golf course.

Trace metal concentrations (Cd, Cu, Pb, Ni, and Zn) were measured in all of the surface water samples and the results compared to the appropriate CTR chronic criterion (samples were collected during the dry season when acute conditions are not applicable). Both the surface water and groundwater samples classify as brackish (salinity is greater than 1 but less than 10 parts per thousand). The CTR requires that when brackish conditions exist in surface waters, the more stringent of either the freshwater or saltwater criteria be applied. With the exception of cadmium, the saltwater criteria are more stringent than the hardness-corrected freshwater criteria. (Note that for selenium, the CTR freshwater chronic criterion is the more stringent.) For freshwater, the CTR freshwater metals criteria are hardness dependent; hardness concentrations in surface waters ranged from 670 to 1500 mg/L. For hardness concentrations greater than 400 mg/L, the CTR requires that a default concentration of 400 mg/L be used. The results of the trace metal analyses and the applicable CTR chronic criteria are shown in Table 4-2.

Dissolved metals exceeding the CTR saltwater chronic criteria were as follows: copper in the HVNP, Inflows 1,2, and 3, and BCCC Lake 3 samples; and nickel in samples from Inflows1 and 3, BCCC Lakes 3 and 5, and the outflow from the BCCC golf course (Table 4-2). Both copper and nickel exceeded the CTR saltwater chronic criteria (3.1µg/L and 8.2 µg/L, respectively) in 5 out of 7 surface water samples. Cadmium exceeded the freshwater chronic criterion (6.2 µg/L) only in the HVNP sample. There were no exceedances of the CTR saltwater chronic criteria for either lead or zinc. Copper concentrations were highest in the samples from Inflows 1, 2 and 3 compared to other sites; nickel concentrations were highest in the Lake 3 sample; and cadmium and lead concentrations were highest in the HVNP sample.

Nitrate concentrations in groundwater and surface water samples were measured at less than 5.0 mg/L. Groundwater nitrate concentrations were slightly higher overall than surface water concentrations; nitrate concentrations in groundwater averaged around 2 mg/L and averaged less than 1 mg/L in surface waters. The highest nitrate concentration measured (3.4 mg/L) in the samples collected on June 21, 2010 was from a groundwater sample collected from BCR piezometer I-41; the lowest concentration measured (0.39 mg/L) was a surface water sample collected from the BCCC golf course outflow structure.

4.3.3 Selenium and Trace Metals in Particulates, Sediment, and Algae

Suspended particulates, algae, and sediment were collected from the HVNP and BCCC Lakes 3 and 5. Suspended particulates were also collected from Inflows 1, 2, and 3 and the BCCC golf course outflow; however, algae and sediment were either not available or not available in sufficient quantities for sampling and analysis at these locations.

Of the samples collected, the highest selenium concentrations were measured in the suspended particulate and sediment samples collected from BCCC Lake 3. The selenium concentrations measured in the algae samples were the highest in the samples collected from Lake 5 (Figure 4-5; Tables 4-4 and 4-5). Particulate selenium concentrations ranged from 14.9 µg/g dry weight (dw) in the sample collected from the HVNP to 46.8 µg/g dw in the sample collected from Lake 3; sediment selenium concentrations ranged from 10.03 µg/g dw in the sample collected from the HVNP to 22.0 µg/g dw in the sample collected from Lake 3; and algae selenium concentrations ranged from 10.74 µg/g dw in the sample collected from Lake 3 to 16.36 µg/g dw in the sample collected from Lake 5. Selenium concentrations measured in the suspended particulate samples collected from BCCC Lakes 3 and 5 were higher than those measured in either the algae or sediment samples. For the HVNP however, particulate selenium concentrations were higher than sediment concentrations (14.9 verses 10.03 µg/g dw), but lower than the algae concentrations (14.9 verses 15.36 µg/g dw).

In general, trace metal concentrations were higher in the suspended particulate samples compared to the sediment and algae samples (Table 4-5). Copper and lead concentrations measured in particulates, sediments and algae were highest in the HVNP samples compared to samples from Lakes 3 and 5; while cadmium, nickel and zinc concentrations measured in particulates, sediments and algae were highest in Lake 3 samples. The lead concentration measured in the particulate sample collected from the BCCC outflow was similar to that measured in the HVNP sample, and nickel concentrations measured in algae samples collected from Lake 5 were similar to those collected from Lake 3.

Selenium concentrations in sediment were compared to the Presser et al. (2004) guidelines (see Table 3-1) for selenium. Trace metal concentrations in sediment were compared to the National Oceanic and Atmospheric Administration (NOAA) Threshold

Effect Levels (TELs) and Probable Effect Levels (PELs) for freshwater sediments (Table 4-6). The TELs were used by USEPA as numeric targets for freshwater sediments in their technical TMDLs for toxic constituents (2000); however, PELs are recommended by the state of California for determining impairment in a water body based on sediment (SWRCB, 2004). There are no equivalent guidelines for selenium and trace metals in algae or suspended particulates.

Selenium concentrations exceeded the Presser et al. (2004) substantive ecological risk guideline and cadmium and nickel concentrations exceeded the NOAA TELs in sediment samples collected from the HVNP and BCCC Lakes 3 and 5 (Table 4-5). Cadmium concentrations measured in the sediment samples collected from the HVNP, and BCCC Lakes 3 and 5 also exceeded the NOAA PEL for cadmium. No other trace metals measured in the sediment samples exceeded their respective NOAA PEL. Copper exceeded the NOAA TEL in sediment samples collected from the HVNP and Lake 3 and zinc exceeded the NOAA TEL in the sediment sample collected from Lake 3. Selenium concentrations measured in algae and sediment samples collected from the HVNP and BCCC Lakes 3 and 5 though elevated were lower than those measured in similar samples collected in 2008 and 2009 from the freshwater areas in the BCNP.

4.3.4 Selenium and Trace Metals in Fish, Frog, and Bird Egg Tissue

Overall, tissue samples collected from the HVNP contained the lowest concentrations of selenium though total selenium concentrations in water were the highest measured in surface waters in the BCW watershed (Figure 4-5, Tables 4-4 and 4-7). As will be discussed in Section 4.3.5, this is reflected by the lower particulate concentrations and subsequently lower partitioning coefficient (K_d) at this location compared to BCCC golf course Lakes 3 and 5. Selenium concentrations measured in composite crayfish, frogs, and mosquitofish tissue samples collected from the HVNP and BCCC Lakes 3 and 5 though elevated were lower than those measured in similar samples collected in 2008 and 2009 from the BCNP. Median selenium concentrations in fish tissue are shown on Figure 4-6 for the HVNP, BCCC golf course, and the BCNP.

Cadmium and copper concentrations measured in mosquitofish tissue collected from the HVNP were higher than those measured in fish collected from BCCC Lakes 3 and 5 (Table 4-7). Lead was only detected in two composite tissue samples: mosquitofish collected from the HVNP and crayfish collected from Lake 5. Lead concentrations in both samples were not much higher than the method detection limit. Nickel concentrations were lowest in the mosquitofish composite sample collected from Lake 3; nickel concentrations measured in composite mosquitofish tissue samples collected from the HVNP and Lake 5 were similar to each other. Zinc concentrations were the highest in mosquitofish collected from Lake 5.

A copper concentration of 115.6 µg/g dw was measured in the composite crayfish tissue sample collected from BCCC golf course Lake 5, which is high compared to copper concentrations in other species collected. However, crayfish have copper-based blood (hemocyanin) instead of the iron-based blood (hemoglobin) found in vertebrates such as mammals, fish, and birds. Copper concentrations measured in crayfish tissue samples collected by CH2M Hill in 2009 from various freshwater locations in the BCNP were also elevated compared to other invertebrates and fish, and were even higher than the concentrations measured in the sample collected from Lake 5. As the size of the crayfish that were sampled from these two locations have not been compared, it is difficult to determine whether or to what degree the elevated copper concentrations in the crayfish are natural or elevated with respect to background conditions.

Selenium concentrations in fish and bird egg tissue were compared to the proposed site-specific objectives (SSOs) for selenium of 5.0 µg/g dw and 8.0 µg/g dw, respectively (SARWQCB 2009). There is very little information available on selenium effects in amphibians; however, since frogs are also egg layers as are fish and birds, and selenium concentrations measured in African clawed frogs were similar to tissue concentrations measured in fish, the selenium concentration of the composite frog tissue sample collected from BCCC Lake 3 was also compared to the proposed fish tissue SSO. As there is also limited data on selenium effects in invertebrates, selenium concentrations in crayfish were compared to the Presser et al. (2004) substantive ecological risk guidelines for selenium in bird diet.

Selenium concentrations measured in fish tissue and bird eggs were elevated well above their respective proposed tissue SSOs (Table 4-7 and Figure 4-5). Selenium concentrations measured in mosquitofish collected from the HVNP, and BCCC Lake 3 and Lake 5 exceeded the proposed fish tissue SSO of 5.0 µg/g dw (Table 4-7). Selenium concentrations measured in frog tissue collected from BCCC Lake 3 exceeded the fish tissue SSO and crayfish tissue concentrations measured in samples collected from Lake 5 exceeded the Presser et al. (2004) guideline for substantive ecological risk for selenium in bird diet. Both PBGR bird eggs collected by CH2M Hill from the vicinity of BCCC Lakes 4 and 5 in June 2010 exceeded the proposed bird egg tissue SSO for selenium (Table 4-7).

Copper concentrations in fish, frogs, and bird egg tissue were compared to the U.S. Department of the Interior (USDOI) guidelines for assessing ecological risk, cadmium concentrations in fish and frog tissue were compared to the Maximum Tissue Residue Levels (MTRLs) developed by the California State Mussel Watch (SMW) program (SWRCB, 1977-2000) though the program ended in 2000, and zinc concentrations in tissue were compared to the background concentrations given in Eisler (1993) (Table 4-6). While the SMW MTRLs were developed for the protection of human consumers of fish and shellfish[5], and mosquitofish and African clawed frogs are not generally consumed by humans, the MTRLs are used in this report simply as a guideline for comparison to tissue concentrations; guidelines for cadmium concentrations in fish or frogs for protection of wildlife health were not available. Biological effects guidelines could not be found for lead or nickel concentrations in invertebrate, amphibian, fish, or bird egg tissues.

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[5] The State's listing policy (SWRCB 2004) for determining impairment based on tissue does not use MTRLs; however, as stated, in this report the MTRLs are used merely for comparison purposes and are not being used to determine impairment.

Mosquitofish collected from the HVNP exceeded the SMW MTRL for cadmium, and the USDOI (1998) recommended toxicity threshold for copper in whole body fish tissue (Table 4-7). African-clawed frogs collected from BCCC Lake 3 and mosquitofish collected from BCCC Lake 5 exceeded the SMW MTRL for cadmium. No fish or frog tissue concentrations exceeded the Eisler (1993) background concentration for zinc in fish (<700 µg/g dw).

4.3.5 Selenium Partitioning Coefficients

> *"One of the most important biogeochemical steps or links controlling the bioavailability and effects of selenium is the partitioning reactions that determine the distribution between dissolved and particulate phases, where particulate phases include primary producers (such as phytoplankton), bacteria, detritus, suspended inorganic material, and sediments."*
> (Presser and Luoma, 2006)

The pathway for nearly all selenium transfer from the dissolved phase in water to secondary trophic level organisms (e.g., invertebrates) in an ecosystem is through particulate forms, including primary producers such as single-cell organisms like algae. Dietary uptake and bioaccumulation of selenium in animals occurs to a much greater extent than uptake from water (Presser and Luoma, 2006). The partitioning coefficient (K_d) therefore, is an important measure of the selenium bioaccumulation potential in an aquatic ecosystem.

Selenium partitioning can be described by a distribution coefficient, which is the ratio of the selenium concentration in suspended particulate form to the dissolved waterborne fraction of selenium as shown in the equation below:

$$\mathbf{K_d = [Se_{particulate}\ (\mu g/g\ dry\ weight)/Se_{water}\ (\mu g/L)]*1000}$$ [6]

While K_ds can be calculated from algae or bed sediment selenium concentrations, suspended organic particulate concentrations are a much better predictor of the potential for selenium bioaccumulation as they reflect the spectrum of dietary materials available to secondary trophic level consumers. Using the particulate selenium data collected as part of the June 21, 2010 sampling, partitioning coefficients (K_ds) for selenium were calculated for the HVNP, BCCC golf course Lakes 3 and 5, and the golf course outflow to the BCNP. The K_ds calculated from the June 2010 sampling are shown in Table 4-8 and compared to the K_ds calculated by CH2M Hill in 2009. In addition, the particulate K_ds are compared to K_ds calculated using the algae and bed sediment concentrations measured in samples collected from the same water bodies as the particulate samples.

As can be seen in Table 4-8, the K_ds calculated by CH2M Hill from their 2009 data are similar to (i.e., fall within the same range as) those calculated from the Regional Board Teams' June 21, 2010 data. Higher K_ds indicate a higher transfer of selenium from dissolved inorganic forms into the aquatic food web. As expected, K_ds increase

[6] Conversion factor for converting parts per billion to parts per thousand.

downstream as selenium concentrations in water decrease but increase in sediment, algae, and biota. The HVNP K_d is the lowest calculated although it contains the highest concentration of selenium measured in surface waters in the south branch of BCW creek (~58 µg/L). The K_ds calculated for particulate and water column samples collected from BCCC Lake 5 and the golf course outflow structure located at the western end of the golf course are similar, and both are higher than the K_d calculated for samples collected from Lake 3, located east and upstream of these two lakes. The K_d calculated for the outflow from the golf course to the BCNP is only slightly higher than the K_d calculated for Lake 5, possibly indicating only minor contributions of particulate-associated selenium from the north branch of BCW creek. Surface flows through the northern portion of the golf course are not retained in lakes[7] as is the case along the southern portion, so the potential for generation of particulate selenium and bioaccumulation is lower in this area.

With the exception of the HVNP, K_ds calculated for selenium using bed sediment or algae data are substantially lower than those calculated from the particulates. This is important because K_ds calculated from bed sediment or algae selenium concentrations that are then used as a surrogate for particulate selenium concentrations may be underestimating the bioaccumulation potential especially for lentic water bodies with relatively long residence times. This could be a reflection of the increased recycling of selenium, which may result in a higher proportion of particulate selenium as compared to selenium concentrations in algae and sediment. The K_ds calculated using the average of the sediment and algae selenium concentrations measured in Lakes 3 and 5 were 45% lower than the K_ds calculated using the suspended particulate selenium concentrations. It is therefore likely that the K_ds calculated from sediment and algae for the pond and marshes in the BCNP are similarly underestimated. If this pattern follows, K_ds estimated by U.S. Geological Survey (USGS) staff (Presser and Luoma, 2009) for the wetlands in San Diego Creek using algae and/or bed sediment selenium concentrations may also be similarly underestimated.

4.3.6 Patterns in Selenium and Metals Concentrations in Different Media

Matching data sets of selenium, cadmium, copper, lead, nickel, and zinc concentrations in water, particulates, sediment, algae, and mosquitofish are available for the HVNP, and BCCC Lakes 3 and 5 from the June 21, 2010 sampling event. Selenium and metals concentrations in these different media for each location were compared to look for preliminary correlations or patterns in constituent concentrations.

4.3.6.1 Selenium

Total selenium concentrations in water, particulates, sediment, algae, and mosquitofish collected from the HVNP, Lake 3, and Lake 5 were compared (Charts 4-1 through 4-7). As can be seen in Charts 4-1, 4-2, 4-3, and 4-4, total selenium concentrations measured in water were not good predictors of selenium concentrations in particulates, sediment, algae, or mosquitofish. Particulate selenium concentrations correlated well with selenium concentrations in mosquitofish (Chart 4-7), but poorly with selenium

[7] Lake 6 is an offline lake that is supported by storm water runoff and supplemented with potable water to maintain lake levels.

concentrations in sediment (Chart 4-5), and especially in algae (Chart 4-6). The lack of correlation between particulate selenium concentrations and selenium concentrations in algae and sediment is likely a result of several factors. As discussed in section 4.3.5 above, suspended particulates are comprised of a variety of materials including suspended sediments, zooplankton, plant materials, detritus, etc., which results in the particulate concentrations providing a microcosm of the bioaccumulation potential in a water body. Sediment and algae tend to reflect a much more limited view of selenium cycling and bioaccumulation as they are single components in a complex biotic system. Selenium concentrations in mosquitofish also mirror the particulate selenium concentrations because they are lower trophic level fish that feed on zooplankton, small insects, and detritus – components similar to what are found in suspended particulates.

Because of the complexity of selenium cycling and bioaccumulation and the fact that these can differ dramatically between water bodies, assessing potential impacts to beneficial uses from selenium is difficult and time and resource consumptive. While water column concentrations of total selenium, which are measured for comparison to the CTR criteria, are a poor measure of the potential for selenium bioaccumulation in a water body, one measure that appears to hold up well is comparing the relative percent of selenite (Se IV) to selenate (Se VI) in the water column. Selenite is the more bioavailable form of inorganic selenium, and as can be seen in Chart 4-8, the percent selenite measured at the three locations in upper BCW are relatively close to selenium concentrations measured in particulates. While not a complete match, the percentage of selenite in the water column provides a much better indicator of the degree of selenium bioaccumulation that may be occurring than by just looking at total selenium concentrations (Chart 4-1). That said, any complete assessment of potential adverse impacts from selenium requires extensive sampling and monitoring of multiple environmental compartments (water, particulates, sediment, bacteria, algae or other plants, invertebrates, fish, and bird eggs) that selenium may occupy in a water body.

4.3.6.2 Trace Metals

Trace metal concentrations (Cd, Cu, Pb, Ni, Zn) in water, particulates, sediment, algae, and mosquitofish collected from the HVNP, Lake 3, and Lake 5 were compared. For all five trace metals, the highest concentrations measured were found in the suspended particulate samples (Chart 4-9 through 4-13). Trace metals concentrations measured in sediments were generally higher than trace metal concentrations measured in water, algae, or mosquitofish. With the expcetion of zinc, the lowest trace metal concentrations were measured in mosquitofish, which indicates that these metals are not bioaccumulating in the food web.

Particulate trace metal concentrations may be important in helping to determine metals loadings to UNB. The suspended particulates are expected to flocculate out and settle into sediments once they reach saltwater. Load estimates based only on dissolved concentrations in freshwater may underestimate the actual trace metal loads entering the bay from the freshwater drainages. A comparison between total metals concentrations and particulate concentrations should be made to determine whether total metals concentrations are accurately reflecting both dissolved metals concentrations and suspended particulate concentrations.

4.3.7 Pollutant Load Estimates

As discussed in more detail in Section 4.1.1, during the June 21, 2010 sampling event, surface water flow rates were measured by Orange County staff using a Flow Tracker velocimeter. With the exception of Inflow 3 (north branch of BCW creek) all surface water flows were measured using this method. Because the flows were too low at Inflow 3 to use the velocimeter to measure the flow rate, Orange County staff visually estimated the flow rate by timing the movement of an object over a measured length of the tributary and then multiplying that by the cross sectional area. Pollutant loads were estimated by multiplying the flow rate for each location measured by the concentration of the constituent of interest.

4.3.7.1 Selenium

Selenium loads were estimated by calculating the flow rate for each location measured by the dissolved selenium concentration. Selenium loads calculated for the June 21, 2010 sampling event are shown in Table 4-9. Discharges from the BCR underdrains were not measured; however, baseflow measured at the upper end of the HVNP, located just 0.14 miles downstream of the BCR underdrains, was approximately 0.32 cubic feet per second (cfs) or 24,560 gallons per day (gpd). This baseflow is composed primarily of groundwater transported from the BCR underdrains and the Bren and Seaview subdrains (see discussion at the end of Section 2. 1 in this report). Based on a dissolved selenium concentration of 58 µg/L, the selenium load for this location is estimated to be approximately 4 pounds per year (lbs/yr). For the BCCC golf course, the baseflow entering the golf course from Inflow 1, located in the south branch of BCW creek approximately 0.31 miles downstream of the HVNP, was estimated to be 132,495 gpd with a selenium concentration of 35 µg/L and an estimated selenium load of approximately 14 lbs/yr (Table 4-9). Baseflow in Inflow 2 (middle branch of BCW creek) was measured at 85,314 gpd with a selenium concentration of 6 µg/L and an estimated selenium load of approximately 1.5 lbs/yr. Baseflow in Inflow 3 (north branch of BCW creek) was estimated at 2,585 gpd with a selenium concentration of 67 µg/L and an estimated selenium load of 0.5 lbs/yr (Table 4-9).

Baseflow in the south branch of BCW creek increases substantially between the HVNP and the BCCC golf course; discharge at Inflow 1 is more than 5 times greater than flows measured at the upper end of the HVNP. Selenium loads also increase along this stretch of the creek, from 4 lbs/yr to 14 lbs/yr, even though total dissolved selenium concentrations decrease by 64% (from 58 µg/L to 37 µg/L). This indicates that additional flows and selenium inputs are entering the creek, likely from groundwater either as non-point source rising groundwater, groundwater discharged into the creek from passive subdrains, underdrains, or leaky storm drains, and/or urban runoff.

Based on the June 21, 2010 measurements, at least 16 lbs Se/yr enters the eastern end of the BCCC golf course from the combined flows from the three main branches of BCW creek (Inflows 1-3) during dry weather conditions. At the time of sampling, the majority of the selenium loadings were from the south branch of the creek (14 lbs/yr for Inflow 1 verses only 1.5 lbs/yr from Inflow 2, despite its high volume of flow, and only 0.5 lbs/yr from Inflow 3 despite its high selenium concentration). The flows that discharge from the outflow structure located along the west central side of the BCCC golf course were measured at 529,333 gpd; based on the sampling conducted on June 21, 2010, approximately 21 lbs Se/yr is discharged from the BCCC golf course into the BCNP (Table 4-9).

Inflows 1 and 2 (a total base flow of about 218,000 gpd) join on the golf course before entering Lake 3 and contribute a total of almost 16 lbs Se/yr. Water flows from Lake 3 to Lake 4 and then to Lake 5 before exiting the golf course at the outflow. Baseflow measured at the outlet from Lake 5 was 342,548 gpd and the selenium load was approximately 13 lbs Se/yr. This indicates that flows increase through this portion of the golf course; another 125,000 gpd entered the south branch of BCW creek on the golf course between the east side of the golf course and Lake 5. However, through this same stretch of BCW creek, there was actually a net loss of about 3 lbs Se/yr, likely as a result of retention and bioaccumulation of selenium in the golf course lakes.

If there are no additional significant inflows into the golf course between the Lake 5 outlet and the outflow, then about 187,000 gpd and 8 lbs Se/yr is contributed to the surface flows on the BCCC golf course from the north branch of BCW creek (Table 4-9). Since the selenium load from Inflow 3 where it enters the northeast end of the golf course was estimated at about 0.5 lb Se/yr, another 7.5 lbs Se/yr must enter the golf course between Inflow 3 and the golf course outlet structure. Inflows 4 and 5, located in the north branch of BCW on the north side of the golf course (see Figure 3-3) were not measured in June 2010, though they were measured by CH2M Hill in May 2009. CH2M Hill calculated that these inflows contributed slightly less than 2 lbs/yr to the north branch of BCW creek. Additional flows and selenium loads must enter this section of the creek from groundwater discharges from residential storm drains, rising groundwater into the creek, leakage from Lake 6, or a combination of all three potential sources.

There are several storm drains or subdrains that discharge into the golf course from the surrounding residential areas (see Figures 2-3 and 2-4 and discussion under Section 2.2.2). None of these discharges were measured on June 21, 2010. Most of these discharge points are very difficult to sample or measure because they are from underground pipes that daylight on the golf course and have very low flows. However, an attempt should be made to determine the flow rates and selenium concentrations from these drains in order to gain a better understanding of selenium contributions and losses that are occurring in the water bodies on the BCCC golf course.

The dry weather baseflows and selenium loads measured on June 21, 2010 are higher than those measured on May 8, 2009 by CH2M Hill even though the selenium concentrations measured at the inflows are similar. This may be a result of the different years and amount of precipitation received prior to when the flows were measured[8], the timing and relative contributions of either off-site or on-site irrigation, or the different methods used to estimate flows. CH2M Hill's flow and selenium load estimates from their 2009 study are shown in Table 4-10.

4.3.7.2 Trace Metals

Load estimates were also calculated for trace metals (Cd, Cu, Pb, Ni, and Zn) (Table 4-11) for the five sites measured and sampled (HVNP, Inflows 1-3, and the outflow from the BCCC golf course to the BCNP). There is a significant increase in flow and trace metal loads in the south branch of BCW creek from the HVNP to where Inflow 1 daylights on the BCCC golf course, indicating additional inputs from either rising groundwater or urban runoff. With the exception of copper, there is a net gain in trace metals dry weather loads as BCW creek flows though the BCCC golf course, either from loadings from the unmeasured inflows from residential storm drains and subdrains that daylight on the golf course or from golf course irrigation and maintenance activities, or a combination of both. Around 2 lbs/yr of copper are lost between the east and west ends of the golf course, likely via sequestration of copper in the golf course lake sediments. Based on the 2010 data, annually approximately 3 lbs cadmium, 4.5 lbs copper, 0.26 lbs lead, 14 lbs nickel, and 8.4 lbs zinc are transported via dry weather surface flows from the BCCC golf course into the BCNP (Table 4-11).

4.3.7.3 Nitrate

Under dry weather flow conditions, about 530 lbs of nitrate are estimated to enter the BCCC golf course from the three main branches of BCW creek, with the largest load (approximately 335 lbs) coming from the south branch of the creek during the June 2010 investigation (Table 4-11). Nitrate loads more than triple in the south branch of BCW creek from the HVNP to where it discharges into the BCCC golf course (from 97 lbs to 335 lbs/yr). A total of approximately 628 lbs nitrate exit the golf course and enter the BCNP on an annual basis, indicating that at a minimum, an additional 98 lbs nitrate are discharged into BCW creek as it flows through the BCCC golf course.

4.3.7.4 Data Gaps in Pollutant Load Estimates

Currently, there are only sufficient data to estimate pollutant loads in BCW creek for two points in time and at only one location: the BCCC golf course on May 8, 2009 (CH2M Hill) and June 21, 2010 (Regional Board Team). These pollutant load estimates are dry weather estimates. Additionally, there are no corresponding dry weather pollutant load estimates available for either BCW Upper or BCW Lower (BCNP) for these time frames because there were not sufficient funds available to collect the data needed from those areas. Therefore, estimates for pollutant loads entering UNB from BCW watershed under dry weather conditions cannot be made.

Also, no estimates of wet weather loadings for pollutants, including selenium, nitrate, and trace metals, are available for the BCW watershed due to lack of sufficient data on both pollutant concentrations and flow volumes under storm conditions. Additional data

[8] Approximately 6.87 inches of rain were recorded at the Corona del Mar rain gauge station located at BCR in 2008/2009, while 12.72 inches of rain were recorded at that station during 2009/2010.

on seasonal pollutant loads and flow volume patterns are needed in order to determine the relative contribution to pollutant loads that enter Newport Bay each year from the BCW watershed. However, the proposed TMDLs for selenium for the Newport Bay watershed are dry weather TMDLs because it is under dry weather conditions that sensitive fish and bird species are most at risk from selenium as dry weather conditions predominate during the breeding season. While wet weather can ultimately increase selenium in surface waters via vadose zone flushing of the shallow groundwater aquifer in the BCW watershed, it is under low flow conditions that the greatest concentrations and recycling of selenium are likely to occur in surface water bodies.

Figure 4-1. Locations sampled on June 21, 2010 in the BCW watershed by the Regional Board Team.

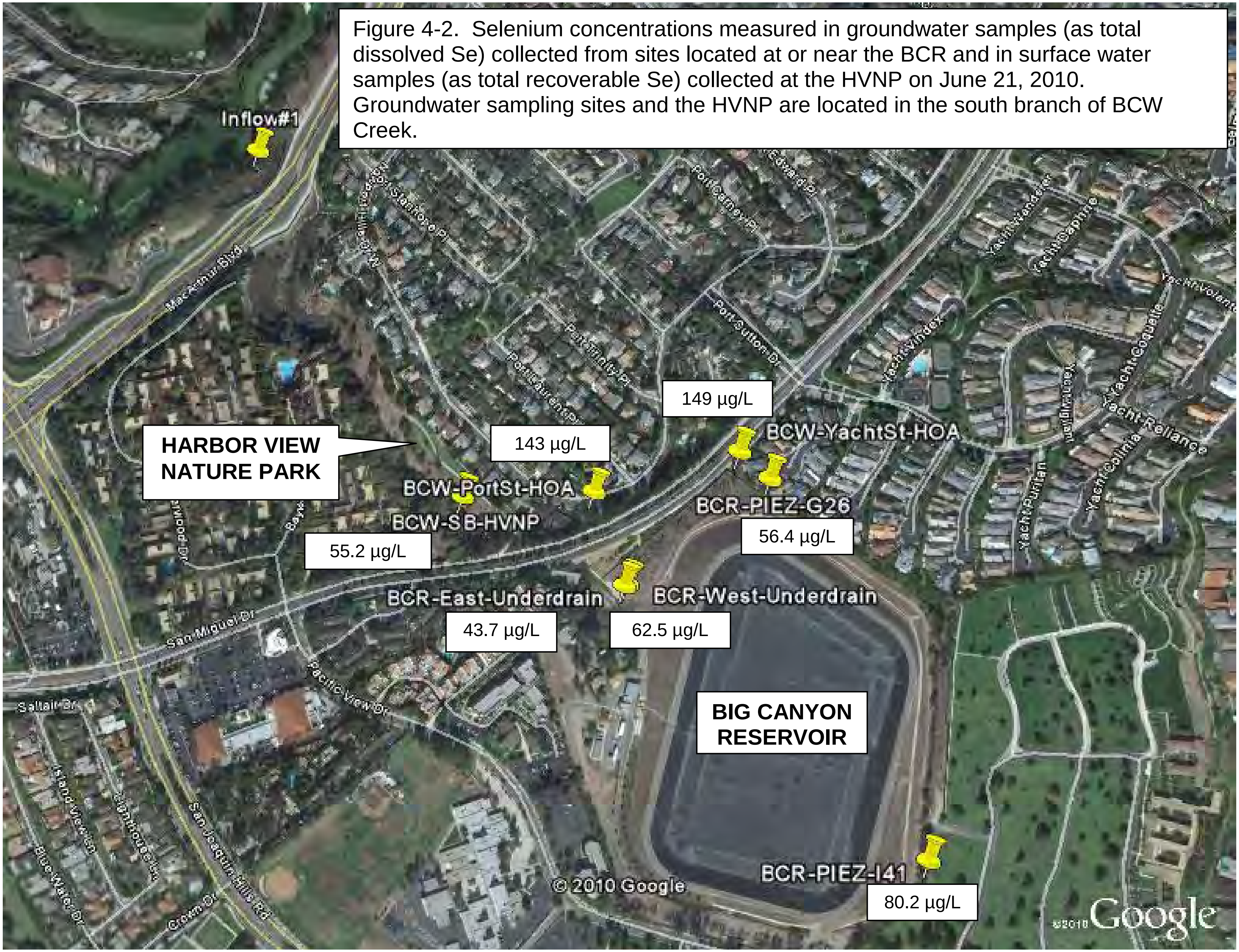


Figure 4-2. Selenium concentrations measured in groundwater samples (as total dissolved Se) collected from sites located at or near the BCR and in surface water samples (as total recoverable Se) collected at the HVNP on June 21, 2010. Groundwater sampling sites and the HVNP are located in the south branch of BCW Creek.

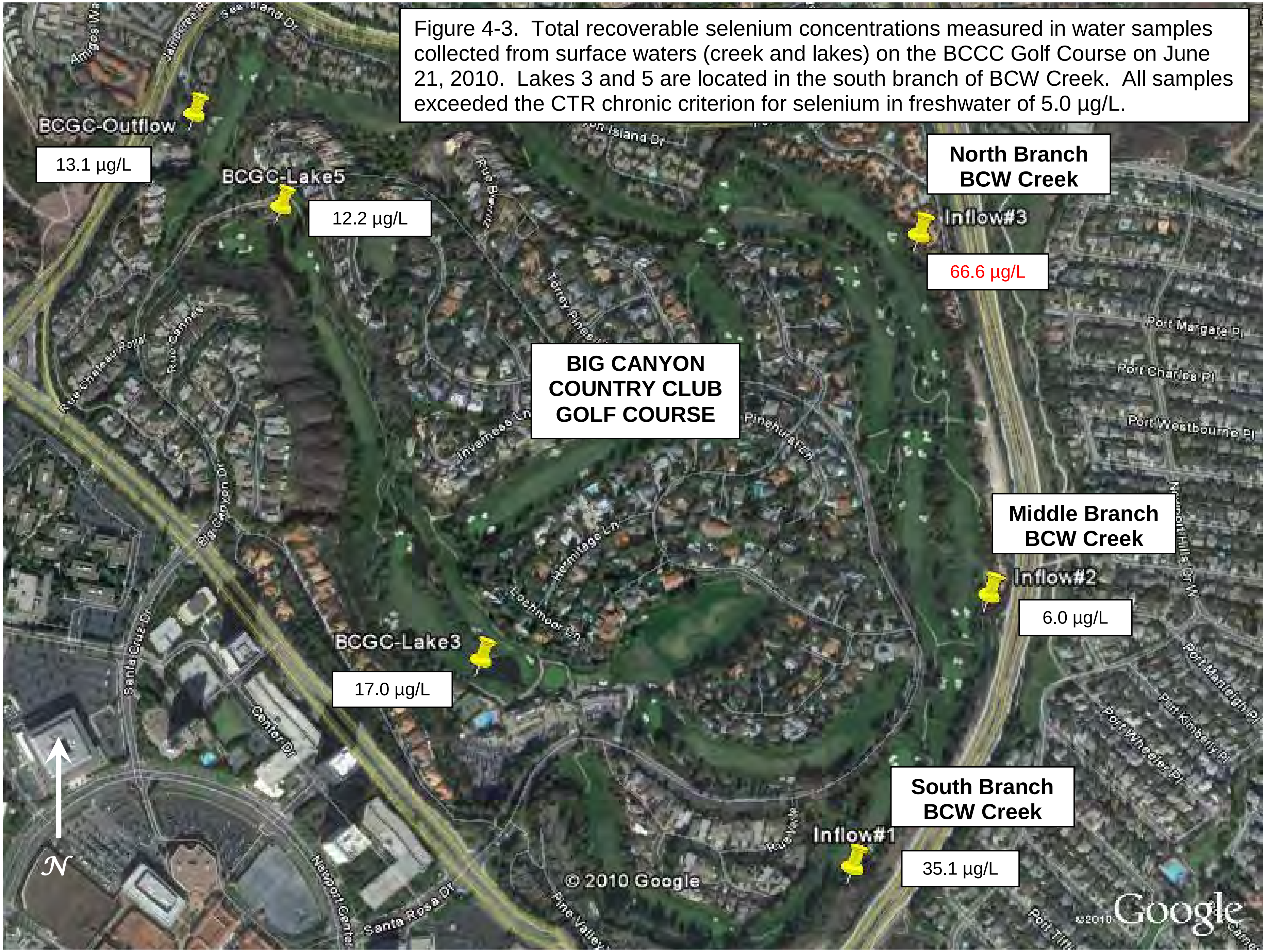


Figure 4-3. Total recoverable selenium concentrations measured in water samples collected from surface waters (creek and lakes) on the BCCC Golf Course on June 21, 2010. Lakes 3 and 5 are located in the south branch of BCW Creek. All samples exceeded the CTR chronic criterion for selenium in freshwater of 5.0 µg/L.

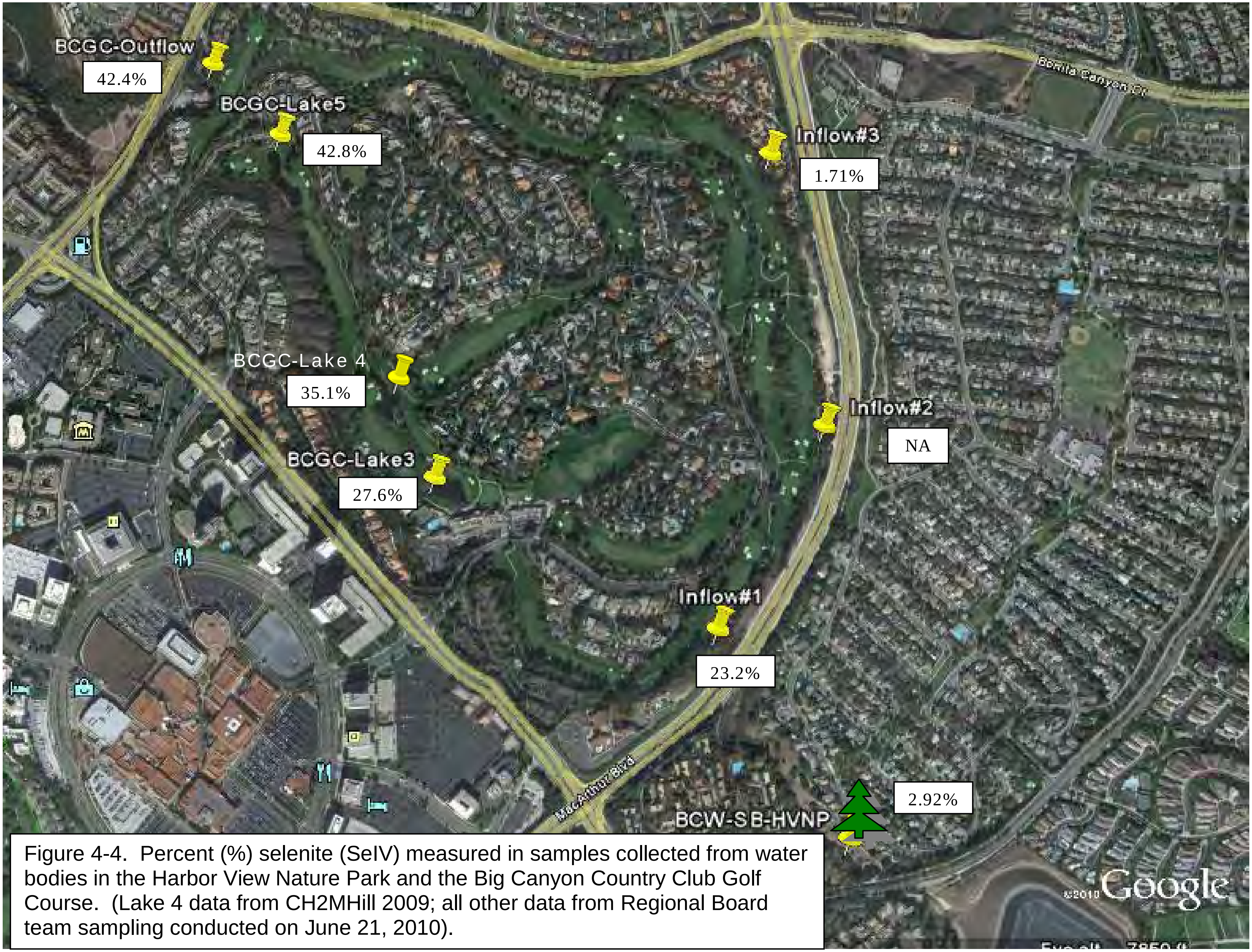


Figure 4-4. Percent (%) selenite (SeIV) measured in samples collected from water bodies in the Harbor View Nature Park and the Big Canyon Country Club Golf Course. (Lake 4 data from CH2MHill 2009; all other data from Regional Board team sampling conducted on June 21, 2010).

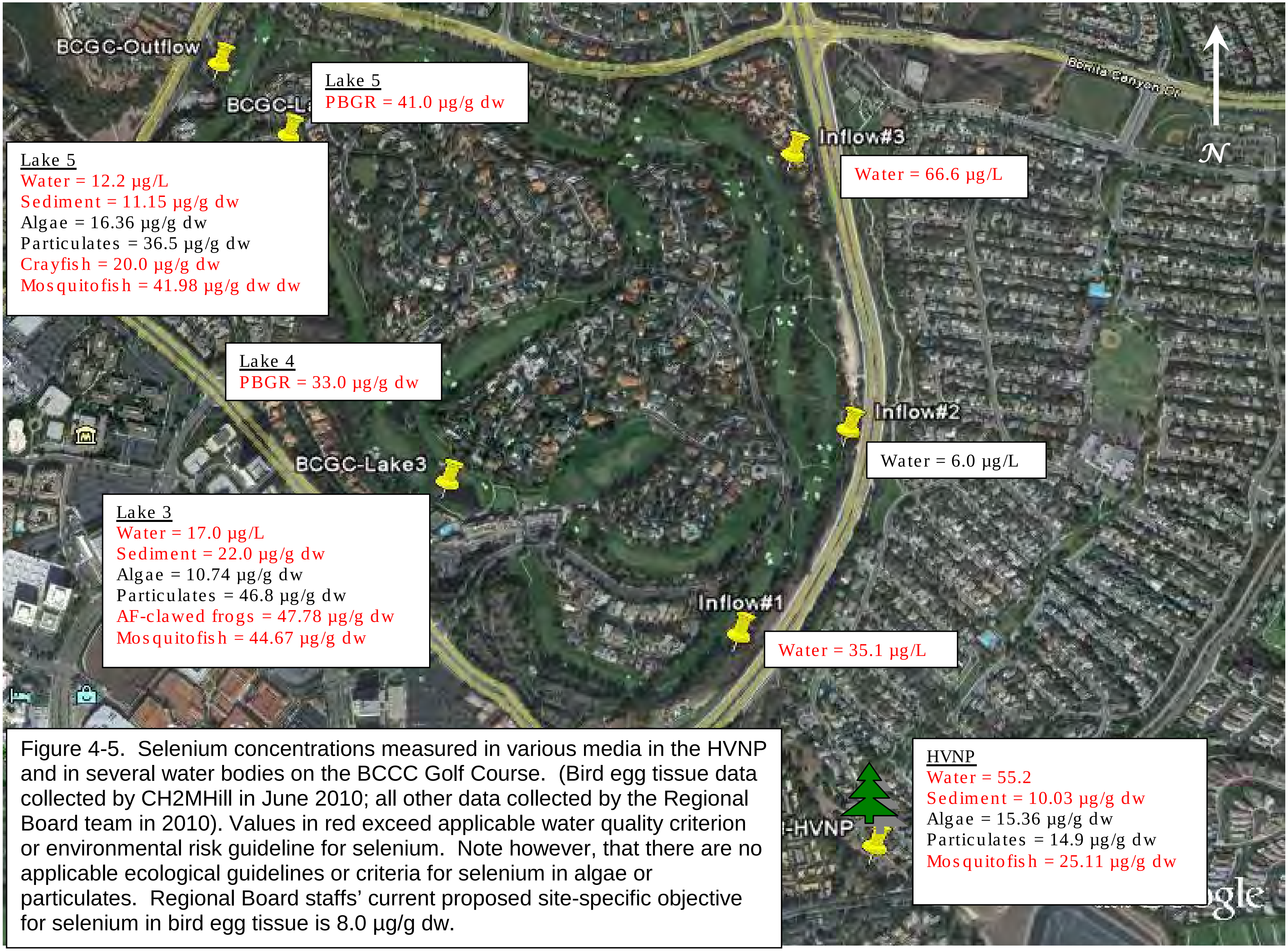


Figure 4-5. Selenium concentrations measured in various media in the HVNP and in several water bodies on the BCCC Golf Course. (Bird egg tissue data collected by CH2MHill in June 2010; all other data collected by the Regional Board team in 2010). Values in red exceed applicable water quality criterion or environmental risk guideline for selenium. Note however, that there are no applicable ecological guidelines or criteria for selenium in algae or particulates. Regional Board staffs' current proposed site-specific objective for selenium in bird egg tissue is 8.0 µg/g dw.

Figure 4-6. Selenium concentrations in fish tissue in the BCW watershed (BCNP and BCCC are median concentrations; only one fish tissue composite has been collected to date from the HVNP). Regional Board staffs' current proposed site-specific objective for selenium in fish tissue is 5.0 µg/g dw.

Table 4-1. Field data collected during the June 21, 2010 sampling event in the Big Canyon Creek watershed.

FIELD PARAMETERS

Location	Latitude[1]	Longitude[1]	Field Meter	Date	Water Body Type	Flow (cfs)	Flow (GPM)	Depth* Measurement Taken (m)	Depth* Measurement Taken (ft)	Temp. (°F)	Specific Conductivity (µS/cm)	Dissolved Oxygen Conc. (mg/L)	pH	Turbidity (NTU)
BCR-PIEZ-I41	33.6099	117.8553	Horiba	6/21/2010	Groundwater	NA	NA	9.57	31.4	69.1	5380	8.7	6.97	87
BCR-PIEZ-G26	33.6138	117.8572	Horiba	6/21/2010	Groundwater	NA	NA	2.59	8.5	68.7	5040	3.45	7.6	800
BCR-East-Underdrain	33.6126	117.8599	Horiba	6/21/2010	Groundwater	NA	NA	0.01	0.03281	72.1	3210	5.6	7.8	34
BCR-West-Underdrain	33.6127	117.8590	Horiba	6/21/2010	Groundwater	NA	NA	NA - pumped from sump		71.1	5110	4.02	7.8	17
BCW-YachtSt-HOA	33.6141	117.8576	Horiba	6/21/2010	GW/Storm Drain	NA	NA	NA - collected from manhole		67.8	8030	2.02	8	9
BCW-PortSt-HOA	33.6137	117.8595	Horiba	6/21/2010	GW/Storm Drain	NA	NA	NA - collected from manhole		67.8	8950	0.4	7.7	2
BCW-SB-HVNP	33.6136	117.8612	YSI	6/21/2010	Creek	0.038	17.0	0.285	0.94	76.1	4762	10.17	8.01	--
BCW-SB-MAIN (Inflow #1)	33.6186	117.8647	YSI	6/21/2010	Creek/Storm Drain	0.205	92.0	0.01	0.03281	66.0	4809	9.96	7.84	--
BCW-MB-MAIN (Inflow#2)	33.6225	117.8633	YSI	6/21/2010	Creek/Storm Drain	0.132	59.3	0.01	0.03281	65.6	2150	9.16	7.87	--
BCW-NB-MAIN (Inflow #3)	33.6269	117.8628	YSI	6/21/2010	Creek/Storm Drain	0.004	1.8	0.01	0.03281	66.3	3436	8	7.5	--
BCGC-Lake3	33.6204	117.8705	YSI	6/21/2010	Pond	NAM	NA	0.319	1.05	76.9	4760	14.51	8.15	--
BCGC-Lake5	33.6276	117.8741	YSI	6/21/2010	Pond	0.530	238.0	0.686	2.25	79.2	5439	9.73	8.14	--
BCGC-Outflow	33.6289	117.8758	YSI	6/21/2010	Creek/Storm Drain	0.819	367.6	0.344	1.13	78.5	5265	8.85	8.27	--

* Depth to groundwater for piezometers
[1] Sampling locations at BCGC (lakes and outflow) and the HVNP were obtained using a Garmin GPS 76; all other locations estimated using Google™ Earth.

BCGC = Big Canyon Country Club Golf Course
BCR = Big Canyon Reservoir
BCW = Big Canyon Wash
HOA = Home Owners' Association
HVNP = Harbor View Nature Park

GW = Groundwater
MB = Middle Branch
NA = Not Applicable
NAM = Not Able to Measure
NB = North Branch

PIEZ = piezometer
SB = South Branch
NR = Not Reported
BCR leakage rate = 4 gpm or 0.018 AF per day

Table 4-2. Trace metals concentrations measured in groundwater and surface water samples collected from the Big Canyon Country Club golf course, the Harbor View Nature Park, and in the vicinity of the Big Canyon Reservoir.

Location	Water Type	Specific Conduc-tivity (µS/cm)	Salinity** (g/L)	DISSOLVED TRACE METALS[2] (µg/L)					TOTAL HARDNESS[3] (mg/L)	HARDNESS-CORRECTED CTR CHRONIC CRITERIA FOR DISSOLVED TRACE METALS IN FRESHWATER (µg/L)					CTR CHRONIC[1] CRITERIA FOR DISSOLVED TRACE METALS IN SALTWATER (µg/L)				
				Cd	Cu	Pb	Ni	Zn[4]		Cd	Cu	Pb	Ni	Zn	Cd	Cu	Pb	Ni	Zn
BCR-PIEZ-I41	GW	5380	2.909	4.90	7.20	0.09	9.60	27.00	2000	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BCR-PIEZ-G26	GW	5040	2.710	0.73	12.00	0.10	6.80	15.00	400	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BCR-East-Underdrain	GW	3210	1.659	0.73	12.00	0.10	6.80	15.00	980	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BCR-West-Underdrain	GW	5110	2.751	19.00	11.00	0.04	16.00	7.40	1100	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BCW-YachtSt-HOA	GW	8030	4.498	5.00	23.00	0.05	16.00	25.00	2100	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BCW-PortSt-HOA	GW	8950	5.061	10.00	17.00	0.05	18.00	18.00	2000*	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BCW-SB-HVNP	SW	4762	2.548	9.94	5.04	0.556	7.22	7.50	1100	6.2	29	11	168	382	9.3	3.1	8.1	8.2	81
BCW-SB-MAIN (Inflow #1)	SW	4809	2.575	2.00	10.00	0.10	10.00	10.00	1400	6.2	29	11	168	382	9.3	3.1	8.1	8.2	81
BCW-MB-MAIN (Inflow#2)	SW	2150	1.073	0.19	9.60	0.09	7.10	6.20	670	6.2	29	11	168	382	9.3	3.1	8.1	8.2	81
BCW-NB-MAIN (Inflow #3)	SW	3436	1.786	1.30	8.90	0.10	9.30	11.00	830	6.2	29	11	168	382	9.3	3.1	8.1	8.2	81
BCGC-Lake3	SW	4760	2.547	5.40	3.69	0.097	12.70	5.90	1300	6.2	29	11	168	382	9.3	3.1	8.1	8.2	81
BCGC-Lake5	SW	5439	2.944	1.76	2.25	0.119	9.22	2.10	1500	6.2	29	11	168	382	9.3	3.1	8.1	8.2	81
BCGC-Outflow	SW	5265	2.842	1.76	2.77	0.162	8.76	5.20	1500	6.2	29	11	168	382	9.3	3.1	8.1	8.2	81

*Estimated total hardness ** Salinity estimated from specific conductance. GW = Groundwater SW = Surface water NA = Not Applicable

1 CTR criteria only apply to surface waters. Surface water samples collected under dry weather conditions; therefore the CTR chronic criteria are the applicable water quality objectives.
2 Water samples qualify as "brackish" water (salinity >1 and <10 parts per thousand); therefore, for dissolved metals the more stringent of the fresh or saltwater criteria are applied.
3 For hardness concentrations greater than 400 mg/L, the CTR requires that a default concentration of 400 mg/L be used.
4 The high detected concentrations of zinc in the preparation blanks used by Applied Speciation and Consulting indicate that the sample results will be biased high due to possible zinc contamination.

NB = North Branch of BCW Creek MB = Middle Branch of BCW Creek SB = South Branch of BCW Creek

Exceeds CTR Chronic Criterion for Metal in Freshwater
Exceeds CTR Chronic Criterion for Metal in Saltwater
Maximum Concentration Measured

Table 4-3. Selenium concentrations and species measured in surface water and ground-water samples.

Location	SELENIUM CONCENTRATIONS						
	Se Total	Se Dissolved	SeVI	SeIV	SeCN	MeSe(IV)	SeIV
	µg/L						%
BCW Upper							
BCR-PIEZ-I41*	NA	80.2	70.3	<0.71	<0.49	<0.52	NA
BCR-PIEZ-G26*	NA	56.4	NA	NA	NA	NA	NA
BCR-East-Underdrain*	NA	43.7	NA	NA	NA	NA	NA
BCR-West-Underdrain*	NA	62.5	53.3	<0.71	<0.49	<0.52	NA
BCW-Yacht St-HOA*	NA	149.0	NA	NA	NA	NA	NA
BCW-Port St-HOA*	NA	143.0	NA	NA	NA	NA	NA
BCW-SB-HVNP	55.2	58.3	45.8	1.7	<0.49	<0.52	2.92
BCW Middle							
BCW-SB-MAIN (Inflow #1)	35.1	36.7	20.3	8.53	<0.49	0.332J	23.2
BCW-MB-MAIN (Inflow#2)	6.0	6.1	NA	NA	NA	NA	NA
BCW-NB-MAIN (Inflow #3)	66.6	72.7	55.5	1.24	<0.49	<0.52	1.71
BCGC-Lake3	17.0	16.7	8.15	4.61	<0.49	<0.52	27.6
BCGC-Lake5	12.2	11.7	3.95	5.01	<0.49	<0.52	42.8
BCGC-Outflow to BCNP (BCW Lower)	13.1	12.7	4.71	5.38	<0.49	<0.52	42.4

NA = Not Analyzed * Groundwater samples; all other samples are surface water samples.
NB = north branch of BCW creek MB = middle branch of BCW creek SB = south branch of BCW creek
HOA = Home Owners' Association
SeVI = selenate SeIV = selenite
SeCN = methylselenitic acid
MeSe(IV) = selenomethionine
J = trace detection "<" less than the minimum detection limit for that constituent

Table 4-4. Selenium concentrations in various media collected from water bodies in the Big Canyon Country Club Golf Course and the Harbor View Nature Park.

				Selenium Concentration		
				Water	**Algae, Sediment, Tissue**	
Location	Media	Tissue Estimated % solids[1]	TSS (mg/L)	Se Dissolved (ug/L)	Selenium (ug/g ww)	Selenium (ug/g dw)
BCW-HVNP	water		5.1	58.3		
	particulates					14.9
	sediment					10.03
	green filamentous algae					15.36
	crayfish	21.2			NF	NF
	mosquitofish	22.5			5.65	25.11
	African clawed frogs	19.4			NF	NF
BCGC-Lake 3	water			16.7		
	particulates		6.0			46.80
	sediment					22.00
	green filamentous algae					10.74
	crayfish	21.2			NF	NF
	mosquitofish	22.5			10.05	44.67
	African clawed frogs	19.4			9.27	47.78
BCGC-Lake 5	water			11.7		
	particulates					36.10
	sediment					11.15
	green filamentous algae					16.36
	crayfish	21.2			4.24	20.00
	mosquitofish	22.5			9.45	41.98
	African clawed frogs	19.4			NF	NF
	PBGR bird egg tissue					41.00
BCW-Outflow	water			12.7		
	particulates		7.4			39.3

[1] Percent solids for tissue samples estimated from data collected in 2008 in the Big Canyon Creek Nature Park
NF = Not found

Table 4-5. Selenium and trace metal concentrations in particulates, sediment, and algae.

Location	Media	Selenium (µg/g dw)	Cadmium (µg/g dw)	Copper (µg/g dw)	Lead (µg/g dw)	Nickel (µg/g dw)	Zinc (µg/g dw)
HVNP	particulates	14.9	203	159	29.3	70.4	310
	sediment	10.03	9.21	74.06	11.32	23.98	80.14
	algae	15.36	28.42	33.31	3.53	13.65	47.11
Lake 3	particulates	46.80	231	120	7.43	133	505
	sediment	22.00	39.39	68.22	5.5	31.24	148.4
	algae	10.74	40.02	11.2	0.83	21.8	67.42
Lake 5	particulates	36.10	32	55.8	9.11	64.3	152
	sediment	11.15	8.86	30.56	6	28.5	77.22
	algae	16.36	13.4	16.32	1.53	21.48	48.54
Outflow	particulates	39.3	55.9	113	29.4	102	305

Note: Algae samples were collected from the east and west ends of Lake 5 and the analytical results averaged.

Concentration exceeds Presser et al. (2004) substantive biological effects guideline (Table 3-1) or NOAA sediment TELs (Table 4-6).

Table 4-7. Selenium and trace metal concentrations in biota.

Location	Media	Selenium (µg/g dw)	Cadmium (µg/g dw)	Copper (µg/g dw)	Lead (µg/g dw)	Nickel (µg/g dw)	Zinc (µg/g dw)
HVNP	mosquitofish	23.7	3.2	22.4	0.50	2.5	112.0
Lake 3	mosquitofish	42.2	0.76	4.9	ND	0.6	97.2
	frog	47.8	2.8	12.3	ND	1.0	85.8
Lake 4	PBGR bird egg	33.4	0.13	3.1	NA	NA	36.4
Lake 5	crayfish	20.0	4.8	115.6	0.35	4.6	79.0
	mosquitofish	39.7	1.5	7.8	ND	2.2	137.6
	PBGR bird egg	40.7	0.12	4.1	NA	NA	45.4

ND = Not Detected
NA = Not Analyzed
PBGR = Pied-billed grebe
Concentration exceeds biological effects guideline (Tables 3-1 and 4-6).
Concentration exceeds proposed Se tissue SSO (fish tissue SSO = 5 µg/g dw Bird egg tissue SSO = 8 µg/g dw)

Table 4-6. Guidelines used to compare to metal concentrations in sediment and biota samples collected from locations in middle and upper Big Canyon Creek.

USDOI 1998 Guidelines for Ecological Effects (surface waters)

Media	No Effect	Level of Concern	Toxicity Threshold
Copper			
Water (µg/L)	0.23	0.23-12	12
Sediment (µg/g dw)	34	34-270	270
Plants (µg/g dw)	3.0-30	—	>20
Fish, whole body (µg/g dw)	9.8	9.8-13.3	13.3
Bird eggs (µg/g dw)	5.5	—	—
Zinc			
Water (µg/L)	<30	30-110	110
Sediment (µg/g dw)	150	150-410	410
Plants (µg/g dw)	27-150	150-300	>300
Fish, whole body (µg/g dw)	—	—	—
Bird eggs (µg/g dw)	50	—	—

NOAA SQuiRTs: Trace Metals in Freshwater Sediments

Metal	TEL (µg/g dw)	PEL (µg/g dw)
Cd	0.596	3.53
Cu	35.7	197.0
Pb	35.0	91.3
Ni	18.0	35.9
Zn	123.1	315.0

Eisler 1993 - Background Concentrations of Zinc

Fish tissue	<700	(µg/g dw)
Birds	<210	(µg/g dw)

SMW MTRLs

Metal	Tissue (µg/g ww)	Tissue (µg/g dw)
Cd	0.3	1
Cu	15	60
Pb	2	8
Ni	NA	NA
Zn	45	180

Table 4-8. Selenium Concentrations in Bed Sediment, Algae, and Suspended Particulates and Calculated Partitioning Coefficients (K_ds).

		Selenium Concentration			**Partitioning Coefficient**			**CH2MHill May 8, 2009 Sampling Results**		
		Water	**Algae, Sediment, Particulates**							
Location	Media	Se Dissolved (ug/L)	Selenium (ug/g ww)	Selenium (ug/g dw)	Kd algae	Kd sediment	Kd particulates	Water Se Diss. Concentration (ug/L)	Particulate Se concentrations (ug/g dw)	CH2MHill 2009 Kd
BCW-HVNP	water	58.3			263.46	172.04	256	NA	NA	NA
	particulates			14.9						
	sediment			10.03						
	green filamentous algae			15.36						
BCGC-Lake 3	water	16.7			643.11	1317.37	2802	20.20		1941
	particulates			46.80					39.20	
	sediment			22.00						
	green filamentous algae			10.74						
BCGC-Lake 5	water	11.7			1398.29	952.99	3085	13.30		3398
	particulates			36.10					45.20	
	sediment			11.15						
	green filamentous algae			16.36						
BCW-Outflow	water	12.7			NA	NA	3094	14.10	NA	NA
	particulates			39.3						

NA = Not available

Table 4-9. Selenium loads estimated from data collected in the Big Canyon watershed in June 2010.

Location	Total Diss. Se (ug/L)	Flow Rate (cfs)	Flow Rate (gpd)	Loads (mg/d)	Loads (lbs/d)	Loads (lbs/yr)
HVNP	55.2	0.038	24560	5131	0.0113	4.13
Inflow 1	35.1	0.205	132495	17602	0.0388	14.18
Inflow 2	6.0	0.132	85314	1947	0.0043	1.57
Inflow 3	66.6	0.004	2585	652	0.0014	0.52
Lake 5 outlet	12.2	0.530	342548	15818	0.0349	12.74
Outflow to BCNP	13.1	0.819	529333	26246	0.0579	**21.14**
Estimated total Se loads from north branch of BCW creek						8.4

Table 4-10. Selenium loads estimated from data collected in the Big Canyon watershed in 2009.

Location	Total Diss. Se (ug/L)	Flow Rate (cfs)	Flow Rate (gpd)	Loads (mg/d)	Loads (lbs/d)	Loads (lbs/yr)
Inflow 1	41.7	0.082	52998	8365	0.0184	6.74
Inflow 2	4.74	0.121	78204	1403	0.0031	1.13
Inflow 3	64.5	0.032	20682	5049	0.0111	4.07
Inflow 4+	24.3	0.016	10341	951	0.0021	0.77
Inflow 5 only	41.3	0.01	6463	1010	0.0022	0.81
Outflow	14.6	0.3	193895	10715	0.0236	**8.63**

Table 4-11. Nitrate and trace metal loads, Harbor View Nature Park and Big Canyon Country Club Golf Course.

LOCATION	**DISSOLVED TRACE METALS LOADS (lbs/yr)**					**NITRATE LOADS (lbs/yr)**
	Cd	**Cu**	**Pb**	**Ni**	**Zn**	
HVNP	0.74	0.38	0.04	0.54	0.56	97.14
Inflow 1	0.81	4.03	0.04	4.03	4.03	334.6
Inflow 2	0.05	2.49	0.02	1.84	1.61	181.7
Inflow 3	0.01	0.07	0.00	0.07	0.09	13.37
Total Inflows 1-3	0.87	6.59	0.06	5.95	5.73	529.7
Outflow to BCNP	**2.83**	**4.46**	**0.26**	**14.11**	**8.37**	**628.1**
Net Gain/Loss	1.96	-2.13	0.20	8.16	2.64	98.44

Photograph 4-1. Taking surface flow measurements with the Flow Tracker velocimeter at Inflow #1 (south branch of Big Canyon Creek) where it enters the golf course.

Photograph 4-2. Taking surface flow measurements at a low flow area (Lake 5 outlet).

Photograph 4-3. Lowering the plastic bailer into a piezometer to collect a groundwater sample.

Photograph 4-4. Tranferring groundwater sample to clean sanitized plastic bucket prior to placing it into clean plastic bottles for shipment to the analytical laboratories.

Photograph 4-5. Big Canyon Reservoir East and West underdrains.

Photograph 4-6. Collecting a groundwater sample from the Port Street HOA subdrain.

Photograph 4-7. Harbor View Nature Park sampling location.

Photograph 4-8. Inflow #1 (south branch of Big Canyon Creek) where it enters the BCCC golf course.

Photograph 4-9. Inflow #2 (middle branch of Big Canyon Creek).

Photograph 4-10. Sampling Inflow #3 (north branch of Big Canyon Creek).

Photograph 4-11. Big Canyon Country Club golf course Lake 3.

Photograph 4-12. Big Canyon Country Club golf course Lake 5.

Photograph 4-13. Collecting mosquitofish in Lake 5.

Photograph 4-14. Outflow from Big Canyon Country Club golf course just east of Jamboree Rd.

Photograph 4-15. Mosquitofish and crayfish collected from Lake 5.

Photograph 4-16. African clawed frogs collected from Lake 3.

Chart 4-1. Comparison of Total Selenium Concentrations in Water (µg/L) to Selenium Concentrations in Particulates (µg/g dw), Harbor View Nature Park and Big Canyon Country Club Golf Course

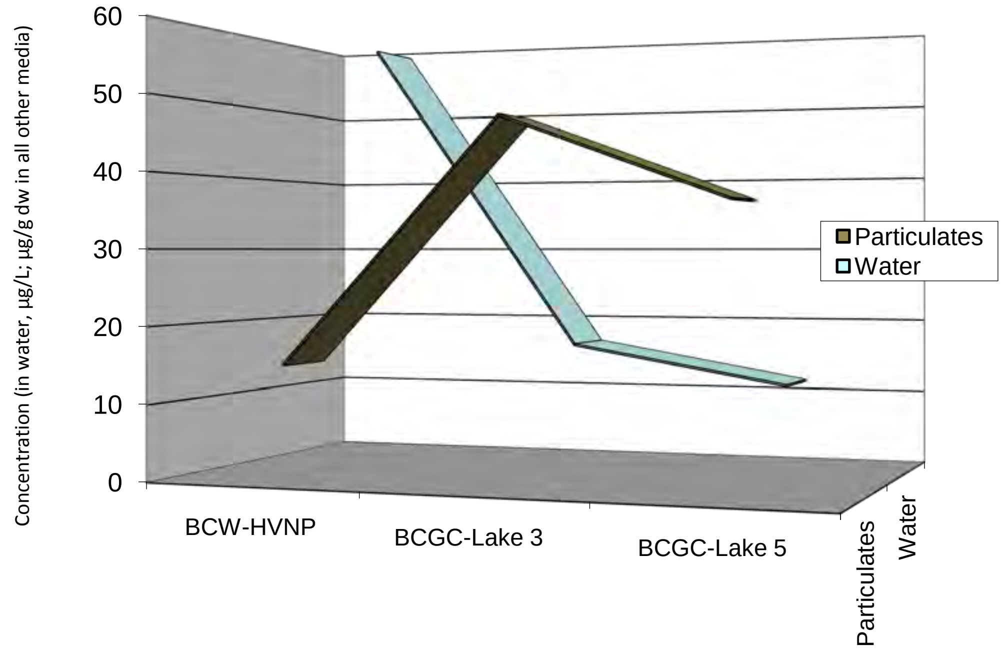


Chart 4-2. Comparison of Total Selenium Concentrations in Water (µg/L) to Selenium Concentrations in Sediment (µg/g dw), Harbor View Nature Park and Big Canyon Country Club Golf Course

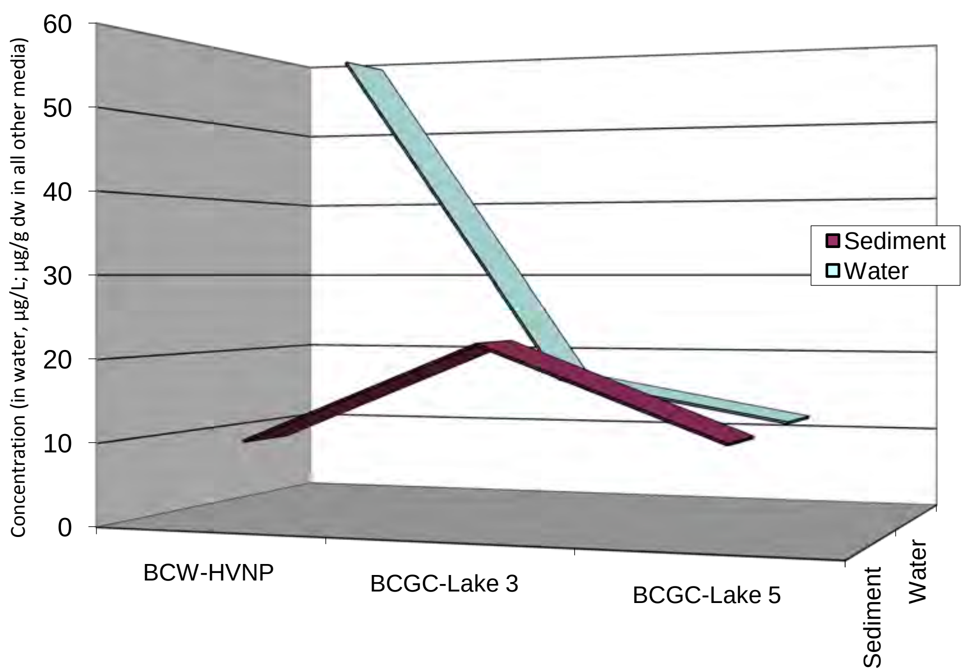


Chart 4-3. Comparison of Total Selenium Concentrations in Water (µg/L) to Selenium Concentrations in Algae (µg/g dw), Harbor View Nature Park and Big Canyon Country Club Golf Course

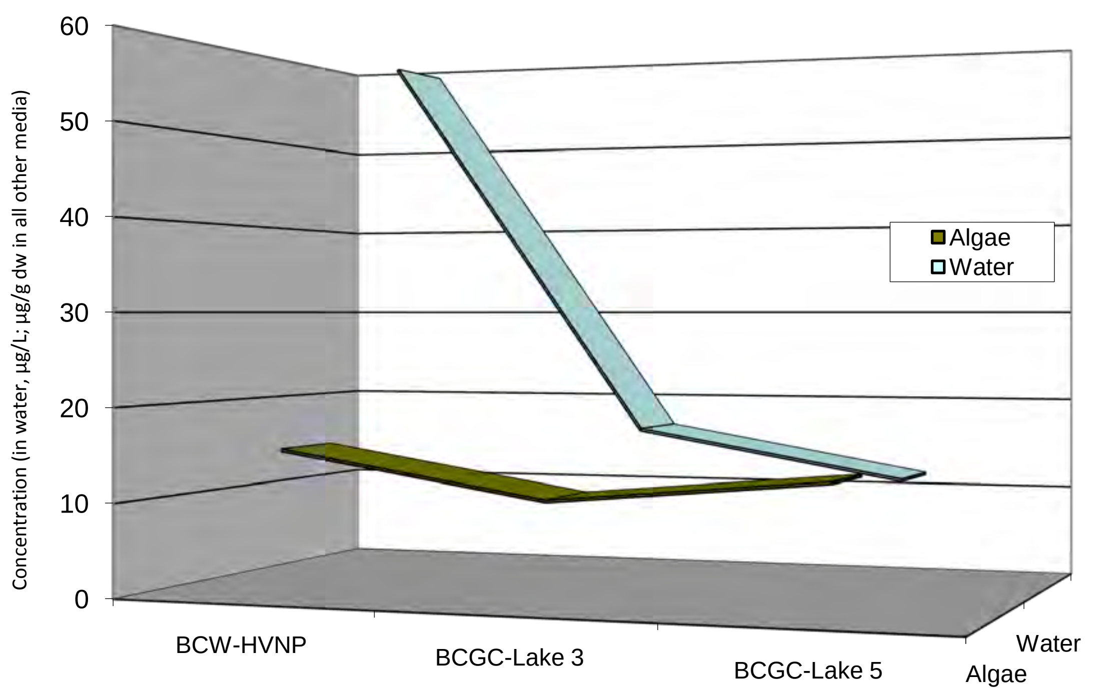


Chart 4-4. Comparison of Total Selenium Concentrations in Water (µg/L) to Selenium Concentrations in Mosquitofish (µg/g dw), Harbor View Nature Park and Big Canyon Country Club Golf Course

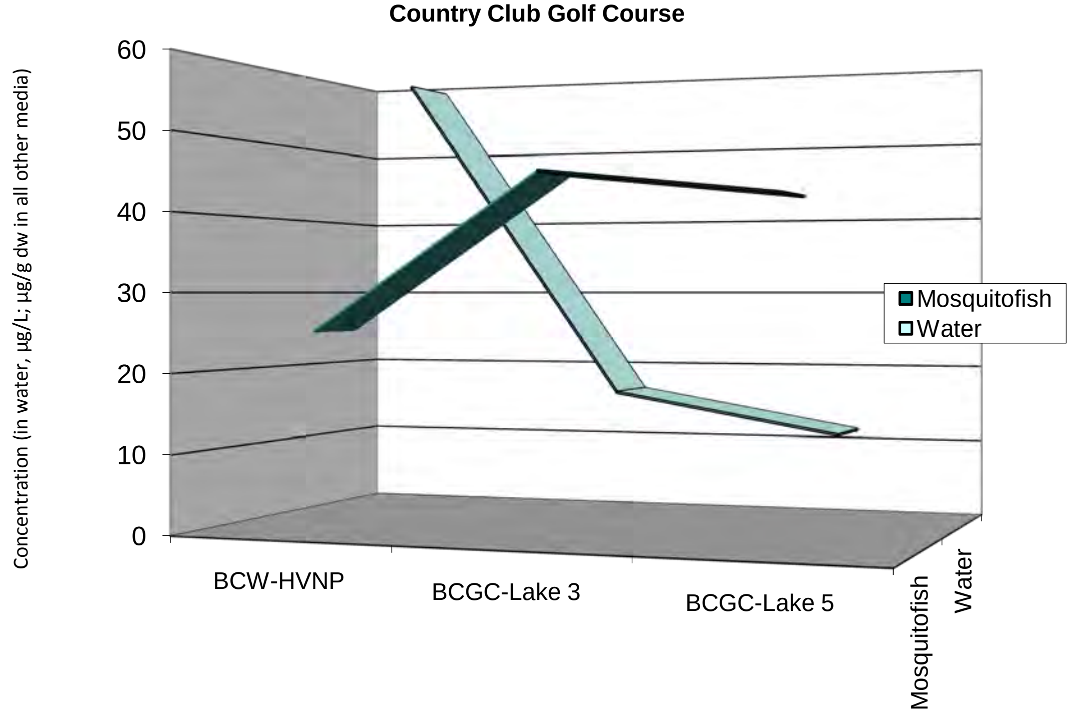


Chart 4-5. Comparison of Total Selenium Concentrations in Particulates (µg/g dw) to Selenium Concentrations in Sediment (µg/g dw), Harbor View Nature Park and Big Canyon Country Club Golf Course

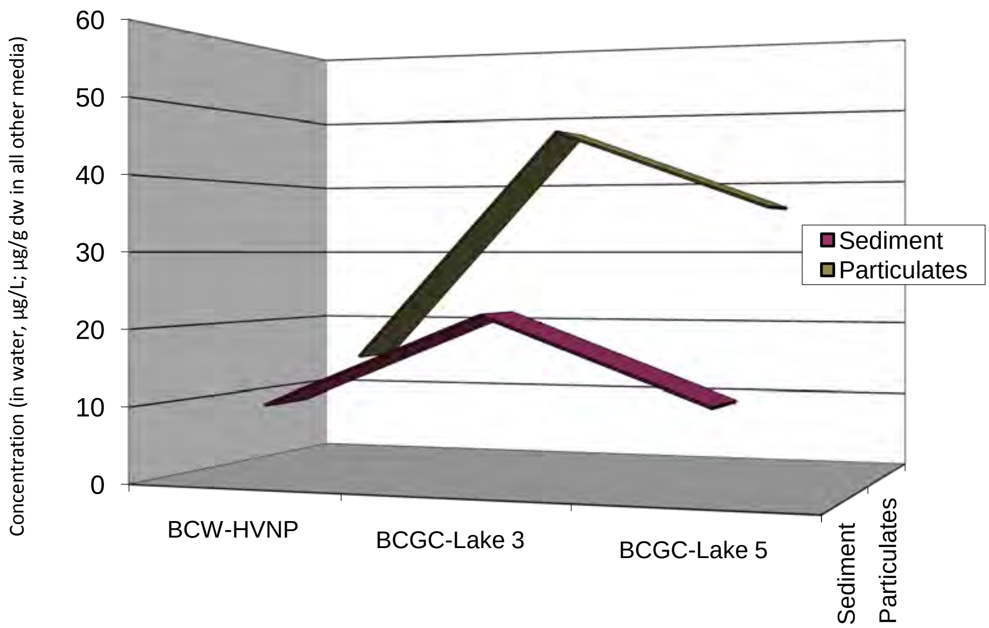


Chart 4-6. Comparison of Total Selenium Concentrations in Particulates (µg/g dw) to Selenium Concentrations in Algae (µg/g dw), Harbor View Nature Park and Big Canyon Country Club Golf Course

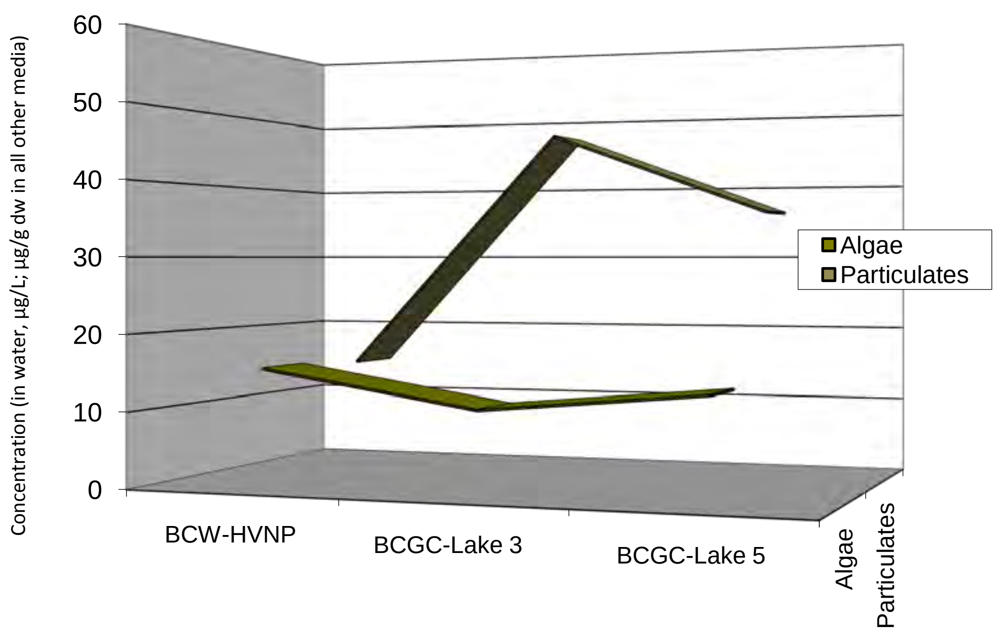


Chart 4-7. Comparison of Selenium Concentrations in Particulates (µg/g dw) to Selenium Concentrations in Mosquitofish (µg/g dw), Harbor View Nature Park and Big Canyon Country Club Golf Course

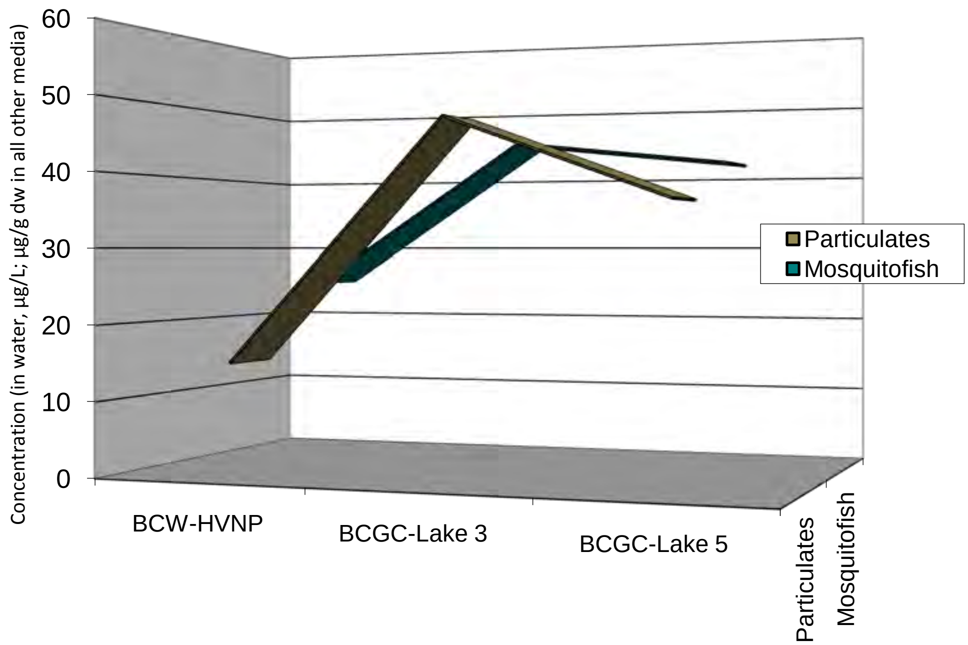


Chart 4-8. Comparison of Selenium Concentrations in Particulates (µg/g dw) to Percent (%) Selenite in Water, Harbor View Nature Park and Big Canyon Country Club Golf Course

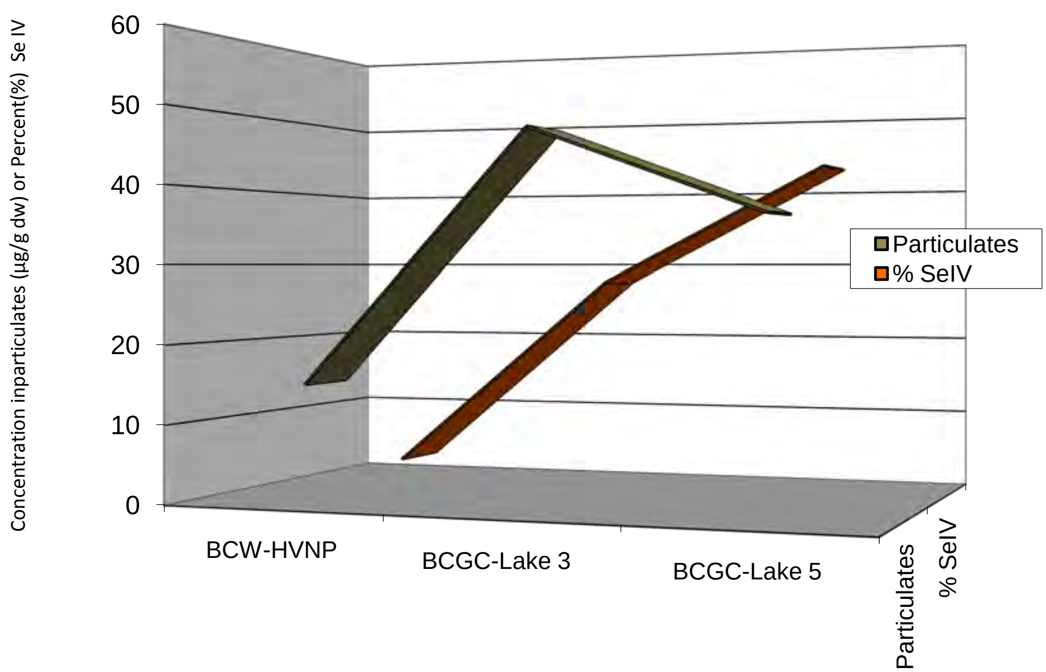


Chart 4-9. Cadmium Concentrations in Various Media: Big Canyon Country Club Golf Course and Harbor View Nature Park

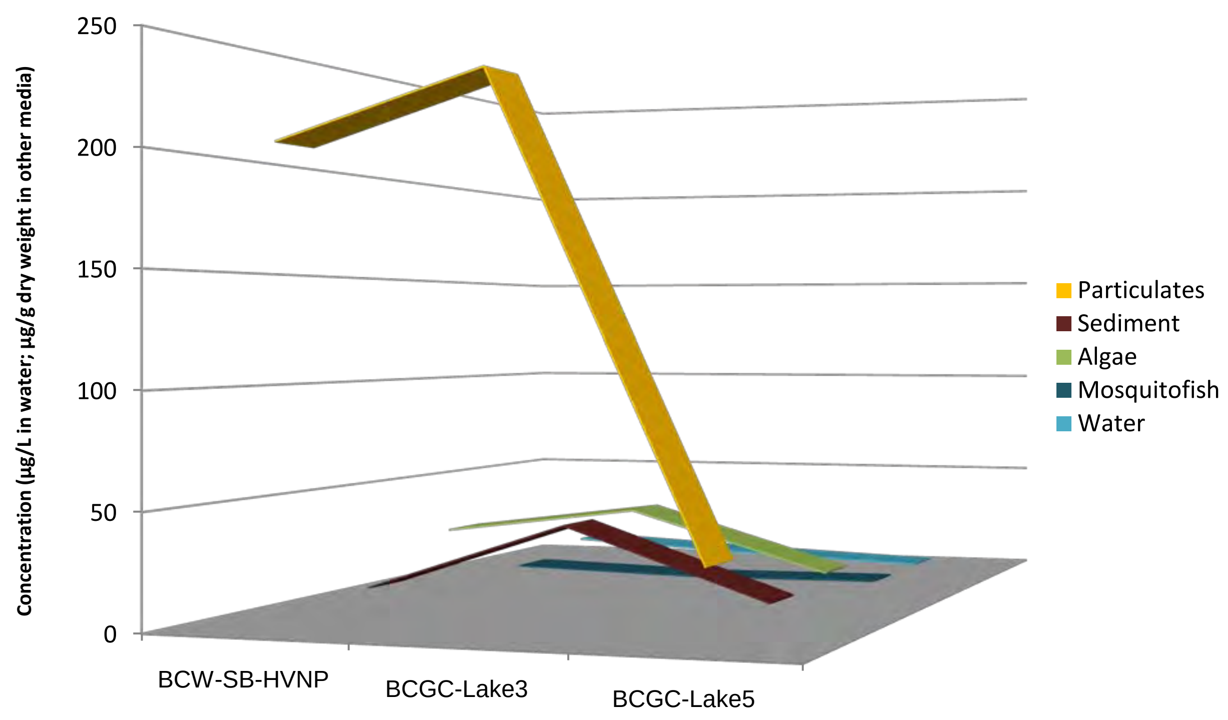


Chart 4-10. Copper Concentrations in Various Media: Big Canyon Country Club Golf Course and Harbor View Nature Park

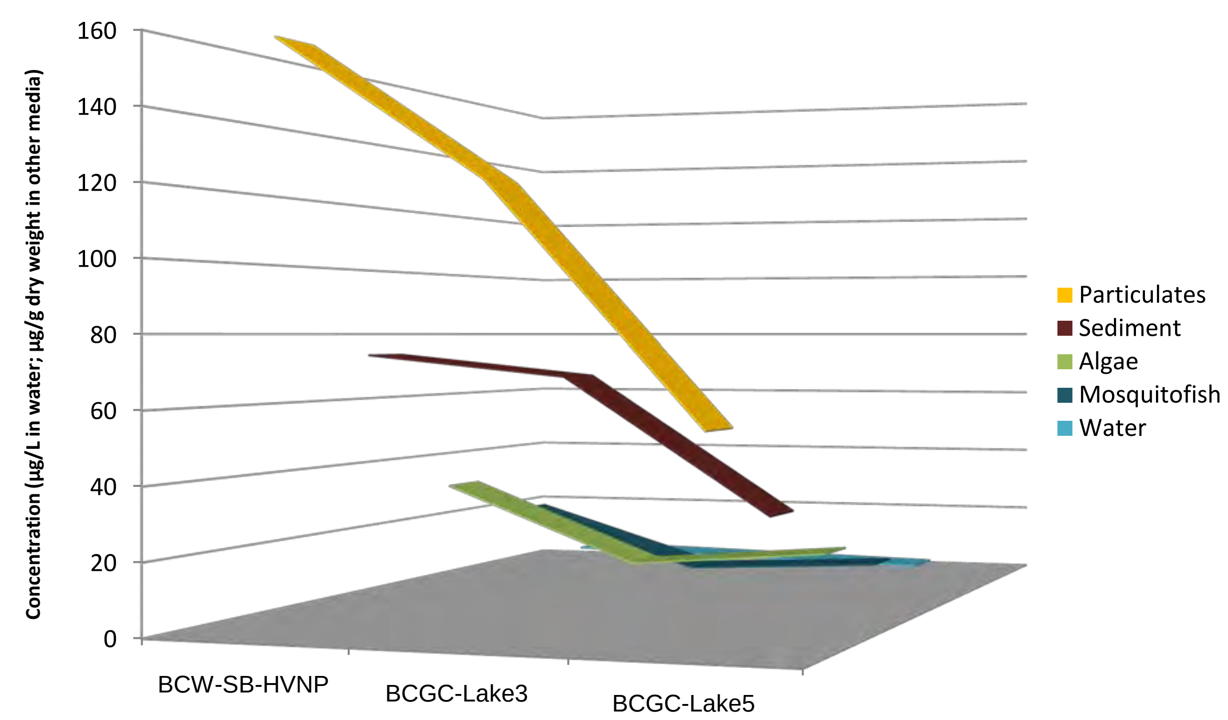


Chart 4-11. Lead Concentrations in Various Media: Big Canyon Country Club Golf Course and Harbor View Nature Park

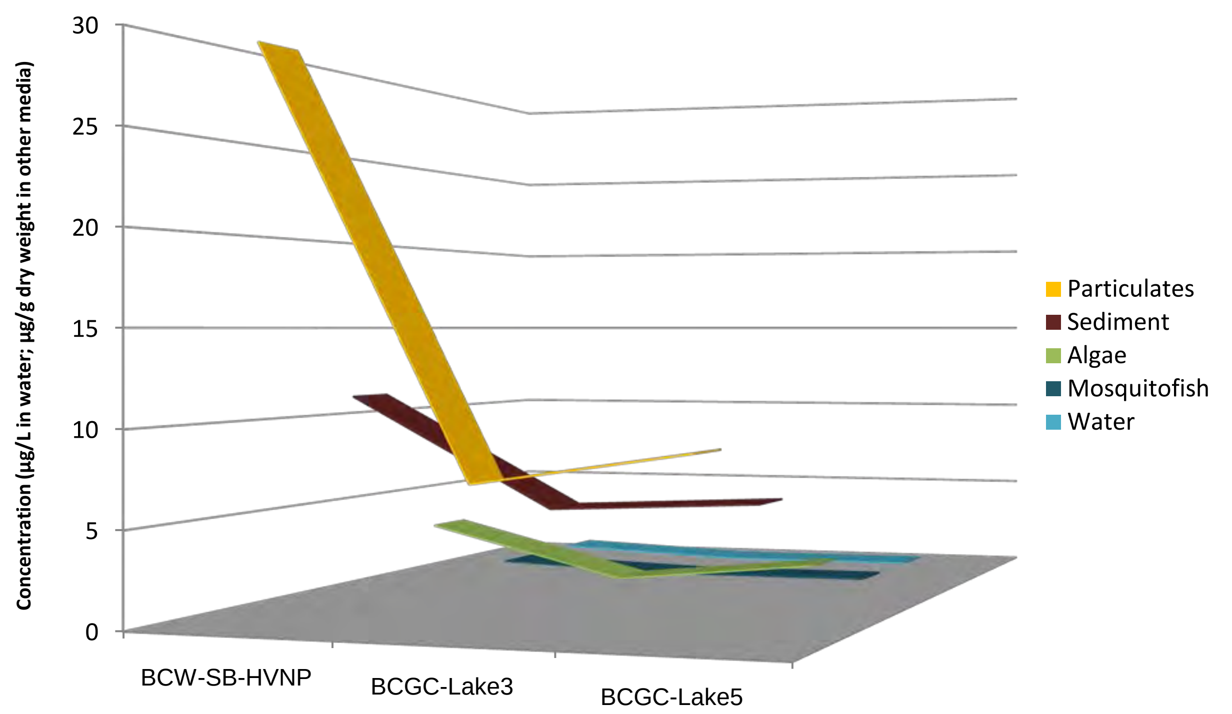
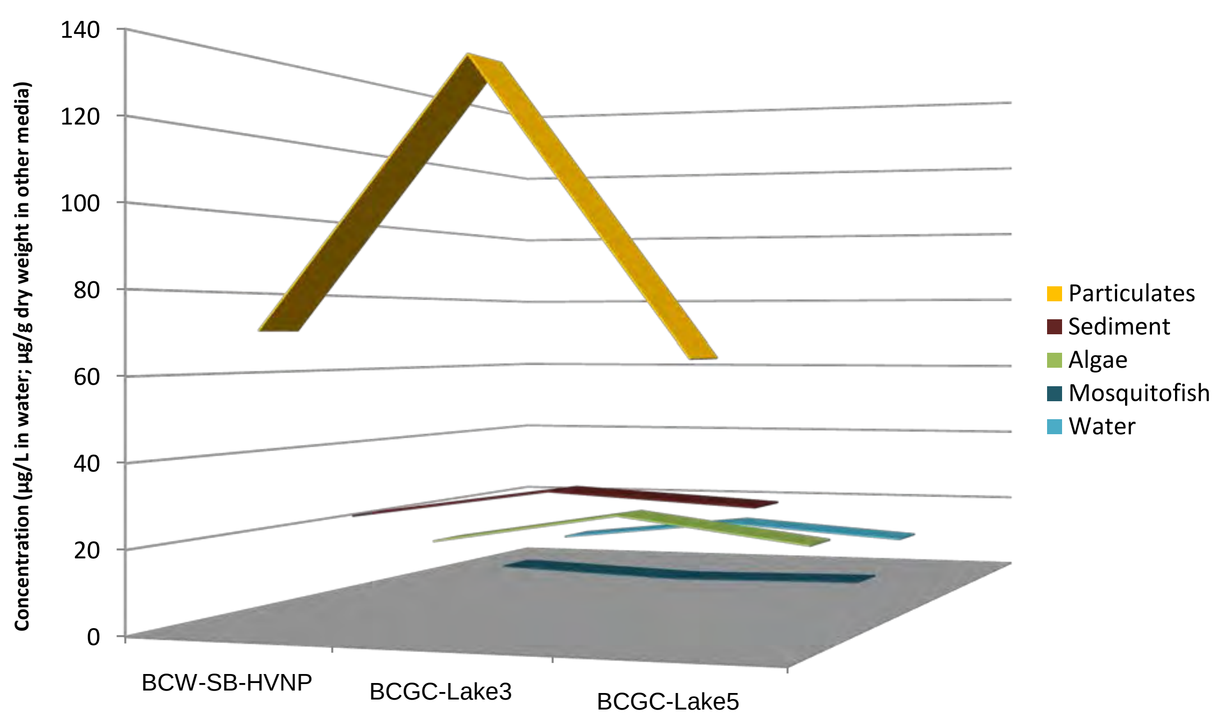


Chart 4-12. Nickel Concentrations in Various Media: Big Canyon Country Club Golf Course and Harbor View Nature Park



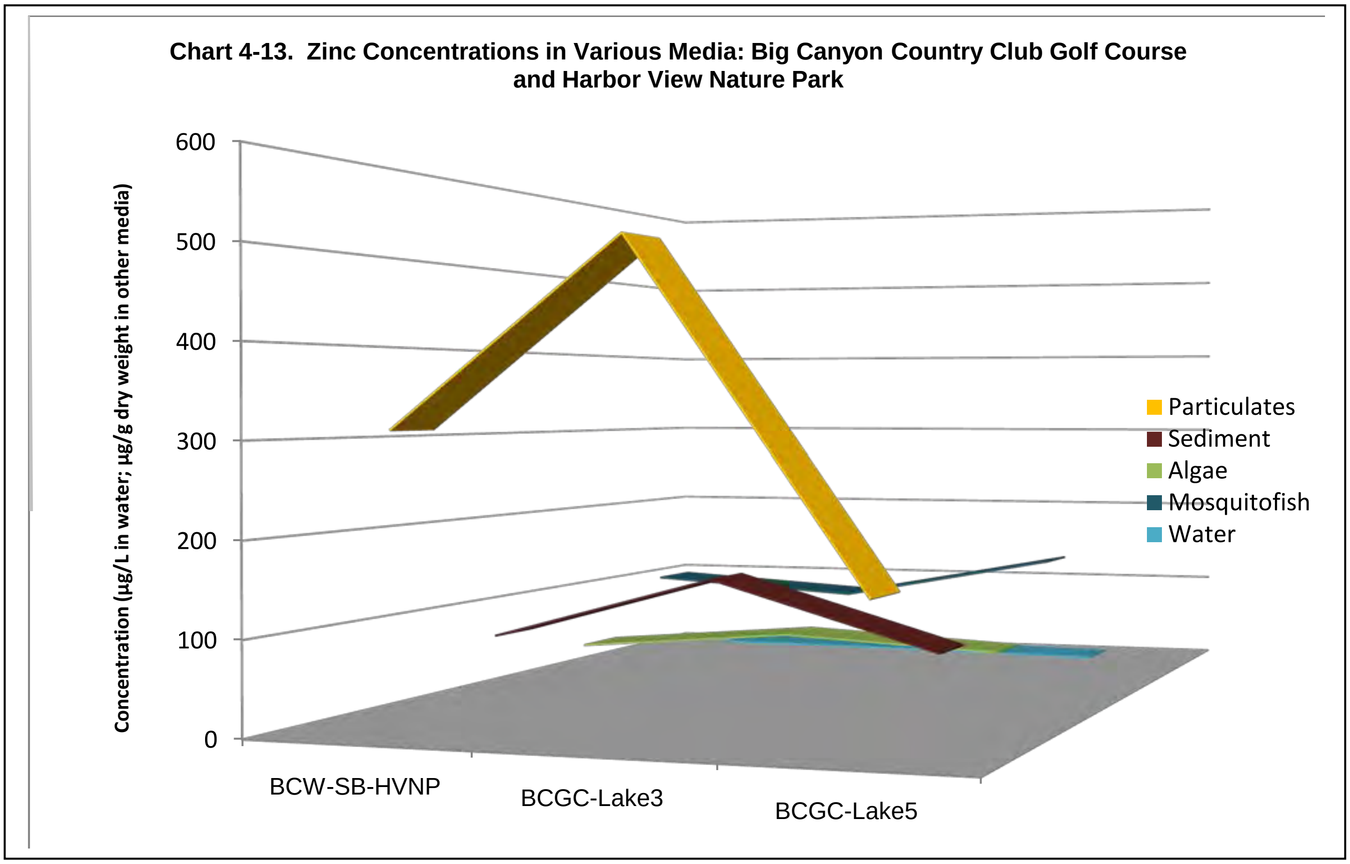


Chart 4-13. Zinc Concentrations in Various Media: Big Canyon Country Club Golf Course and Harbor View Nature Park
Concentration (µg/L in water; µg/g dry weight in other media)
600
500
400
300
200
100
0
BCW-SB-HVNP
BCGC-Lake3
BCGC-Lake5
Particulates
Sediment
Algae
Mosquitofish
Water

5.0 Hydrogeochemical Source Tracking

The geochemical fingerprint of both surface water and groundwater can often be used to track the sources of the water. Concentrations of cations and anions, pH, or other constituents in a water body generally reflect, or will be altered by, the geochemistry of the geological formation that the water flows over (for surface water) or through (for groundwater) and can thus be used for source tracking. As discussed below, several of these hydrogeochemical markers were used in the BCW watershed to see if it could be determined whether waters collected from different portions of the watershed were from different sources, even with the limited data available. This is important in determining the source of the water that is mobilizing selenium from the underlying bedrock in the watershed and in assessing potential source controls or treatment methods to aid in reducing selenium concentrations in the surface waters and aquatic-based food webs in the watershed.

5.1 Identifying Patterns of Water Chemistry

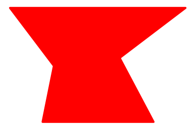
Stiff diagrams provide a pattern of the major ion chemistry of water samples (Stiff, 1951). Several selected anions and cations are plotted on parallel horizontal axes. Four cations and four anions are most commonly used but other constituents can also be added to these plots (e.g., nitrate, pH, conductivity, total dissolved solids). Cations are plotted to the left of a vertical zero axis and anions to the right of the zero axis. When the resulting points are connected, they form an irregular polygonal pattern (Figure 5-1) that can be used to define waters with similar chemistry that may arise from the same (or similar) recharge source (Todd, 1980). Comparison of the shape and spatial distribution of Stiff diagrams can therefore, be used to identify sources of groundwater and/or surface water in a watershed or groundwater basin.

Using hydrogeochemical parameters measured in water samples collected in the lower portion of BCW watershed (BCNP) from June 9-11, 2008 and in the middle and upper portions of the BCW watershed on June 21, 2010 (BCW Middle and BCW Upper), Regional Board staff generated Stiff diagrams using a public domain software (Boghici and Boghici, 2001). Four cations (calcium [Ca], potassium [K], magnesium [Mg], sodium [Na]), four anions (chloride [Cl], carbonate [CO_3], bicarbonate [HCO_3], and sulfate [SO_4]), and total dissolved solids (TDS) were used to plot the diagrams. The geochemical parameters and sampling locations used to generate the stiff plots for the BCW watershed are shown in Table 5-1 The Stiff diagrams plotted for the BCW watershed are shown in Figures 5-2a-e[1].

Sufficient data was available to plot Stiff diagrams for groundwater samples collected in BCW Upper from the headwaters of the south branch of BCW creek. Geochemical data from groundwater samples collected from two of the

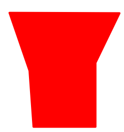
[1] Because concentrations of potassium and carbonate are much lower than the other ions plotted (for freshwater, K < 12 mg/L and CO_3 <1 mg/L), they are not visible at the scale of the diagrams shown in Figures 5-2a-e.

piezometers (G-46 and I-41) and the east and west underdrains at the BCR and from one of the nearby subdrains (Yacht Street HOA)[2], as well as the surface water sample collected from the HVNP were plotted (Figure 5-2b). As can be seen in Figure 5-2b, the pattern of the Stiff diagrams for these samples resembles a warped hourglass or anvil pattern similar to that shown below:



This same pattern can be seen in the sample collected from the flows in the south branch of BCW creek that daylight on the BCCC golf course (Inflow 1) just west of MacArthur Boulevard (Figure 5-2b). The pattern of the Stiff diagrams in this area indicates a common source of water and confirms that leakage from the BCR is the major source of water to the south branch of BCW creek. Slight variations in the signatures of the Stiff diagrams (compare east and west underdrain signatures) may be a result of longer retention times in the subsurface (e.g. Yacht St. HOA subdrain), which generally result in an increase in concentration of some dissolved constituents in the water, a greater influence of one water source over another (e.g. irrigation water over precipitation or potable water), or possibly, analytical error.

If we look at the area of the watershed located northwest of the BCR (BCW middle), where flows from the middle (Inflow 2) and northern (Inflow 3) branches of BCW creek daylight on the BCCC golf course, we can see that the pattern of the Stiff diagrams are different than that seen in the vicinity of the BCR (Figure 5-2d). This pattern resembles a thick “Y” shaped column as shown below:



This observation is supported by lower sulfate concentrations and total dissolved solids (TDS) measured in these water samples compared to the samples collected in the south branch (see Table 5-1). The selenium concentrations in the middle branch of BCW creek (Inflow 2) are substantially lower than those measured in the northern branch and the southern branch (see Section 4.3.2, Table 4-3, and Figure 4-3). While the Stiff diagram patterns are similar between the northern and middle branches of BCW creek, they are different from the

[2] The sampling crew did not have enough sample containers to collect sufficient water to allow for analysis of all of the geochemical parameters needed for a Stiff diagram for the Port Street HOA subdrain. At the time of sampling, the names of the subdrains were not known and they were labeled based on their geographic locations. The Yacht St HOA subdrain is actually called the Seaview subdrain and the Port St HOA subdrain is known as the Bren or Bren Tract subdrain. The Bren drain is tributary to the Seaview drain. Groundwater from both drains is discharged into the HVNP (see Sections 2.0 and 4.0 for more information).

southern branch, which indicates a different source(s) of water for this portion of the watershed. The low selenium concentrations in the middle branch of BCW creek may be a result of the different geologic formations and structures that characterize this branch of the creek (see Figure 2-3) or because flows in this branch of the creek are supported by urban runoff and/or leakage from the Spyglass Hill Reservoir with minimal or no groundwater inputs.

The hourglass/anvil pattern seen in the upper portion of the southern branch of BCW creek (BCW upper) can be traced downstream through the lakes on the BCCC golf course (BCW Middle; see Figure 5-2c and 5-2d) all the way through the BCNP to UNB (BCW Lower; see Figure 5-2e). On Figure 5-2e, the influence of saltwater from UNB on the shape of the Stiff diagrams (primarily due to high sodium chloride and TDS) is clearly seen in the water samples collected from the main and northern channels of BCW creek that enter the salt marsh just west of Back Bay Drive.

While the surface water patterns in the BCNP echo that seen in the samples collected from the BCCC golf course and areas upstream of the BCNP, indicating a common water source (BCR), the pattern of the Stiff diagrams plotted from the water samples collected in 2008 from three storm drains/subdrains located along the northern margin of the BCNP are distinctly different indicating a different source(s) of water for these drains. Of the three drains, SD #1appears to flow perennially and has a small catchment area at its discharge point. Water flows from the catchment into the riparian area located along the northern side of the lower part of the canyon, and then into the north channel of BCW creek, which discharges to UNB. (Figure 5-2e). The selenium concentration measured in the water from this drain during the 2008 baseline monitoring investigation was 13 µg Se/L. Given the volume of the flow from this drain and its perennial nature, it is likely that the drain is intercepting groundwater. In 2008, the only other storm drain that contained flowing water was SD #3. In 2009, a sample of water was also collected and analyzed from SD #4. Selenium concentrations in SD#3 and 4 have ranged from non-detect (in SD #4) to less than 5 µg Se/L (SD #3).

As can be seen in Figure 5-2e, the hydrogeochemical signatures of SD #3 and 4 are different than SD #1. The majority of the cations and anions measured in water samples collected from these drains are lower in concentration than those measured in water collected from SD #1 or the surface water in BCW creek (Table 5-1). Since both drains are also low in selenium and appear to only flow sporadically, it is likely that irrigation water or other urban runoff, not groundwater, is the source of water in these drains.

5.2 Summary

Though this analysis is preliminary, the hydrogeochemical markers used to plot the data collected from the BCW watershed indicate that there are different sources of water that feed the shallow perched aquifer that is the source of selenium in surface and ground waters. While local precipitation is likely one source of water common to the BCW watershed, the groundwater and surface waters in the south branch of the creek and the area around the BCR display similar patterns in water chemistry confirming that leakage from the BCR is the main source of water in this branch of the creek. However, the water in the north and middle branches of BCW creek display a different pattern and are likely influenced by a different source(s) of water, not directly related to BCR[3].

Even though the data used in this analysis is very limited (single samples at two different points in time: 6/9-11/08 and 6/21/10), comparison of the 2010 metals and hydrogeochemical data to data collected in 2008 indicate that the 2010 analytical results fall within a similar range of values (compare Stiff diagrams for BCCC Outflow, plotted from data collected in 2010 and BCNP Inflow, plotted from data collected in 2008). Monitoring of these parameters and other constituents that may be used to track patterns in water chemistry should be continued as part of a program to identify the sources of water in other areas of the BCW watershed, especially the middle and northern branches of BCW creek.

[3] BCR contains potable water which is used for both drinking water and residential irrigation in the BCW watershed. However, the water that leaks from the reservoir is influenced by the underlying Monterey Formation (see discussion in Section 2.1 of this report) resulting in a different chemical signature than the water in the reservoir itself.

Figure 5-1. Examples of Stiff diagrams. The horizontal distance from the vertical axis is based on the number of milliequivalents per liter of each anion or cation. (Hem, J.D., 1985. US Geological Survey Water-Supply Paper 2254.)

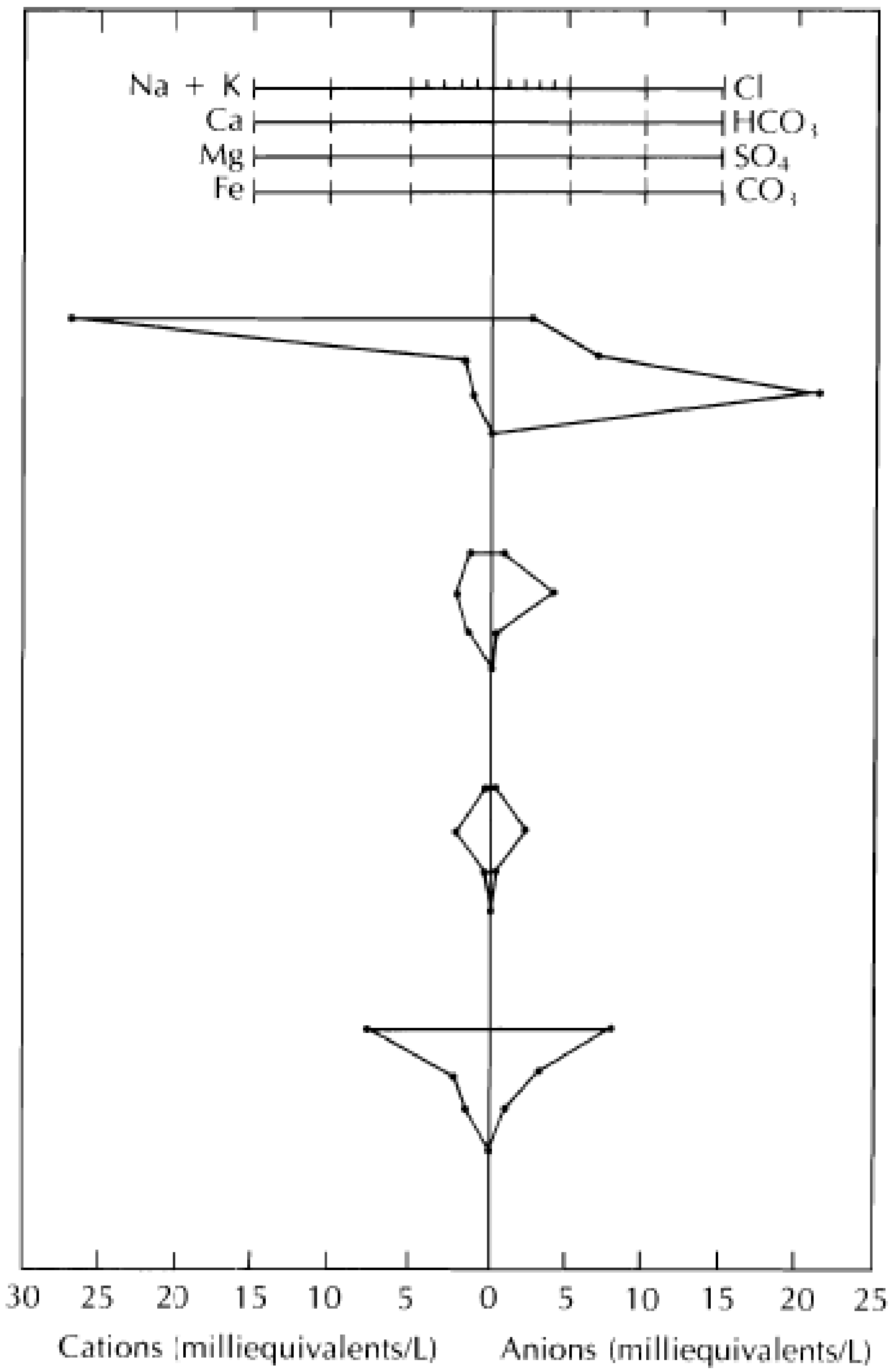


Figure 5-2a. Overview of Stiff diagrams used to aid in identifying waters that may have a common source in BCW Watershed.

Figure 5-2b. Stiff diagrams plotted for groundwater (Yacht St HOA, BCR underdrains, piezometers G-26 andd I-41) and surface water (HVNP) in the vicinity of the BCR (BCW Upper).

Figure 5-2c. Stiff diagrams plotted for groundwater and surface water (HVNP, Inflow 1, Inflow 2, BCCC Lake 3) in the south branch of BCW creek where surface water and groundwater flow into the BCCC golf course.

Figure 5-2d. Stiff diagrams plotted for surface water flows on the BCCC golf course (BCW Middle). Surface water that flows into the golf course from the eastern and northern portions of the canyon join at the northwestern end of the golf course (BCCC Outflow) and flow through a culvert under Jamboree Road into the BCNP.

Figure 5-2e. Stiff diagrams plotted for storm drains (SD #1-3) and surface water flows in the BCNP. Exaggerated top-portions of the Stiff diagrams plotted for the saltwater marsh (SWM) water samples illustrate the effect that high sodium, chloride, and TDS have on the shape of the diagrams. Note that the warped hourglass shape is well defined from the water bodies on the BCCC golf course (Lake 5 and the Outflow) all the way downstream along BCW creek (BCNP Inflow, FWM, RIP, Pond) until it reaches the saltwater marshes in UNB.

Table 5-1. Hydrogeochemical data used to plot Stiff diagrams for the BCW Watershed.

Location	Date Sample Collected	Lat	Long	Ca	Mg	K	Na	Cl	CO3	HCO3	SO4	TDS
Big Canyon Reservoir Area												
BCR-PIEZ-141 (piezometer)	06/21/10	33.6099	-117.8553	334.7	270.0	9.62	460	710	0.85	624	1700	4724
BCR-PIEZ-G26 (piezometer)	06/21/10	33.6138	-117.8572	52.3	63.7	2.50	390.7	790	0.85	616	1200	3884
BCR-WEST-UNDER DRAIN	06/21/10	33.6127	-117.8590	206.1	147.8	6.16	660.8	880	0.85	464	1200	3868
BCR-EAST-UNDER DRAIN	06/21/10	33.6126	-117.8599	175.0	131.3	6.67	304.0	490	0.85	308	720	2670
BCW-YACHT ST HOA (Seaview subdrain)	06/21/10	33.6141	-117.8576	380.0	279.8	8.20	830	2100	0.85	472	1000	6120
BCW-PORT ST HOA (Bren subdrain)[1]	06/21/10	33.6137	-117.8595	513.2	219.5	9.48	1100	0	0	0	0	0
Harbor View Nature Park												
BCW-SB-HVNP-WATER	06/21/10	33.6136	-117.8612	209.0	142.0	7.81	486.0	840	0.85	360	1000	3588
Big Canyon Country Club Golf Course												
BCW-SB-MAIN (#1)	06/21/10	33.6186	-117.8647	268.1	183.3	7.59	586.0	1000	0.85	439	1200	4326
BCW-MB-MAIN (#2)	06/21/10	33.6225	-117.8633	117.4	90.5	5.81	367.4	510	0.85	481	530	2467
BCW-NB-MAIN (#3)	06/21/10	33.6269	-117.8628	168.3	99.0	10.00	417.8	720	0.85	432	520	2916
BCGC-LAKE3-WATER	06/21/10	33.6205	-117.8697	231.5	174.1	9.23	489.8	880	0.85	417	1100	4144
BCGC-LAKE5-WATER	06/21/10	33.6275	-117.8741	258.0	217.1	9.88	535.2	930	0.85	397	1400	4500
BCGC-OUTFALL-WATER	06/21/10	33.6289	-117.8758	250.1	208.1	10.26	510.9	880	2.40	379	1300	4310
Big Canyon Nature Park												
BCNP-Inflow	06/11/08	33.6291	-117.8772	260	210	11	490	760	0.85	350	1200	3200
FWM (freshwater marsh)	06/11/08	33.6292	-117.8799	290	220	11	490	740	0.85	370	1300	3400
RIP (riparian)	06/11/08	33.6312	-117.8806	280	210	10	470	770	0.85	390	1400	2200
SD #1 (storm/subdrain)	06/11/08	33.6328	-117.8832	120	61	15	320	300	0.85	360	530	1500
SD #3 (storm/subdrain)	06/11/08	33.6315	-117.8820	70	17	6.2	86	83	0.85	210	140	540
SD #4 (storm/subdrain)	06/11/08	33.6308	-117.8798	79	21	14	130	130	0.85	200	170	650
FWMP-A (Pond)	06/11/08	33.6312	-117.8826	290	230	11	510	760	0.85	390	1400	9500
FWMP-B (Pond)	06/11/08	33.6312	-117.8834	330	240	12	550	850	0.85	410	1500	3800
FWMP-C (Pond Outflow)	06/11/08	33.6316	-117.8843	320	240	11	540	860	0.85	420	1500	3800
FWMP-D (Pond)	06/11/08	33.6316	-117.8844	310	230	11	520	760	0.85	420	1400	3700
SWM-MC (saltwater marsh main channel)	06/11/08	33.6316	-117.8852	350	660	190	4600	9900	0.85	290	2000	19000
SWM-NC (saltwater marsh north channel)	06/11/08	33.6333	-117.8848	240	240	63	1500	3000	0.85	490	1200	7100

[1] Sampling team did not have enough sample bottles to collect sufficient water for geochemical analysis for this location.

6.0 Conclusions and Recommendations

Review of the data available for the BCW watershed indicate that selenium concentrations in surface waters pose a potential risk to fish and wildlife throughout the watershed, especially in areas where water is ponded and residence times for particulates and organisms are relatively long, such as the ponds on the BCCC golf course and the mitigation pond located in the lower part of the BCNP. A preliminary analysis and comparison of geochemical parameters in groundwater samples collected from areas around the BCR (including the BCR underdrains) and from surface water samples collected from the south branch of BCW creek indicate that leakage from the BCR is the dominant source of water in this branch of the creek. This is supported by studies conducted on behalf of the City of Newport Beach in the mid 1970s and 1980s.

One of the largest data gaps is the lack of consistent and seasonal data on flows in the BCW watershed. Water quality and flow monitoring as well as potential mitigation or source control measures should be developed for the BCW watershed. In addition, a detailed analysis of the sources of water that are mobilizing selenium in the watershed still needs to be made, especially for the low selenium waters present in the middle branch of BCW creek. A preliminary assessment of the data needed to complete the selenium investigations in the BCW watershed and develop a selenium management and mitigation plan is included under the Section 6.2.

6.1 Conclusions

The following conclusions are based on Regional Board staffs' review of both recent and older investigations into groundwater, geology, hydrology, selenium, and water quality in the BCW watershed. Several general conclusions based on previous investigations and data collected since the early 1970s and extending up to 2009 are presented first, followed by conclusions specific to the Regional Board Team's June 21, 2010 study of selenium in surface water and groundwater in the upper half of the BCW watershed (BCW Middle and Upper), east of the BCNP.

- In the BCW watershed, a shallow, perched groundwater table appears to underlie portions of the area between San Miguel Road, Ford Road, and MacArthur Boulevard. However, the extent of the aquifer and its characteristics have not yet been investigated. The aquifer is likely maintained by a combination of local precipitation, golf course and urban landscape irrigation, leakage from the BCR and possibly, leaking water lines. Much of the BCW watershed, including the area around the BCR, is underlain by the Miocene Monterey Formation, a formation which is known to contain selenium as well as several other trace elements. Measurements of selenium concentrations in groundwater in the vicinity of BCR confirm that the shallow groundwater table contains high concentrations of selenium. Selenium is mobilized from subsurface deposits by infiltrating water and is then transported by rising groundwater to surface waters via seeps, leaky storm drains, subdrains, or other conduits.

- Investigations of groundwater flow around the BCR in the mid- to late 1970s revealed that the underlying Monterey Formation is highly fractured and conducts and transmits significant quantities of groundwater. Local groundwater mounds form along the east, south, and southwestern reservoir walls in response to rises in reservoir levels. Net underflows from the reservoir were estimated to flow towards the west/northwest at approximately 6 gpm. It was concluded that the major source of groundwater in the vicinity of the reservoir was the reservoir itself.

- Groundwater flow rates and directions for flow through the Monterey Formation in the vicinity of the BCR are based on very limited data that is more than thirty-five years old. Flow estimates based on more recent data would provide a more accurate portrayal of current conditions in the vicinity of the BCR, since the area is more densely populated than it was in the 1970s and several changes to the reservoir and reservoir operations have occurred.

- Two residential subdrains (Bren and Seaview drains) constructed in the 1970s, along with the BCR east and west underdrains discharge into the upper end of the HVNP, which is located in the south branch of BCW creek. Measurements of flows in this portion of the creek compared to discharge data from the residential subdrains and BCR underdrains indicate that the surface flows in the creek primarily originate from these discharges.

- A study performed in the mid-1970s determined that at that time, the irrigation at the PVMP cemetery did not result in any significant recharge to the shallow water table in the vicinity of the BCR. However, the irrigated area of the cemetery has doubled in size since the study was completed.

- In the BCW watershed, in many instances surface and subsurface flows are controlled, or heavily influenced by, an extensive system of storm drains. Some of the storm drains act as conduits for irrigation runoff and rising groundwater, transporting these flows with their attendant pollutants to surface waters in BCW creek.

- Though based on limited data and observations, local residential and commercial landscape irrigation may be an important source of water in the BCW watershed.

- While local precipitation is certainly a periodic source of water to the shallow perched aquifer in the BCW watershed, it does not appear to be as influential on groundwater recharge and selenium mobilization as more local sources of water such as leakage from the BCR.

- There is a significant lack of hydrologic data for the BCW watershed, especially for flow volumes in different portions of the creek and seasonal variations in flows. Pollutant load estimates and other flow-dependent data can only be used as preliminary estimates for qualitative purposes.

- Data collected in various portions of the BCW watershed over the last several years indicate that selenium concentrations in water, sediment, and biota are at levels that may pose an ecological threat to fish and wildlife that inhabit the area. Selenium cycling and bioaccumulation in BCW creek are exacerbated by the fact that many areas of the main branch of the creek (south branch) have been modified so that water is retained resulting in a number or ponds and marshes throughout the drainage. The longer residence times for particulates and biota in these areas results in increased cycling of selenium into its more bioavailable forms resulting in greater bioaccumulation throughout the food web.

- During the June 21, 2010 monitoring, the southern and middle branches (Inlfows 1 and 2, respectively) of BCW creek at their point of discharge to BCCC golf course contained the largest flows while the lowest flows were recorded in the north branch. Comparison of the total inflows from the three main branches of BCW creek where they enter the eastern end of the golf course to the total outflow from the BCCC golf course at its western end indicate that additional flows (approximately 0.5 cfs) enter the golf course from residential storm drains, sub drains, golf course and/or residential landscape irrigation, or as rising groundwater directly into the creek.
- Sampling and analyses of water, sediment, and fish tissue collected from surface waters in the HVNP and BCCC golf course Lakes 3 and 5 indicate that selenium concentrations exceed fish and wildlife ecological risk guidelines. Selenium concentrations measured in mosquitofish exceeded the proposed fish tissue SSO of 5.0 ug/g dw and two Pied-billed grebe bird eggs collected by CH2M Hill from the vicinity of BCCC Lakes 4 and 5 in June 2010 exceeded the proposed bird egg tissue SSO for selenium of 8.0 µg/g dw.
- The bioaccumulation potential for lentic water bodies where particulates and organisms have relatively long residence times may be underestimated if partitioning coefficients (K_ds) calculated from bed sediment or algae selenium concentrations are used as surrogates for particulate selenium concentrations.
- The highest concentrations of trace metals measured in various media collected from the HVNP and BCCC golf course Lakes 3 and 5 were found in the suspended particulate samples. Particulate trace metal concentrations may be important in helping to determine metals loadings to Upper Newport Bay.
- The percentage of selenite in the water column provides a better indicator of the degree of selenium bioaccumulation that may be occurring than total selenium concentrations. Any complete assessment of potential adverse impacts from selenium however, requires extensive sampling and monitoring of multiple environmental compartments (water, particulates, sediment, algae or other plants, invertebrates, fish, and bird eggs) that selenium may occupy in a water body.
- There is a significant increase in flow and selenium, trace metal, and nitrate loads in the south branch of BCW creek from the HVNP to where Inflow 1 daylights on the BCCC golf course, indicating additional inputs from either rising groundwater or urban runoff.
- Based on the June 2010 measurements, a minimum of 16 lbs Se/yr enters the BCCC golf course from the three main branches of BCW creek (Inflows 1-3) during the dry season. The majority of the selenium loadings are from the south branch of the creek (14 lbs/yr). Approximately 21 lbs Se/yr exits the golf course and enters the BCNP. Not counting potential selenium losses in the golf course ponds and riparian

areas, a minimum of an additional 5 lbs Se/yr must enter the golf course from sources other than surface water inflows from BCW creek.

- There are several storm drains/subdrains that discharge into the BCCC golf course from the surrounding residential areas, none of which were measured on June 21, 2010. Additional selenium loadings likely enter surface waters either from these drains, from infiltration/leakage from the golf course lakes, from rising groundwater directly into the creek, or some combination of all of three of these potential sources.
- With the exception of copper, there is a net gain in trace metals loads as BCW creek flows though the BCCC golf course, either from loadings from the unmeasured inflows from residential storm drains/ subdrains that daylight on the golf course or from golf course irrigation and maintenance activities, or a combination of both. Based on the June 2010 data, approximately 3 lbs cadmium, 4.5 lbs copper, 0.26 lbs lead, 14 lbs nickel, 8.4 lbs zinc are transported via dry weather surface flows from the BCCC golf course into the BCNP on an annual basis. However, around 2 lbs/yr of copper is lost between the east and west ends of the golf course, likely via sequestration of copper in the golf course lake sediments.
- Based on the June 21, 2010 data, approximately 628 lbs/yr of nitrate are transported from the BCCC golf course into the BCNP during dry weather flows. As only 530 lbs nitrate per year enter the golf course from the three main branches of BCW creek, at least an additional 98 lbs of nitrate per year are discharged to BCW creek during the dry season as it flows through the BCCC golf course.
- The hydrogeochemical markers used to plot the data collected from the BCW watershed indicate that there are different sources of water that feed the shallow perched aquifer that is the source of selenium in surface and ground waters. While local precipitation is likely one source of water common to the BCW watershed, the groundwater and surface waters in the south branch of the creek and the area around the BCR display similar patterns in water chemistry, while the water in the north and middle branches of BCW creek display a different pattern and are likely influenced by a different source(s) of water.
- A consistent pattern in hydrogeochemical markers can be traced from groundwater in the vicinity of the BCR to surface flows in the south branch of BCW creek at the HVNP, westward through the BCCC golf course lakes, then downgradient into the BCNP until the freshwater in the creek meets the saltwater in UNB. The relative uniformity of this pattern confirms that leakage from the BCR is the major source of water to the south branch of BCW creek.
- While the hydrogeochemical data collected to date is limited, comparison of the 2010 metals and hydrogeochemical data to data collected at other locations in the watershed in 2008 indicate that the 2010 analytical results fall within a similar range of values.

6.2 Recommendations

The following tasks are recommended by Regional Board staff to help to fill in existing data gaps and to aid in the development of a comprehensive selenium management and mitigation plan for the BCW watershed.

6.2.1 WATER QUALITY MONITORING

1. Water samples should be collected and analyzed for general chemistry, metals, selenium, and selenium species on at least a semi-annual basis (though quarterly monitoring is recommended initially) to determine seasonal patterns in concentrations, and to identify areas influenced by irrigation or rising groundwater.

   The following monitoring locations are recommended:
   a. Big Canyon Reservoir (BCR) underdrains outflow
   b. Harbor View Nature Park (HVNP)
   c. Inflows 1, 2, and 3 on the Big Canyon Country Club (BCCC) golf course
   d. BCCC golf course Lakes 3 and 4 or 5
   e. BCCC golf course riparian areas on north and south sides of the course
   f. Outflow from the BCCC golf course to the Big Canyon Nature Park (BCNP)
   g. Upper freshwater marsh in the middle section of the BCNP
   h. BCNP riparian area upstream of DFG mitigation pond
   i. BCNP mitigation pond
   j. BCNP storm drain #1(pipe discharge and catchment basin)
   k. BCW creek north channel outflow from BCNP to UNB

2. Particulates should be collected and analyzed for total selenium, selenium species, and metals on a semi-annual (seasonal) basis at the following locations:
   a. HVNP
   b. Inflow 1 on the BCCC golf course
   c. BCCC golf course Lake 3
   d. Outflow from the BCCC golf course to the BCNP
   e. BCNP riparian area upstream of mitigation pond
   f. BCCNP mitigation pond
   g. BCNP north channel outflow to UNB

3. Sediment, algae, macroinvertebrates, fish/frogs, and bird eggs (when available) should be collected and analyzed for total selenium and metals on an annual basis at the following locations[1]:

[1] This assumes that Lakes 1 and 6 continue to function as off-line lakes and that water from BCW creek or selenium-containing groundwater flows from local storm drains are not diverted into these water bodies. Water levels in these two lakes are currently maintained by storm water runoff in the rainy season and are supplemented with potable water in the dry season.

   a. HVNP (if nests are found)
   b. BCCC golf course Lake 4 or 5 (or wherever nests can be found)
   c. BCNP riparian area upstream of mitigation pond or in freshwater marsh upstream of riparian area (if nests are found)
   d. BCNP mitigation pond and salt marsh areas influenced by freshwater flows (if nests are found)

<u>6.2.2 WATER AND SELENIUM SOURCE TRACKING</u>

1. Identify all potential water sources (using isotope or other analyses and hydrogeochemical parameters)[2]
   a. Residential/commercial/green space/park irrigation
   b. BCCC golf course irrigation/ infiltration from lakes
   c. Pacific View Memorial Park (PVMP) irrigation
   d. Spyglass Hill reservoir
   e. Leaking water lines
   f. Local precipitation

2. Determine source(s) of water and reason(s) for low selenium concentrations in the middle branch (Inflow 2) of BCW creek

3. Collect water samples and analyze for total selenium, dissolved selenium, and selenium species:
   a. BCR[3] and Spyglass Hill reservoir[4]
   b. Irrigation water (if different sources):
      i. Pacific View Memorial Park
      ii. Residential
      iii. Commercial
      iv. BCCC Golf Course
      v. City Sports Parks/Recreation Centers
   c. Seeps along San Miguel Drive or in other areas
   d. SD#1 in the BCNP

4. Develop accurate measurements of surface water flow volumes for the major branches of BCW creek in BCW Upper, Middle, and Lower during both dry and wet weather to quantify pollutant sources and loadings in these areas.

[2] BCR has already been determined to be an important source of water to the south branch of BCW creek (Inflow 1). At this time it is not known whether Spyglass Hill reservoir also leaks.
[3] Reservoir water only, not seepage.
[4] Both reservoir water and seepage (if the reservoir leaks).

At a minimum, flows should be measured at the following locations:

a. BCW Lower: the locations where the main channel and the north channel discharge into UNB;

b. BCW Middle: the outlet structure at the west end of the park and the locations where the north, middle, and south branches of BCW creek daylight into the east end of the BCCC golf course (Inflows 1, 2, and 3);

c. BCW Upper: the upper (eastern) end of the south branch of BCW creek in the HVNP and the upper end of the middle branch of BCW creek (in the canyon below the Spyglass Hill reservoir) before it is diverted underground.

5. Quantify relative contribution of different sources of water
    a. Irrigation verses other sources
    b. Flow rates/volumes
    c. Selenium and other pollutant concentrations (e.g. metals)

6. Determine seasonal variations and irrigation influence on surface waters at the following locations to determine a water balance for the watershed:
    a. BCR underdrains
    b. Bren and Seaview subdrains
    c. HVNP (upper (eastern) and lower (western) ends)
    d. BCCC golf course (especially inflows 1 - 3 and the outflow to the BCNP)
    e. BCNP (inflows and outflows – discharges to UNB from the main channel and the north channel)
    f. Storm drains that enter the BCNP
    g. Other locations to be determined

6.2.3 IDENTIFY SELENIUM REDUCTION OPTIONS

1. Estimate potential reductions in selenium concentrations from:
    a. Flow restoration, sediment and vegetation removal, and hydrologic modifications to reduce Se cycling
        i. HVNP
        ii. BCCC Golf Course Lakes 3, 4, and 5 and riparian areas
        iii. BCNP marshes and mitigation pond
    b. Reductions in irrigation inputs (residential and commercial)
    c. Rehabilitation of BCR to reduce/eliminate leakage
    d. Diversion of high selenium water to sanitary sewer (especially Bren and Seaview drains and BCR underdrains if feasible)
    e. Treatment options
        i. Identify potential treatment options and costs
        ii. Identify potential locations (HVNP, BCCC, BCNP)

2. Determine potential impacts and benefits from possible mitigation efforts
    a. Flow restoration efforts on habitat (in particular, waterfowl use), selenium concentrations, and storm flow capacities
    b. Flow reduction effects (irrigation reductions, water diversions) on salt marsh birds beak populations and wetlands habitat

6.2.4 DEVELOP SELENIUM MANAGEMENT AND MITIGATION PLAN

1. Provide preliminary, phased implementation schedule for reducing Se concentrations and restoring beneficial uses
    a. Prioritize identified mitigation options
    b. Provide alternatives/contingency plans
    c. Provide tangible milestones and benchmarks with identified time lines and goals
2. Identify regulatory and environmental needs including potential areas of conflict
    a. CEQA
    b. Permits
    c. Regulatory jurisdictional agencies' regulations (Newport Beach, Orange County, SARWQCB, DFG, USACE)
    d. Environmental groups (Newport Bay Conservancy, Orange County Coast Keeper, Defend the Bay)
3. Identify potential funding sources and mechanisms
    a. Grants/appropriations
    b. Local tax or assessment fee added to water bill, etc.
4. Coordinate with all potentially interested parties
    a. City
    b. DFG
    c. Naturalists and Friends
    d. Orange County Coast Keeper
    e. Regional Board
    f. Orange County
    g. BCCC
    h. Local residents and property owners
5. Coordinate with other projects where possible
    a. BCNP Restoration Project
    b. Road improvements, golf course renovation, water line repairs/replacement, etc.

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Murdoch, George. 05-05-08. City of Newport Beach Utilities Director.

Orton, Dr. Randall. 08-03-10. Las Virgenes Municipal Water District Resource Conservation Manager.

Skinner, Dr. Jack. 11-02-10. Stop Polluting Our Newport.

Stein, Robert. 04-21-11. City of Newport Beach Public Works, Assistant City Engineer.

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