FINAL MONITORING REPORT

FOR THE

CODORNICES CREEK WATERSHED RESTORATION ACTION PLAN, PHASE 2

STATE WATER RESOURCES CONTROL BOARD
GRANT AGREEMENT 04-152-552-0

PREPARED FOR THE

URBAN CREEKS COUNCIL

BY

KIER ASSOCIATES, *FISHERIES AND WATERSHED PROFESSIONALS*
BLUE LAKE, CALIFORNIA

This fish population, stream habitat, and water quality monitoring report was prepared by Kier Associates, *Fisheries and Watershed Professionals* www.kierassociates.net as an element of the Codornices Creek Watershed Restoration Action Plan, Phase 2 project funded through Agreement No. 04-152-552-0 between the California State Water Resources Control Board and the Urban Creeks Council.

The Urban Creeks Council is a non-profit organization working to preserve, protect, and restore urban streams and their riparian habitat. The Urban Creeks Council may be reached at 1250 Addison Street, Ste. 107, Berkeley, CA 94702 (510- 540-6669).

Credit for the cover photo of the Codornices Creek rainbow/steelhead goes to Jeff Hagar of Hagar Environmental Services, consultants to the cities of Berkeley and Albany and the University of California on their Lower Codornices Creek Restoration Project.

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JANUARY, 2007

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INTRODUCTION

This report presents the results of fish, stream habitat, and water quality monitoring activities undertaken as part of the State of California-funded Codornices Creek Watershed Restoration Action Plan, Phase 2 ("CCWRAP-2") project. The overall CCWRAP-2 project addresses the priority native fish restoration needs of Codornices Creek, an urban stream in the northern neighborhoods of Berkeley, California. One of the goals of the CCWRAP-2 project is to establish a program of monitoring the stream's health to enable evaluation of the effectiveness of the restoration efforts over time.

The specific purpose for, and the methods employed in the monitoring activities reported here are detailed in the project Monitoring Plan (Kier Associates 2005a). The quality assurance and quality control steps followed are consistent with those of the California State Water Resources Control Board's Surface Water Ambient Monitoring Program (SWAMP) protocols, and are explained in detail in the CCWRAP-2 project's Quality Assurance Program Plan (QAPP) (Kier Associates 2005b). The San Francisco Bay Regional Water Quality Control Board staff approved both of these plans prior to the initiation of project monitoring in September 2005.

CCWRAP-2 monitoring was planned and implemented to build upon stream investigation results from the predecessor "CCWRAP-1" project (2004) and other studies of the Codornices Creek watershed. The monitoring was specifically focused on strengthening information concerning the stream's native salmonid population, steelhead (*Oncorhynchus mykiss*) and the suitability of its Codornices Creek habitat.

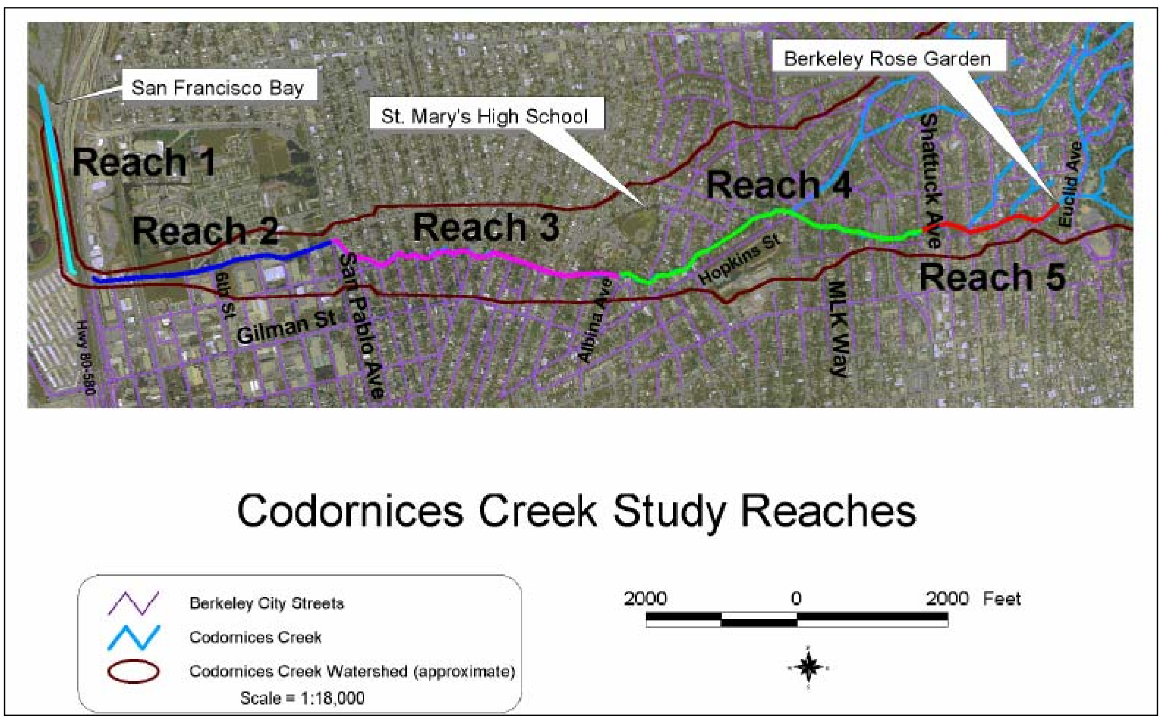


Figure 1. The five reaches of monitoring activity established during the Codornices Creek Watershed Restoration Action Plan, Phase 1 project.

Codornices Creek's native salmonid fish population consists of both resident ("rainbow trout") and sea-going steelhead. Since most of the individuals reported here were juveniles, and their anadromy was, therefore, ambiguous, we simply refer to all as "*O. mykiss*".

Weekly monitoring of conventional water quality parameters was undertaken at established stream stations from September 15 to November 10, 2005 and from July through November 2006. Additionally, dissolved oxygen, a water quality parameter noted as sub-optimal in Codornices Creek in earlier investigations, was measured at 15-minute intervals for 48-hour periods at several locations in September 2005 and, again, in September 2006. Samples of water and of sediments were tested for polycyclic aromatic hydrocarbons (PAHs), a potentially troublesome pollutant in urban watersheds.

Codornices Creek's monitoring reaches were established in the predecessor CCWRAP-1 project (see http://www.urbancreeks.org/sfb_ucc_kierassoc_2004_ccwrap.pdf). Reaches 4 and 5 are currently separated from the downstream reaches, from a fish migration standpoint, by a migration barrier at the Albina Street culvert. This barrier is being addressed in the CCWRAP-2 restoration project.

FISH SURVEYS

Electrofishing

A crew of two fishery biologists and a field assistant electrofished Codornices Creek on September 21-22, 2005 in order to estimate the abundance of *O. mykiss*, to identify the species' upstream and downstream distribution limits, and to record other vertebrate species that might be present. The crew sampled 50- to 100 meter-long sites blocked by ¼" mesh nets. Where salmonid fish were present, the crew made two or three passes. The population size was then estimated using the maximum likelihood method and MicroFish software developed by VanDeventer and Platts (1989).

The sampling sites were selected on the basis of access, dispersion and representativeness. Theoretically, ideal sampling would involve random placement of equally dispersed sites. Sampling in Codornices Creek is limited, however, by access through private property and by 29 culverts, most of which are too vertically restricted for safe electrofishing. The sites were dispersed to assure that they would not cluster within a single portion of a reach, but would span potential barriers and habitat gradients. The representativeness criteria assured that sample sites would not fail to represent the typical quality of available habitat nor some outstanding habitat feature that might be strongly associated with salmonid abundance.

Before sampling all stream sections that were accessible and safe for electrofishing were identified and their habitat characteristics we recorded. Where sections were longer than 100 meters, random sampling was employed to locate the downstream limit of the sampling site.

Reach 1 had little habitat that was not directly influenced by tides. Aquatic vegetation choked sections of Reach 2 below 5th Street, including the recently restored section of channel between the Union Pacific railroad tracks and 5th Street (the Lower Codornices Creek Restoration Project). Sites with large amounts of aquatic vegetation were not sampled in order to avoid the mortalities often associated with electrofishing in such conditions.

For reaches 2 and 3, sample sites reflected the range of habitat quality. All sites included at least one pool. Site (3c) included a pool that extended 15m into the culvert below Neilson Street. In reaches 4 and 5, where earlier investigations indicated that no salmonids would be found, this survey selected sites that represented the best available salmonid fish habitat.

Salmonids (*Oncorhynchus mykiss*) were observed in Reach 2 and Reach 3 only, and stickleback (*Gasterosteus aculeatus*) in Reach 1 and 2, only. No other fish were found. Crayfish were found at all sites. The exotic red swamp crayfish (*Procambarus clarkii*) dominated in the lower reaches and California crayfish (*Pacifasticus sp.*) were abundant in Reaches 3 and 4. Table 1 describes all thirteen sites that were electrofished. Additional data collected at these sites included temperature, shocking duration per pass, pH and conductivity. Water temperature ranged from 14.4 deg. C (58 F) to 17.2 deg C (63 F). Conductivity ranged from 470 uS/cm in the upper reaches to 580 uS/cm at the bottom of Reach 2. All fish were recovered in a bucket and observed upon release. We observed no salmonid mortality, and only one serious spine injury (an 80 mm salmonid).

High depletion ratios at all sites where salmonids were present resulted in site population estimates with very narrow bands of confidence (Table 2). The site population estimates were converted to values of fish per meter to estimate population size per reach and for the creek as a whole (Table 3). Figure 3 charts the relative abundance per site. The estimated salmonid population size for Codornices Creek was 504 fish with a 95% confidence interval of 271-738 fish. Reach 3 contributed more to this estimated population than Reach 2 for two reasons: stream length was 18% greater and it was found to have a slightly higher density of salmonids. The higher density in Reach 3 was not statistically significant.

The size of captured salmonids ranged from 75mm to 232mm with an average size of 131mm and an average weight of 25 grams. Table 2 reports summary length statistics for the fish from each site as well as an assessment of their condition, their "K" factor. As provided in MicroFish, $K = 10^N W / L^3$ where N is set to 5 to achieve near unity values (Barnham and Baxter 1988). K was consistently near 0.7 among all sites except for 3d where K was 1.2.

The higher condition (weight to length ratio) of the fish at the site adjacent to St. Mary's College High School may be the result of artificial feeding. School staff confirmed that feeding often occurs from the Albina Street bridge. Figure 4 plots mass v. length for the captured salmonids. The two heaviest individuals were from site 3d. The length distribution suggests a gap at approximately 150 mm that likely reflects different age classes. Table 2 shows the percentage of the catch at each site that was greater than 150 mm in length.

Scales were taken from a sample of fish of various lengths in order to enable analysis of age-structure that is beyond the scope of this study but may be done by others in the future.

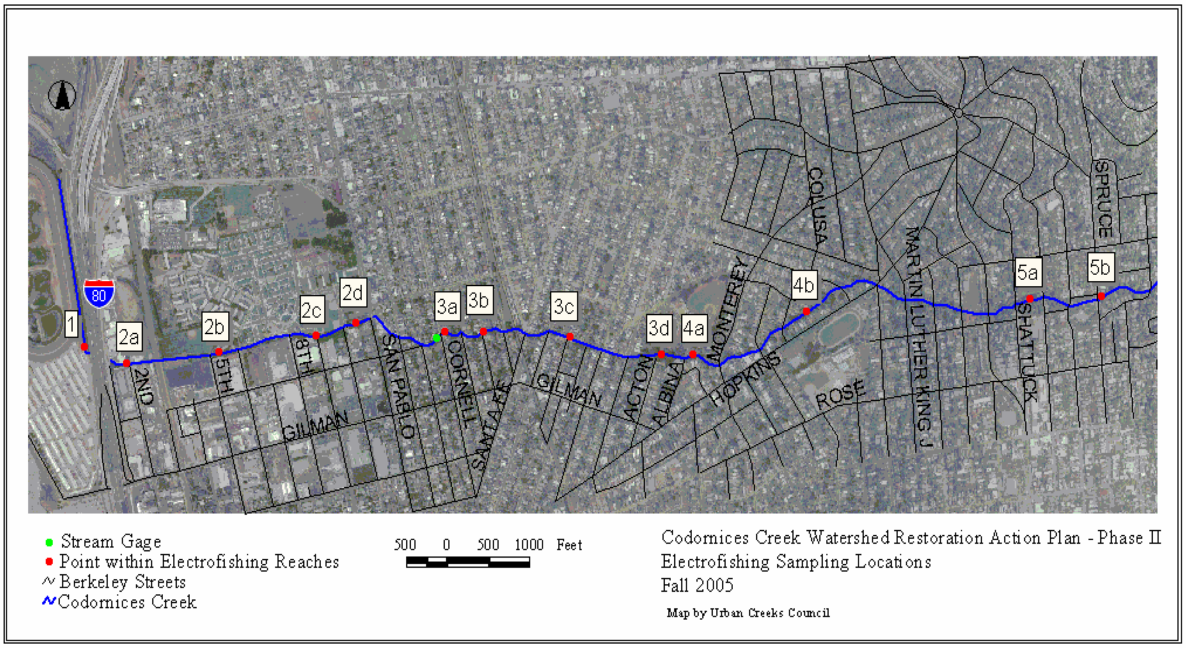


Figure 2. Location of electrofishing reaches. Points represent locations within 50-100 meter-long reaches.

Table 1: Description of sites and the fish found through the electrofishing survey of Codornices Creek on September 21-22, 2005. The column Efish notes the total time, in seconds, that the electrofisher was on, a sum of two or three passes where salmonids (*O. mykiss*) were present.

Site	Length (m)	Efish (sec)	Fish Found	Location
1	80	250	only stickleback	Entire length below I-80 non-estuarine at 2.5' tide
2a	80	623	only stickleback	Top of first riffle above I-80 to (??) 100% aquatic veg.
2b	65	671	salmonids and stkb	5th St to 6th St excluding culvert-pools at ends
2c	50	589	salmonids and stkb	Start 70m from 8th St culvert (incl. storm drain pool)
2d	65	659	only salmonids	10th St culvert to San Pablo culvert
3a	50	362	only salmonids	Behind 1198 Cornell; all habitat between culverts
3b	55	581	only salmonids	1201 Evelyn; rif. above culvert to 15m into culvert
3c	50	561	only salmonids	1201 Neilsen,
3d	69	871	only salmonids	Riffle above Peralta St culvert (incl. 2 weir pools)
4a	80	200+	no fish	Albina St to Monterey St culvert
4b	100	200+	no fish	Beverly St to Colusa St culverts
5a	100	200+	no fish	Extent of Live Oak Park
5b	75	200+	no fish	1201 Spruce upstream to 20' falls

Table 2: Statistics relating to salmonids captured by electrofishing at eight sites in Codornices Creek September 21-23, 2005. The site names are ordered in the upstream direction and reflect that four sites were sampled in each of two reaches. Condition Factor values and population estimates per site were generated using MicroFish software.

Site	2a	2b	2c	2d	3a	3b	3c	3d
Total Catch	0	6	15	23	6	11	10	29
Pop. Estimate	0	6	15	23	6	11	10	29
Standard Error	0	0	0	0.452	0.376	0.328	0.237	0.991
95% Conf. Int.	0	6-6	15-15	22-24	5-7	10-12	9-11	27-31
Site Length (m)	80	65	50	65	50	55	50	69
Fish per Meter	0	0.092	0.3	0.353	0.12	0.2	0.2	0.420
Total Weight (g)	0	138.6	264.4	583	68.6	272.6	315.3	901.8
Condition Factor	n/a	0.787	0.767	0.759	0.816	0.755	0.734	1.24
Avg Length (mm)	n/a	133.0	120.1	140.0	109.3	136.1	151.8	126.7
Length Std Dev	n/a	46.0	41.1	39.5	18.7	48.8	44.4	38.4
Length Max	n/a	223	226	222	135	228	232	225
Length Min	n/a	92	75	97	83	87	104	78
%> 150mm	n/a	17	20	26	0	36	40	21

Table 3: Population estimates for the two salmonid-bearing reaches of Codornices Creek September 2005) and the overall stream.

Reach	2	3	Combined
Length (m)	1094	1298	2392
Fish per Meter	0.187	0.235	0.211
Standard Deviation	0.168	0.129	0.141
Standard Error	0.084	0.065	0.050
Upper 95% CI	0.351	0.361	0.309
Lower 95% CI	0.022	0.109	0.113
Population Estimate	204	305	504
Upper 95% CI	384	469	738
Lower 95% CI	44	141	271

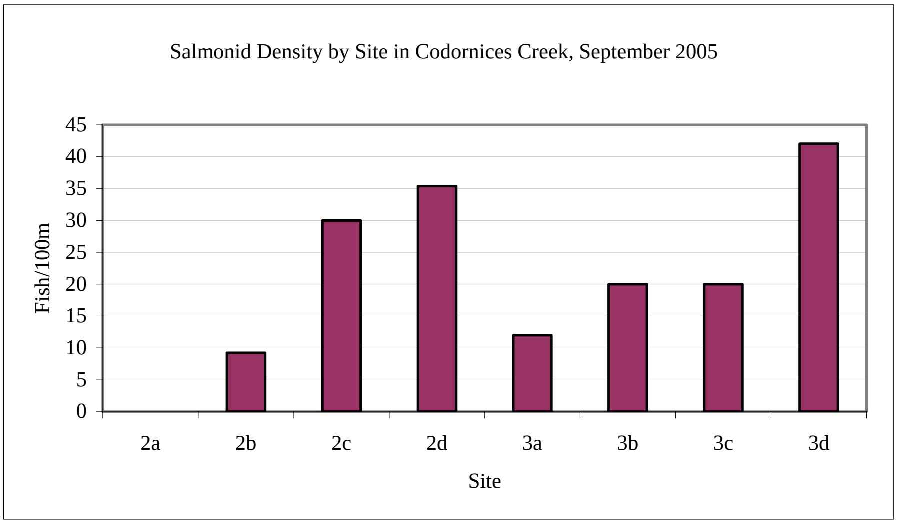


Figure 3: Salmonid density (fish/100 m) as measured by electrofishing in Codornices Creek in September 2005.

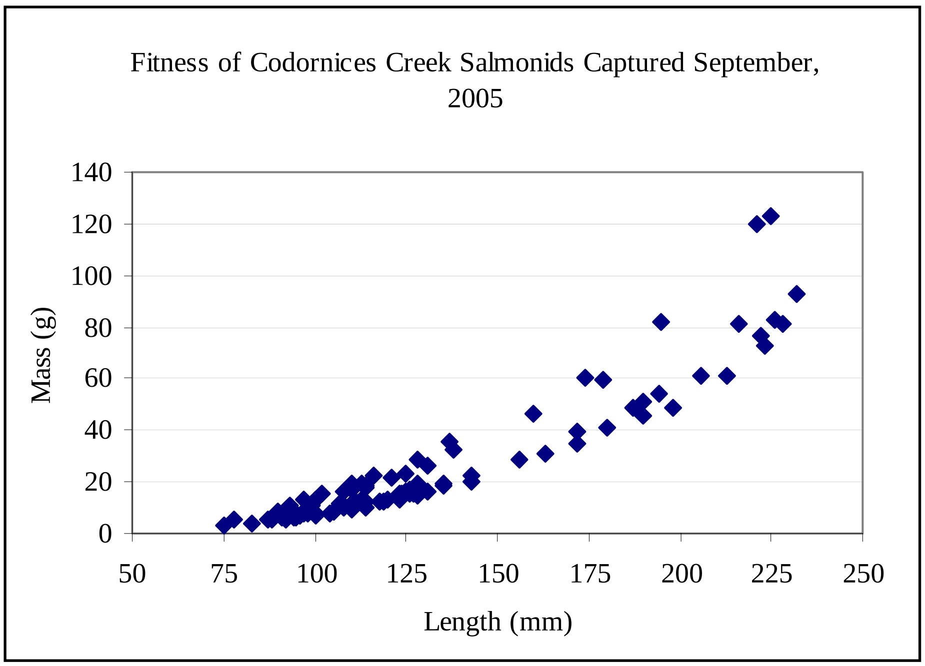


Figure 4: Fitness of salmonids captured in Codornices Creek in 2005 as expressed by mass vs. length. The two heaviest fish were both captured in site 3d located near Albina Street.

Spawning Surveys

A reconnaissance of spawning habitat in Codornices Creek identified four short reaches (approx. 150-300 m in length) that appeared to contain the most probable spawning habitat based on observed gravel size, geomorphology and proximity to cover. From tidewater up to the Albina Street migration barrier, these four reaches were referred to as follows: below 5th Street, between 9th and 10th Streets, below Peralta Street, and below Albina Street.

On January 10, 2006 volunteers were trained to survey the four reaches for fish and redds every two weeks or more often. Volunteers included the advanced biology students of St. Mary's College High School and their instructor, who took responsibility for the reach below Albina Street. In addition, three streamside residents were asked to be watchful for large fish or spawning activity.

Spawning activity by trout (<12") was described at the upper two reaches, but no steelhead (>15") or large redds were observed in any of the regularly surveyed reaches. A resident who lives adjacent to the site below Peralta Street and observed the most spawning activity, stated that 2006 spawning was typical of the last five years. According to his record, trout began spawning in that reach on February 4 and continued until March 20.

Steelhead spawning activity was observed above Masonic Avenue on March 2. Observation and video by Urban Creeks Council staff and others confirmed three adult steelhead in this area over a three day period. One was estimated to be 24" in length and observed to be digging redds (Figure 5). Two others were estimated to be approximately 17". The habitat where spawning occurred seemed marginally suitable due to a substrate of concrete and minimal gravel.

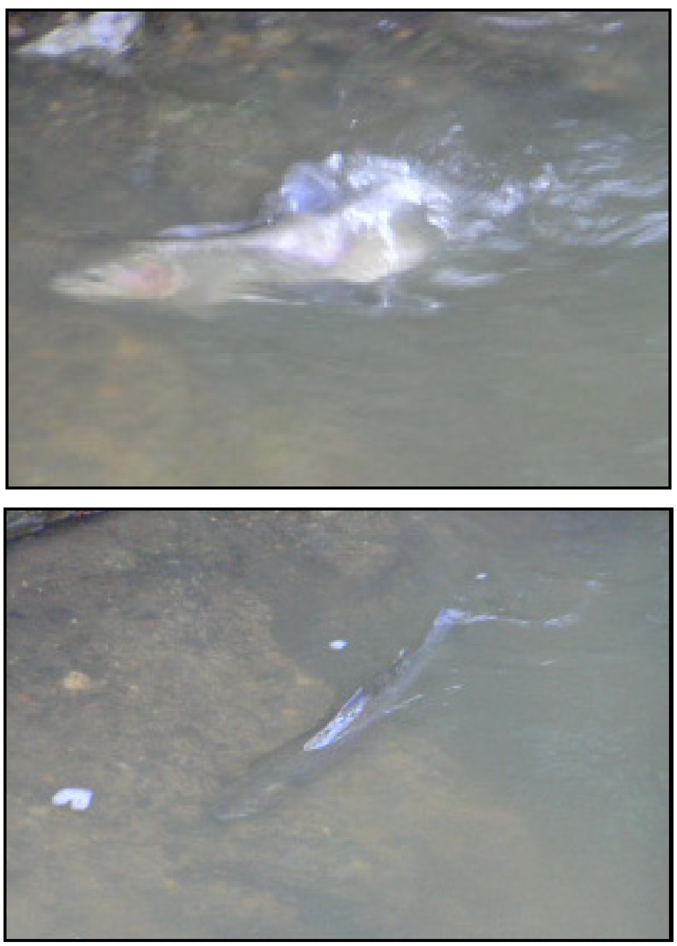


Figure 5. Images of an adult steelhead trout (estimated 24") observed spawning in Codornices Creek near Masonic Avenue on March 3, 2006. Video by Emma Gutzler, Urban Creeks Council

Downstream Migrant Trapping

A 5' square-mouthed fyke net and an 8" PVC pipe was used to capture and funnel downstream migrating fish into a mesh live-box for daily checking during the spring of 2006. The trap was placed approximately 100 meters upstream of the Union Pacific railroad crossing, a location that represented the lowest point on Codornices Creek with suitable flow and channel characteristics for this type of trap. The location was nearly 1 km downstream of the trap site used in 2002 and 2003 by the CCWRAP-1 project. In addition to being more inclusive of all upstream habitats, the new location was seen as favorable due to the recently restored channel that provides a wider floodplain and potentially less damage to the trap at high flow.

The trap was first installed on March 10 in an effort to capture any steelhead smolts moving during the spring migration season. Due to frequent and heavy rains during March and early April of 2006, the trap did not perform adequately for more than five complete 24-hour periods before mid-April. The trap was completely overwhelmed by flow and debris on three occasions. From March 27 to April 16, more than twelve distinct hydrologic events involved peaks of more than 20 cubic feet per second (58 cfs on March 27) and returns to a base flow of 3-4 cfs (Figure 6). The ascending limb of these events typically occurred within two hours and sometimes in as little as 30 minutes. This remarkable rate of change in Codornices Creek flow made the maintenance of a downstream migrant impractical during the storm events.

The trap functioned continuously from April 18 to June 2 during which period only two small rain events caused any increase above the base flow. On May 19 and May 21, Codornices Creek peaked at 6.2 and 6.7 cfs, respectively. When unaffected by rain, streamflow decreased slowly through the spring period and first dropped below 2 cfs on June 2. At flows less than 2 cfs, additional modification of the channel would have been necessary to provide adequate flow into the trap's pipe inlet.

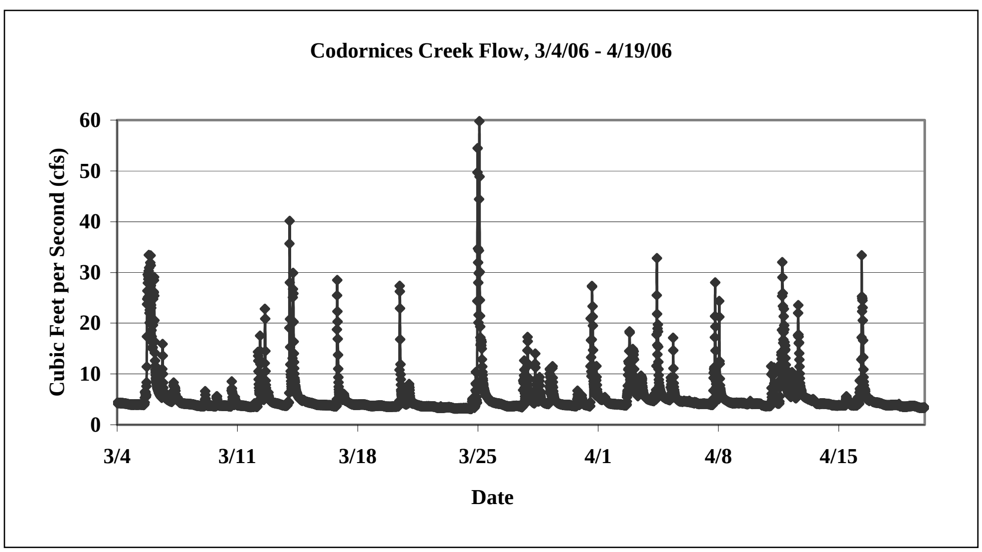


Figure 6. Codornices Creek flow measured at Cornell Avenue for the period March 4 – April 19, 2006.

Table 4. Downstream migrant trap conditions and capture for spring, 2006 in Codornices Creek. *Oncorhynchus mykiss* are reported by fork length in millimeters.

Date	Trap Condition	*O. mykiss*	Stklbk	Other
4/18	Trap reopened			
4/19	fishing well			
4/20	fishing well			
4/21	fishing well		1	
4/22	fishing well		2	1 crayfish
4/23	fishing well			
4/24	fishing well			
4/25	fishing well			
4/26	excavated below trap to ensure proper flow-through			
4/27	fishing well			
4/28	algae now rapidly growing in creek			1 crayfish
4/29	fishing well			
4/30	fishing well			1 salmndr
5/1	used more sandbags for 100% flow capture			
5/2	fishing well			
5/3	fishing well			
5/4	fishing well		1	
5/5	moved trap upstream 20 m and replaced net with weir and direct pipe inlet; 100% flow capture			
5/6	fishing well		6	
5/7	fishing well		2	
5/8	fishing well		4	
5/9	fishing well		3	
5/10	fishing well		3	
5/11	fishing well		3	
5/12	fishing well		4	
5/13	fishing well		5	
5/14	fishing well		6	
5/15	fishing well		3	
5/16	fishing well	75mm	3	
5/17	fishing well		4	
5/18	fishing well		5	
5/19	fishing well		4	
5/20	fishing well , rain yesterday	30mm	5	
5/21	fishing well	65mm	9	
5/22	fishing well, rain yesterday	70mm, 54mm	9	
5/23	fishing well	65mm	14	
5/24	fishing well		15	
5/25	fishing well	60mm	6	
5/26	creek beginning to clog with algae		9	
5/27	fishing well	63mm	6	
5/28	minor vandalism found	65mm, 50mm	9	
5/29	fishing well		7	
5/30	fishing well		8	
5/31	fishing well		8	
6/1	fishing well		19	
6/2	fishing well		16	
	Total capture:	**10**	**199**	

FISH HABITAT MONITORING

The CCWRAP-1 project inventory indicated that steelhead recovery in Codornices Creek may be limited by an oversupply of sediment and a consequent lack of pool habitat. That Plan's recommendations to abate excess sediment is addressed in CCWRAP-2 through erosion control projects, but the process of improving substrate conditions and increasing pool volumes in Codornices Creek will take years. Habitat monitoring focuses on three types of assessments that can establish meaningful baseline conditions for the necessary long-term trend monitoring of streambed health: pebble counts, V-star (V*) and bioassessment.

Pebble Counts

In order to characterize streambed particle size, a minimum of 100 particles was measured at eleven sites following the methods established by Wolman (1954) and Harrelson et al (1994). The pebble count method used in 2006 was intended to replicate the methods used at twenty-two sites in 2003 for CCWRAP-1. Pebble counts can involve observer bias, which makes it difficult to compare data between observers (Marcus et al. 1995, Olsen et al. 2005). Further, differing methods of sampling particles from transects, habitat units, or reaches can also invalidate pebble count comparisons (Kondolf 1995). Unfortunately, the primary observer used in 2003 was not available in 2006 and the methodological reference documents created some ambiguity as to the way in which transects where applied to sample sites.

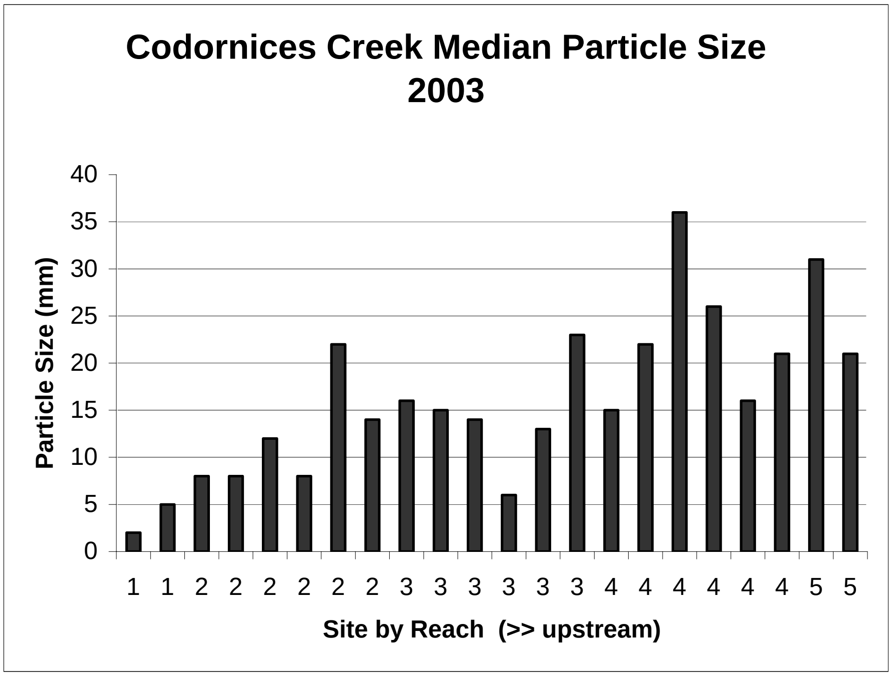
A field assistant from the 2003 Codornices Creek study was employed to provide maximum possible consistency. The assistant measured 100 particles at the first site (2nd Street) for comparison to the results of the field person who collected data at all eleven sites in 2006. The results of this comparison are reported in Appendix A and suggest that observer bias may be a significant factor. In addition, the precise location of the 2003 sites could not be determined and the methods may have varied slightly. In 2006, field observers walked zigzagging transects which included a riffle-pool transition area, but may have also included pool habitat. After additional investigation, we believe that the 2003 pebble counts were done on transects strictly located on pool-riffle transitions.

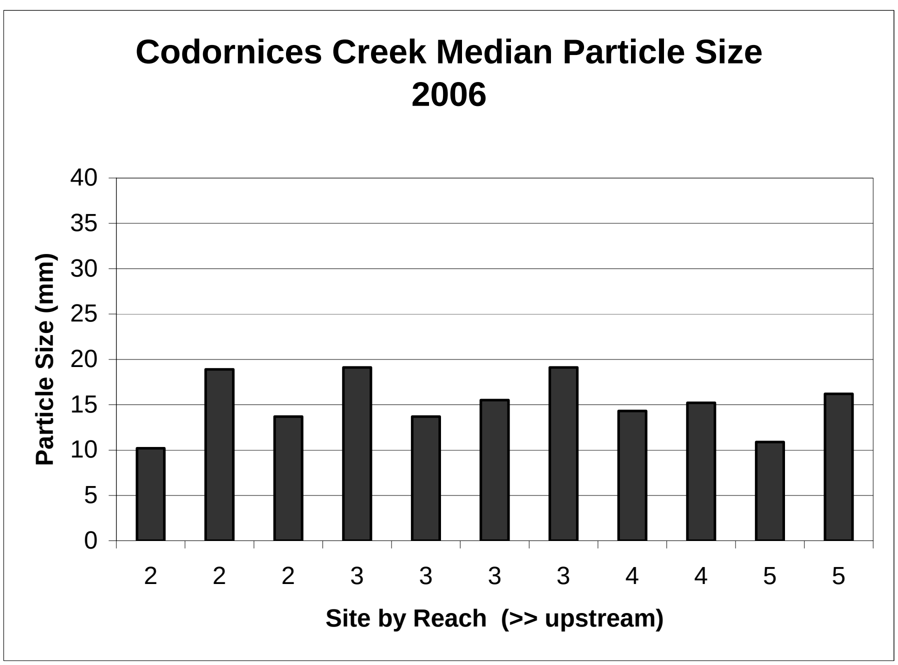
Figures 7a and 7b show the median particle size for each site sampled in 2003 and 2006, respectively. While the sites are not identical, the graphs do provide comparison of the same longitudinal range. The previous data indicate a typical pattern of decreasing particle size from upper sites to downstream sites. The lack of such a pattern in 2006 may be due, in part, to an insufficient number of sites or to some bias by the observer. We believe, however, that the difference is due largely to sampling methods. The method used in 2003 measured particle size at very specific geomorphic units (pool-riffle transition), while the 2006 method measured particle size for short reaches that included varying geomorphic units.

Kondolf (2000) explains how spawning gravel quality can be assessed through a variety of field procedures. Pebble counts are only useful for determining whether stream substrate is sufficiently small to support the spawning of certain sized fish. Median particle sizes in Codornices Creek suggest that trout 10" or greater would be able to spawn in Reaches 2 and

3. In order to assess survival to emergence life history stages, bulk substrate sampling and sorting, or other more intensive procedures are required.

Higher percentages of cobble and boulder at the SMCHS site (near Albina Avenue) support a hypothesis that greater substrate complexity at this site provides greater survival and growth opportunities for *O. mykiss*.





Figures 7a and 7b. The median particle size (d50) for Codornices Creek sites (reported by reach) sampled in 2003 and 2006.

Table 5 shows summary results for pebble counts in 2006. A full reporting can be found in Appendix A. Fine sediment indices in Table 5 are provided for comparison of general characteristics among sites and are not appropriate for inferring survival-to-emergence. Pebble counts have limited utility in assessing percent fine sediment due to a bias against full representation of small particles (Wolman 1954). In addition, pebble counts only measure bed surface particles and are not a direct measurement of the percentages of fine sediment in the substrate.

Table 5. Summary results from pebble counts at eleven Codornices Creek sites in May, 2006.

Reach-Site	**% Fines** *<2mm*	**% Gravel** *2-64mm*	**% Cobble** *64-180mm*	**% Boulder** *>180mm*	**% Bedrock**	**Median (mm)** *d50*
2- 2nd St	12.9	87.1	0	0	0	10.2
2- 5th St	20	60	19	1	0	18.9
2- 8th St	11.6	79.6	7.8	1	0	13.7
3- Masonic	5	88.1	6.9	0	0	19.1
3- Tevlin	5	87.1	7.9	0	0	13.7
3- Peralta	8	81	10	1	0	15.5
3- SMCHS	7.7	77.7	12.6	2	2	19.1
4- Colusa	10.9	79.2	9.9	0	0	14.3
4- MLK Blvd	16.8	78.2	5	0	0	15.2
5- Shattuck	8.1	88.8	3.1	0	0	10.9
5- Cod. Park	8.9	86.1	5	0	0	16.2

Benthic Macroinvertebrates

Benthic macroinvertebrates (BMIs) are a diverse category of animals that share a dependency on the streambed as habitat. While represented primarily by aquatic insects, the category also includes mites, crustaceans, mollusks and worms. The actual constituency of BMIs is strongly influenced by substrate and water quality. Consequently, assessments of stream habitat conditions commonly focus on BMI investigations as this type of bioassessment is considered cost-effective for detecting changes in water quality (Diamond 1996).

BMI sampling and analysis for CCWRAP-2 involved coordination with Far West Restoration Engineering, the firm responsible for evaluating the effectiveness of the Lower Codornices Creek Restoration Project. Separate BMI sampling in Codornices Creek by contractors of Alameda County occurred in the spring of 2003, 2004 and 2006. The California Department of Fish and Game sampled BMIs in Codornices Creek in 2005 under contract with the State Water Resources Control Board's SWAMP program. These other studies used similar methods and are suitable for comparison when adjusted for varying levels of taxonomic differentiation. The Excel-based results of all these BMI samplings were reviewed and evaluated during the preparation of this report. However, results from these other studies are not tabulated nor described in detail here, pending final reporting by their respective investigators. The CCWRAP-2 BMI sampling effort was not associated with a physical habitat evaluation prescribed by some rapid bioassessment protocols (e.g. Barbour et al, 1999). Such habitat data was, however, collected along with BMIs for Alameda County and SWAMP.

Procedures for collecting samples in the field and processing samples followed the revised (CDFG 2003) California Stream Bioassessment Procedure (CSBP). The sampling sites consisted of 100-meter reaches. Three transects were randomly selected from the available riffle habitat at each site. At three locations along each transect, BMIs were captured in a D-framed net by disturbing 1 square foot of substrate upstream of the net to a depth of 15 cm. For each reach the three samples were pooled in the laboratory and sub-sampled for a total of 500 specimens. BMIs were determined following the CSBP Level 1 taxonomic effort procedure.

Field sampling occurred on May 5, 2006. Mr. Jonathan Lee assisted with field sampling and performed laboratory processing. He also calculated summaries of standard metrics using the California Tolerance Values (Ode and CAMLnet 2003). Discrete taxa from each sample and sub-sample remnants were preserved in 70% ethanol. BMI sampling results from 2006 were evaluated using standard metrics including richness (number of taxa) and EPT indices. EPT refers to the orders Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies) which are generally more sensitive to water pollution and habitat impairment than are other subcategories of BMIs.

Six sampling site locations were chosen according to the CCWRAP monitoring reaches, the planned restoration activities for lower Codornices Creek, and the goal of evaluating salmonid fish habitat. The lower Codornices Creek restoration projects (not directly associated with the CCWRAP) are to progress upstream in three phases starting with that project completed in 2004 between the Union Pacific railroad crossing and 5th Street. A fourth, and lowest project section from Interstate 80 up to the railroad crossing is also proposed for restoration (by UCC) and contains a SWAMP "integrator" station where the most extensive water quality data of any Codornices site has been collected.

In addition to one BMI site for each of these four sections, two sites were chosen to reflect representative conditions of the segment between San Pablo Avenue and the salmonid fish barrier at Albina Avenue (CCWRAP-designated Segment 3). The site near Albina Street provides more canopy cover and less artificial channel entrenchment than the site at Evelyn Street, which was chosen to represent the majority of that segment. The six sampling site locations are described in Table 6 and represented in Figure 8.

Table 6: Description of six sites used for BMI sampling in Codornices Creek. Each site is a reach of 100 meters that includes multiple riffles.

Code	Name	Location Description
COD-1	2nd Street	Reach begins at riffle below 2nd Street and extends 50 m above point of nearest access from street
COD-2	4th Street	Between Union Pacific railroad tracks and 5th Street; Reach ends immediately below footbridge
COD-3	6th Street	Reach ends below 6th Street culvert
COD-4	10th Street	Reach ends below 10th Street culvert
COD-5	Evelyn St	Reach begins with first riffle upstream of Evelyn Street
COD-6	Albina St	Reach ends 60 m below Albina Avenue bridge

The six Codornices Creek samples contained 26 discrete taxa. Taxa richness per site ranged from 10 to 18 (Table 7). Not accounting for different taxa of Chironomidae, taxa richness ranged from 8 to 16. Only three of these taxa were from the orders Ephemeroptera, Trichoptera or Plecoptera (EPT taxa). All taxa identified in the samples and the counts per site are reported in Appendix B.

Chironomids dominated the samples and ranged from 86% (2nd Street) to 44% (Albina Avenue) of all organisms identified. Even when examined at the lower taxonomic level, the samples were dominated by one of two ubiquitous chironomid subfamilies/tribes. The mayfly Baetis (Baetidae) represented more than 20% of the sample in the two upper sites. The only other abundant taxon was Oligochaetae (worms). All these abundant taxa have high water pollution tolerance values. Oligochaetae were most dominant at 6th Street where a strong smell of anaerobic activity was noted during sampling.

Figure 8: The location of BMI sampling sites on Codornices Creek in 2006 are represented by points at the bottom of each 100-meter reach.

Standard California Tolerance Values (CTV) range from 0 (highly intolerant) to 10 (highly tolerant) and reflect the ability of the organism to tolerate one or several pollutants, including fine sediment, nutrients, and contamination by metals or hydrocarbons. The CTV values for all the taxa identified from Codornices Creek samples are reported in Appendix B..

The tolerance values for Chironomidae are 5, 6, or 7 (depending on subfamily/tribe). The mean tolerance value for each site ranged from 5.32 (Albina Avenue) to 5.58 (6th Street).

Of the three EPT taxa found, two have high tolerance. The caddisfly Hydroptila (Hydroptilidae) has a CTV of 6. The abundant mayfly Baetis has a tolerance value of 5. Baetis ranged from 5 to 20% of the samples and followed a clear pattern of increasing upstream abundance. One stonefly of the genus Malenka (Nemouridae) was found in the sample from each of the upper two sites. Malenka has a CTV of 2.

Table 7: Summary metrics for BMIs sampled at six Codornices Creek sites on May 5, 2006. For each metric, the values reflecting best condition are bolded and values reflecting worst condition are italicized.

METRIC	**2nd**	**HP**	**6th**	**10th**	**EVLYN**	**ALB**
Taxa Richness	*10*	13	14	14	**18**	16
Richness (Chironomidae only)	*8*	11	12	12	**16**	13
EPT Taxa Richness	2	2	2	2	**3**	2
EPT Index (%)	*4*	6	9	15	**27**	22
Sensitive EPT Index (%)	0.00	0.00	0.00	0.00	**0.20**	**0.20**
Dominant Taxon (%)	*86*	66	77	72	46	**44**
Mean Tolerance Value	5.52	5.43	*5.58*	5.45	5.35	**5.32**
Shannon's Diversity Index	*0.59*	0.92	0.89	0.95	**1.48**	1.4

The results of our BMI sampling indicate general impairment of aquatic habitat in Codornices Creek. Healthy streams have from 20 to 40 unique taxa and more than 10 EPT taxa (Jonathan Lee, pers. com.). By comparison, Codornices Creek has approximately half that taxa richness, almost no sensitive EPT, and moderate to severe dominance by the pollution-tolerant Chironomidae and Oligochaetae. The diversity of BMIs is higher for the sites above San Pablo Avenue than for the sites below. The lowest site at 2nd street shows the highest degree of habitat impairment.

The results of the other BMI sampling efforts are very similar and within the range of temporal variability in their sampling. The Alameda County contractors actually sampled 4th Street and Albina on the very same day as this study. Data collected by both Alameda County and this study from the completed lower Codornices Creek habitat restoration project at 4th Street do not suggest that any improvement to aquatic health has yet resulted from the project relative to pre-project conditions. The planted riparian corridor at this project site appeared to be just beginning to have a positive influence on aquatic habitat during spring, 2006. Other contractors sampled an upstream site at Live Oak Park in 2004 and 2005. The results for that sampling support the hypothesis that the spatial trend of increasing diversity and aquatic health continues upstream in Codornices Creek, but nowhere does it exceed levels considered unimpaired. Inferences regarding water quality impairment are discussed in the closing section of this report.

Habitat evaluations by other BMI contractors and by the CCWRAP-1 project quantify low levels of canopy cover, high percentages of fine sediment, and entrenched channels. These conditions are known to limit the diversity of BMIs by reducing allochthonous food supply and habitat complexity, and by increasing direct impacts from high-flow events. High rates of sediment mobility, as indicated by the small particle size and channel entrenchment, cause reduced benthic habitat for supporting diverse BMI communities. At low flows, such sites typically develop a community composed of small grazing organisms capable of rapid colonization and reproduction (Lenant et al. 1981).

V* Survey

V* (V-star) is a measure of the degree to which pools are filled by fine sediment. We followed the procedures described by Hilton and Lisle (1993) to determine V* for twelve pools in Codornices Creek on September 7-8, 2005. This involved detailed measurements of pool dimensions and depths, including riffle crest depth and residual pool volume as shown in Figure 9. The depth of fine sediment was determined by forcing a calibrated stainless steel rod through the pool bottom sediment until contacting an armor layer of less mobile sediment. Four to seven transects were systematically assigned in each pool and a minimum of forty probe points were sampled. Up to 100 probe points were sampled in larger pools. An Excel template developed by the North Coast Regional Water Quality Control Board was used to calculate V* summary statistics.

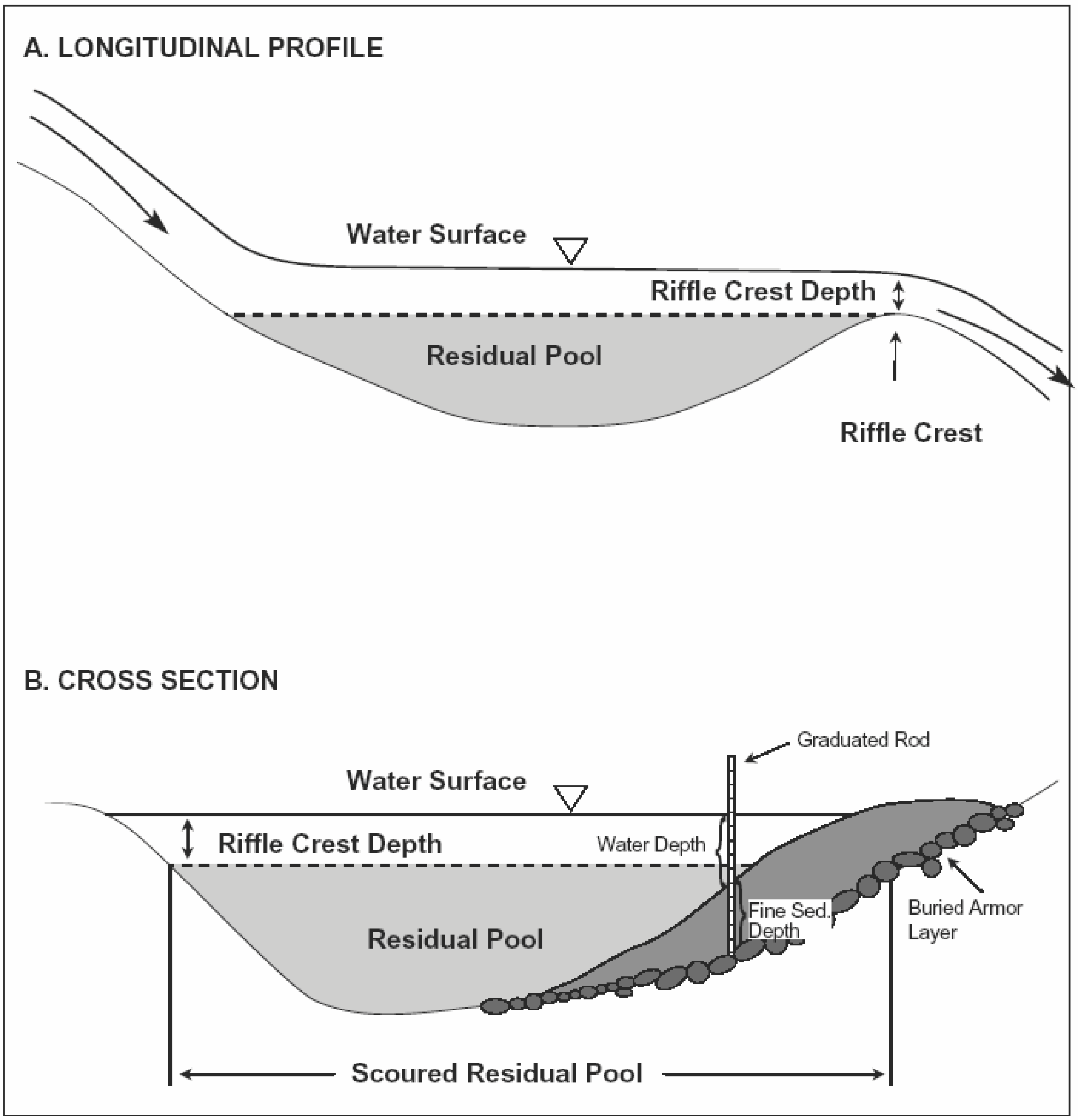


Figure 9: From Hilton and Lisle 1993 – "(A) Longitudinal profile of a pool, showing the riffle crest and the area included in the residual pool volume. (B) Cross section of a pool, showing measurement of water and fine sediment depth and volume of water and fine sediment in the scoured residual pool." Note the depiction of how the rod measures fine sediment to the depth of an armor layer.

Twelve pools were selected according to criteria designed to support the detection of changes in sediment deposition levels over time. The pools selected were large enough to persist in channel-changing events and they typically represented the largest naturally formed pools available. We did not select pools likely to be changed by bank modification or restoration projects. Reach 1 was deemed unsuitable for V* due to the influence of tidal backwater. Reach 2 was not included in this survey due to channel changes from current and planned restoration projects. All twelve pools were, then, located between San Pablo Avenue and Live Oak Park. Sampled pools were mapped and described on the back of datasheets to enable their relocation.

V* Results

V* for individual pools ranged from 0.13 to 0.52 (Table 8). The weighted average of V* for all pools was 0.31 (std error = 0.034). The weighted average V* is most strongly influenced by the largest pools. The distribution of pool sizes in Codornices Creek was tightly concentrated, however, around a median of three cubic yards.

Table 8: Summary of V* results in Codornices Creek on September 7-8, 2005. Pools are numbered from downstream to upstream.

Pool #	Location	Residual Vol (yd^3)	Avg Width (ft)	V*
1	1198 Cornell Street	3.13	7.80	**0.40**
2	1201 Evelyn Street	2.97	4.80	**0.16**
3	above Masonic Street, below BART	3.72	4.76	**0.13**
4	below Albina Avenue., lower plunge pool	2.43	11.00	**0.23**
5	below Albina Avenue., upper plunge pool	2.93	10.50	**0.29**
6	below Albina Avenue., bank scour pool	3.24	8.82	**0.34**
7	above Albina Avenue., near bridge	3.10	7.20	**0.41**
9[1]	Colusa Street, downstream most pool	5.35	7.23	**0.24**
10	Colusa Street, middle pool	2.01	6.72	**0.44**
11	Colusa Street, upstream pool	0.84	6.88	**0.52**
12	Live Oak Park, below Oxford Street.	1.71	12.50	**0.42**

[1] Pool #8 is not included here. It was found, upon closer examination, to be formed by a deposition of sediment on top of woody debris lodged at the mouth of the Monterey Street culvert.

The only regional evaluation of V* as an index of habitat condition is provided by Knopp (1993) who tested V* and other methods on more than fifty streams in northern coastal California. Knopp found that watersheds moderately and highly disturbed by logging activities had median V* values of 0.31 and 0.39, respectively. His control group of 12 undisturbed watersheds had a median V* of 0.17 with a minimum of 0.07 and a maximum of 0.27. Based on this study, the North Coast Regional Water Quality Control Board (NCRWQCB) established 0.21 as a target V* value for streams recovering from sediment impacts (Fitzgerald 2004).

The NCRWQCB target may not be appropriate for Codornices Creek given its differences in geology and land use as compared to those examined by Knopp. Knopp studied only watersheds geologically composed of the Franciscan Complex and variously impacted by logging. He did not study urbanized watersheds. Codornices Creek watershed is urbanized and geologically composed of various materials on top of Franciscan Complex.

Impacts from urbanized watersheds would likely affect residual pool volume filling differently than impacts from logging. For example, urbanized watersheds have higher runoff coefficients and are typically influenced by artificial confinement. These conditions could potentially cause greater flushing of fine sediments. V* has not been evaluated for urbanized watersheds.

V* measures just one aspect of a complex and dynamic relationship between sediment yield and aquatic habitat. Salmonid biologists find V* useful because of how it helps characterize pool habitat, an important habitat unit for salmon growth and survival. Pool filling has led, in some demonstrated cases, to the reduction of pools to depths less than adequate for various life history stages of salmonids. This result of increased sediment yield is typically associated with decreased bed particle size, decreased gravel permeability and increased rates of suspended sediment.

Several sediment metrics have documented relationships to salmonid habitat condition and may yield more conclusive results than V*. These include bed particle composition, spawning gravel permeability, and suspended sediment. Although the cost of measuring any of these parameters exceeds the entire budget for this monitoring project, they should be considered as quantitative means to assess sediment as a factor which limits aquatic habitat.

Changes in V* values would be indicative of a change in the result of the sediment-habitat relationship. Repeated surveys of the same pools in the future will allow powerful detection of changes in V* through paired sample statistics.

WATER QUALITY MONITORING

Water quality monitoring by CCWRAP-2 focused on two activities: Sampling for detection of polycyclic aromatic hydrocarbons (PAHs), and measuring conventional parameters (temperature, pH, conductivity and dissolved oxygen) at stations dispersed along Codornices Creek reaches 2 and 3. Sampling stations are described in Table 9 and mapped in Figure 10. In addition, dissolved oxygen and water temperature were investigated using continuously recording meters.

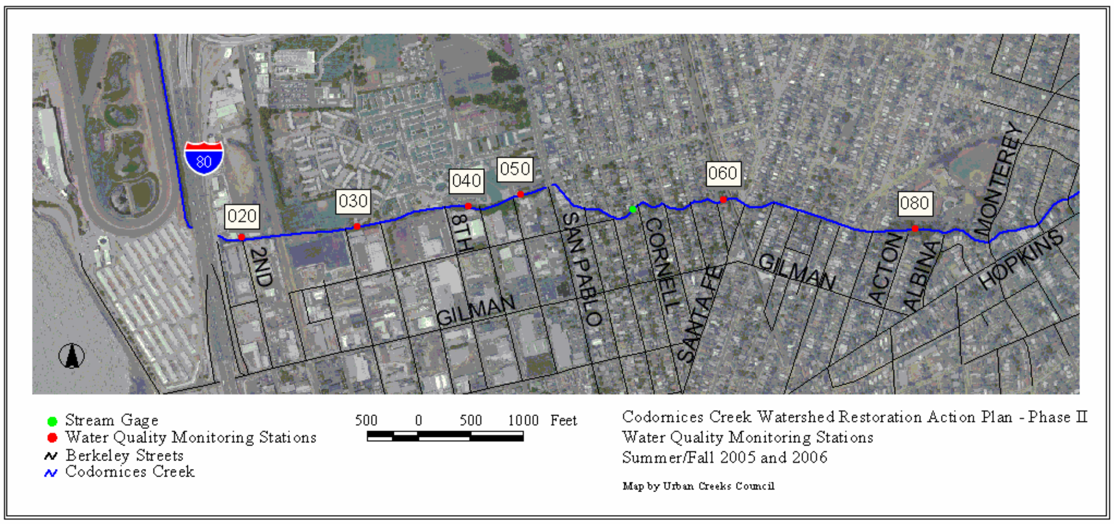


Figure 10. Locations of six water quality monitoring stations used in CCWRAP-2.

Table 9. Water quality monitoring stations in Codornices Creek used by SWAMP and/or CCWRAP-2. Reference column provides simple location name. Shaded stations are not priorities for CCWRAP-2.

Station	Reference	Sample Location	Description
COD-020	2nd Street.	1m above foot crossing	Bottom of Reach 2; SWAMP Integrator site
COD-030	5th Street.	15m above culvert	Upstream of 2004 restoration project and areas dominated by aquatic vegetation
COD-040	8th Street.	10m above culvert	Upstream of open canopy and downstream of 9th Street outfall; SWAMP Trash site.
COD-050	10th Street	5m above culvert	Top of Reach 2
COD-060	BART	3m above culvert	Midpoint of Reach 3; Access via Masonic Avenue
COD-080	Albina Avenue.	10m below bridge	Top of Reach 3; SWAMP continuous monitoring site
COD-120	Live Oak Park	3m below Oxford Street	Top of Reach 4

Polycyclic Aromatic Hydrocarbons

Developed with the assistance of the San Francisco Bay Regional Water Quality Control Board staff, the *Monitoring Plan for the Codornices Creek Watershed Restoration Action Plan, Phase 2* (Kier Associates, 2005b), explicitly called for an assessment of problems for salmonid growth and survival which might associated with concentrations of polycyclic aromatic hydrocarbons (PAHs) in the stream. PAHs are common urban pollutants that may come from vehicle emissions, fuel spills, or even natural decomposition of organic material in anaerobic environments.

The assessment of these PAHs issues was performed by Dr. Robert Coats and is included as Appendix C of this report. Dr. Coats, who has a long familiarity with Codornices Creek conditions, collected water samples following an early-season storm in fall, 2005, and six sediment samples from three different locations, in fall and spring, and had them analyzed for 18 different PAH compounds commonly found in urban settings. The results of these analyses are discussed in detail in Appendix C, where they are presented alongside those from sampling conducted earlier in 2005 by the State's SWAMP program.

Dr. Coats found no exceedences in either the water or the sediments tested of published quality criteria. Concentrations of some compounds in Codornices Creek sediments are higher than those reported for San Francisco Bay sediments. The mix of compounds identified in Codornices Creek suggests a "primary pyrogenic source, with occasional episodic input from petroleum sources". Dr. Coats concludes that "the likely pyrogenic sources include vehicle emissions, runoff from fresh asphalt, used crankcase oil, wood smoke, and creosote."

Dr. Coats' report notes that the "absence of evidence of a problem is not evidence of the absence of a problem" but recommends that future water quality monitoring in Codornices Creek concentrate on the conventional parameters of temperature and dissolved oxygen – and that consideration be given to monitoring, as well, for chloramines, which have recently replaced chlorine for disinfecting municipal water supplies, given the devastating effect on salmonids which may occur from accidental discharges of municipal water to streams.

Weekly Sampling of Conventional Parameters

SWAMP data from 2003 indicated that dissolved oxygen drops to levels lethal to salmonids in lower Codornices Creek. To quantify the geographic and temporal extent of dissolved oxygen problems, conventional water quality parameters were measured at dispersed sites weekly and at select sites dissolved oxygen was measured for continuous 48-hour periods.

Weekly water quality sampling occurred pre-dawn, or within the first 30 minutes after dawn, in order to record dissolved oxygen levels at their potential lowest due to nighttime plant respiration. The instruments used included a dry electrode pocket pH meter, a spirit bulb thermometer, a pocket conductivity meter with ATC, and a rapid pulse dissolved oxygen probe with membrane. A continuous recording phase membrane meter was placed at select locations to record diurnal fluctuations of dissolved oxygen. All equipment was checked, maintained and calibrated according to SWRCB Clean Water Team standards. For details, refer to the project QAPP (Kier Associates 2005).

Three different people participated in the sampling in 2005 and an additional two volunteers participated in 2006. Approximately 40% of the conductivity measurements failed to meet data quality objectives specified in the QAPP due to post-calibration results that indicated inaccuracy of 5-10%. The "drift" in our pocket conductivity meter seemed to worsen over time. Approximately 5% of the pH readings did not meet data quality objectives for either precision or accuracy. In no case was the differential greater than 0.3 units.

The results of weekly sampling during 2005 (8 weeks) and 2006 (16 weeks) are reported in detail in Appendix C. Figures 11-14 chart results for pH and dissolved oxygen. Levels of pH generally remained between 7.4 and 8.5, which are normal and do not indicate problems for salmonids and other aquatic life. However, pH at COD-080 increased steadily throughout the 2006 sampling period, and exceeded 8.5 units during three weekly measurements in October. This level suggests potential problems for *O. mykiss* due to elevated toxicity of ammonia. The data from both years suggests a trend of decreasing pH from upstream to downstream locations.

Dissolved oxygen measurements greater than 7.0 mg/L are generally good for salmonids and our pre-dawn measurements met these criteria for all sites above San Pablo Avenue. In lower Codornices Creek, we measured dissolved oxygen was less than 7.0 mg/L at three locations. At COD-020 (2nd St) dissolved oxygen was less than 5.0 mg/L for the entire summer. At site COD-030 (5th St) dissolved oxygen was marginally unsuitable in 2005. At Site COD-050 (10th St), dissolved oxygen was marginally unsuitable in 2006. At 10th Street the dissolved oxygen levels were much lower in 2006 than 2005, but returned to normal levels later in the season.

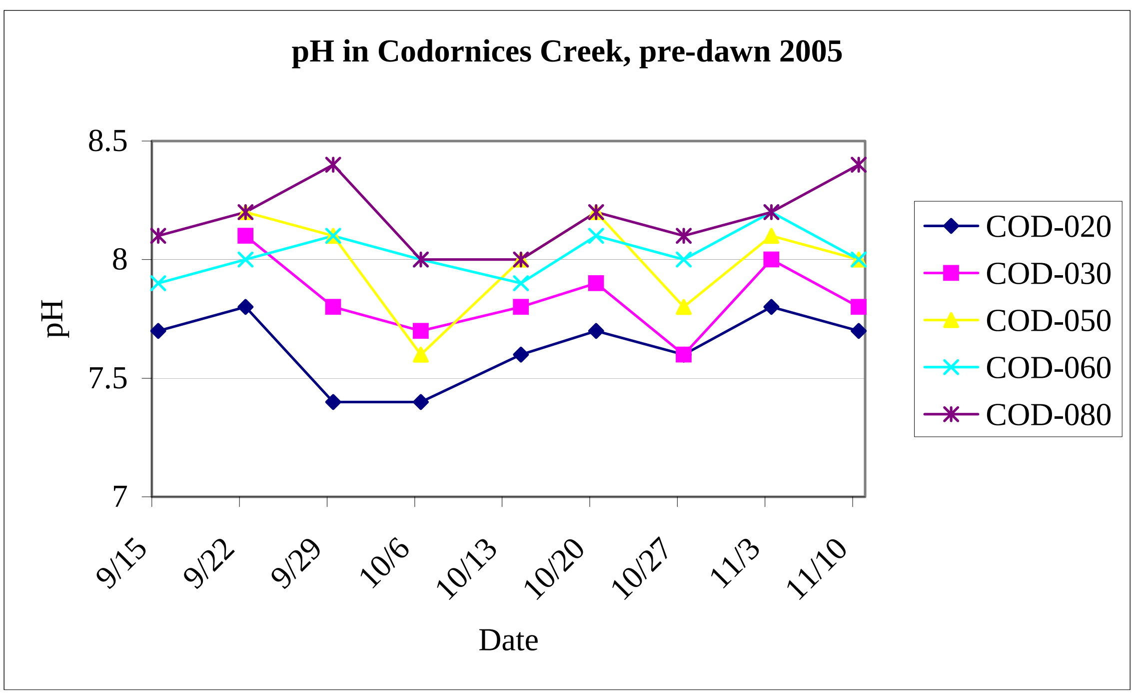


Figure 11: pH values recorded near dawn at five Codornices Creek sites in the fall of 2005.

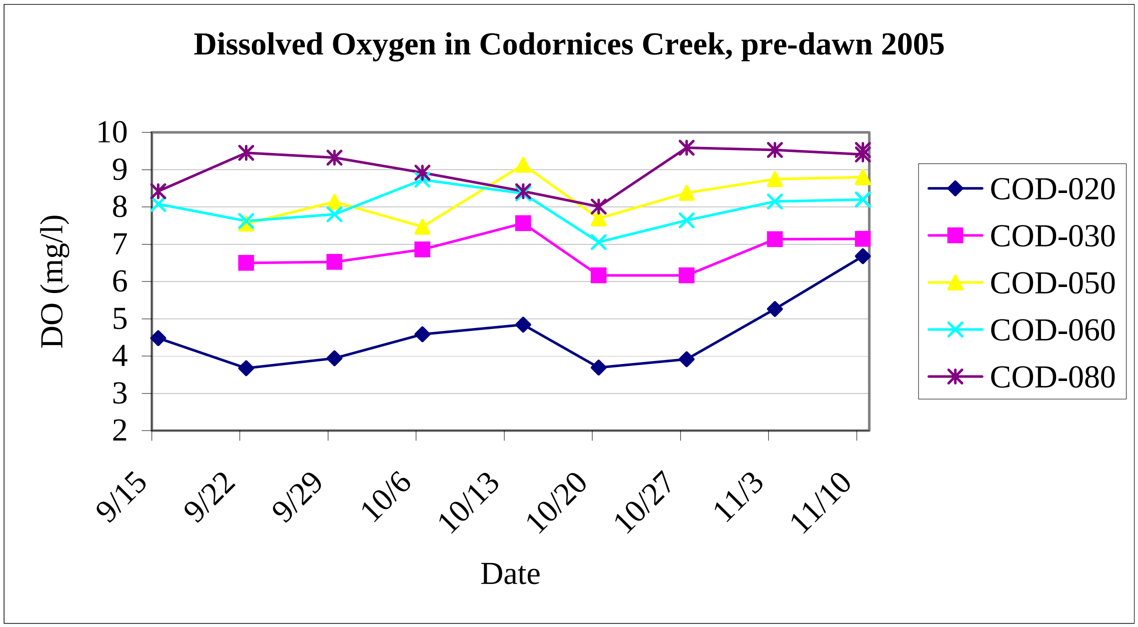


Figure 12: Dissolved oxygen values recorded near dawn at five Codornices Creek sites in the fall of 2005.

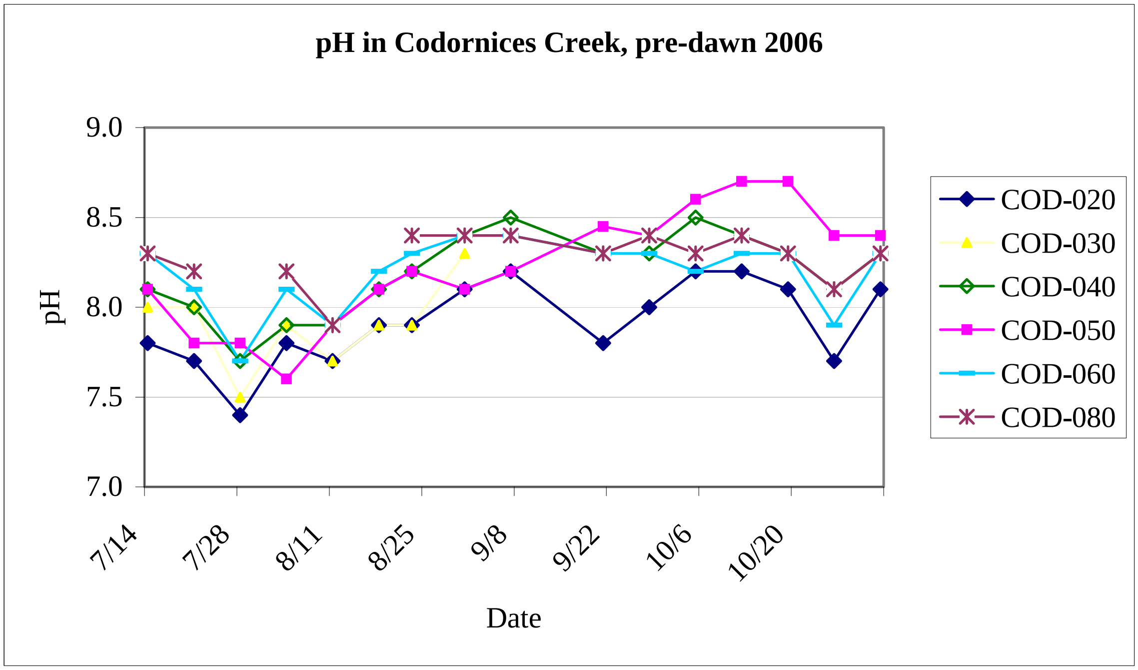


Figure 13: pH values recorded near dawn at six Codornices Creek sites in the summer and fall of 2006.

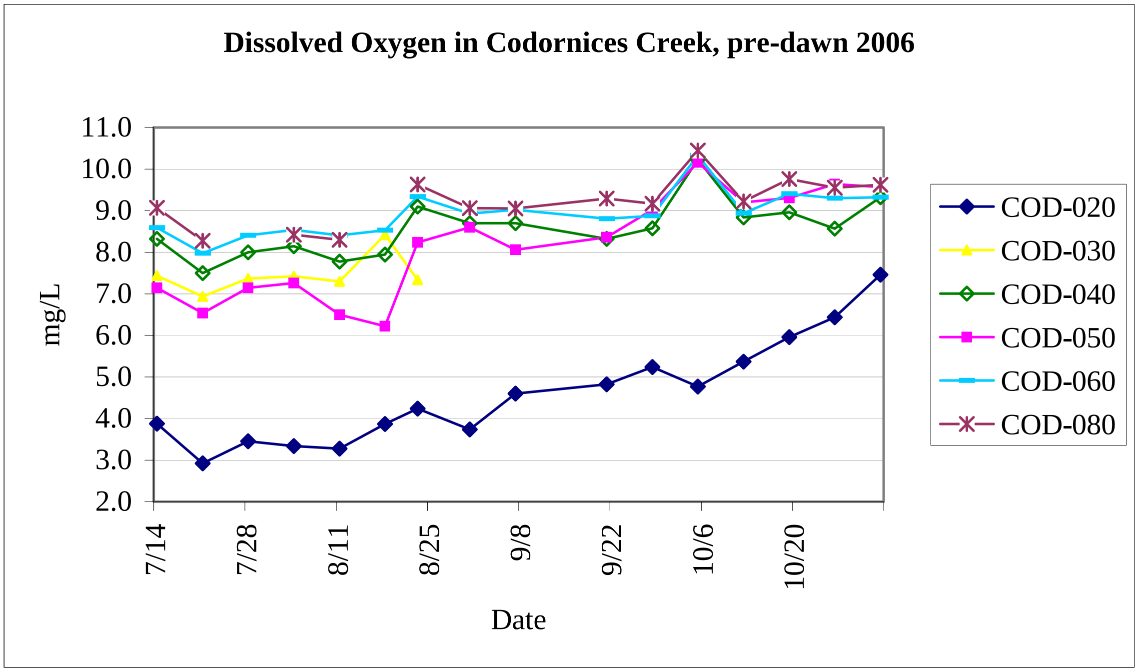


Figure 14: Dissolved oxygen values recorded near dawn at six Codornices Creek sites in the summer and fall of 2006.

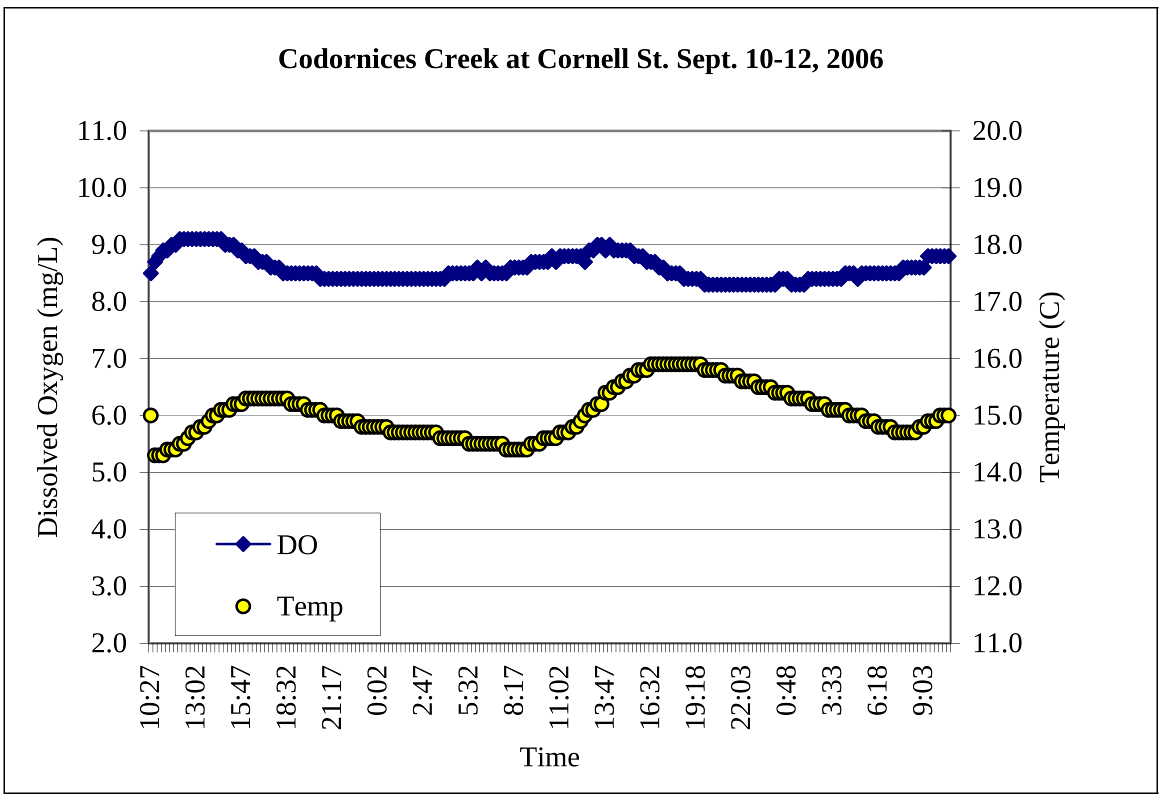
Dissolved Oxygen Assessment

The State Water Resources Control Board provided a Hach continuous-recording dissolved oxygen meter that could store up to 48-hours of data collected at 15 minute intervals. The meter was employed for CCWRAP-2 in two ways. We stationed the meter at three locations in order to characterize actual ranges of dissolved oxygen over 48-hour periods. We also used the meter to measure dissolved oxygen at various microhabitats in lower Codornices Creek in order to evaluate the spatial extent of low dissolved oxygen problems.

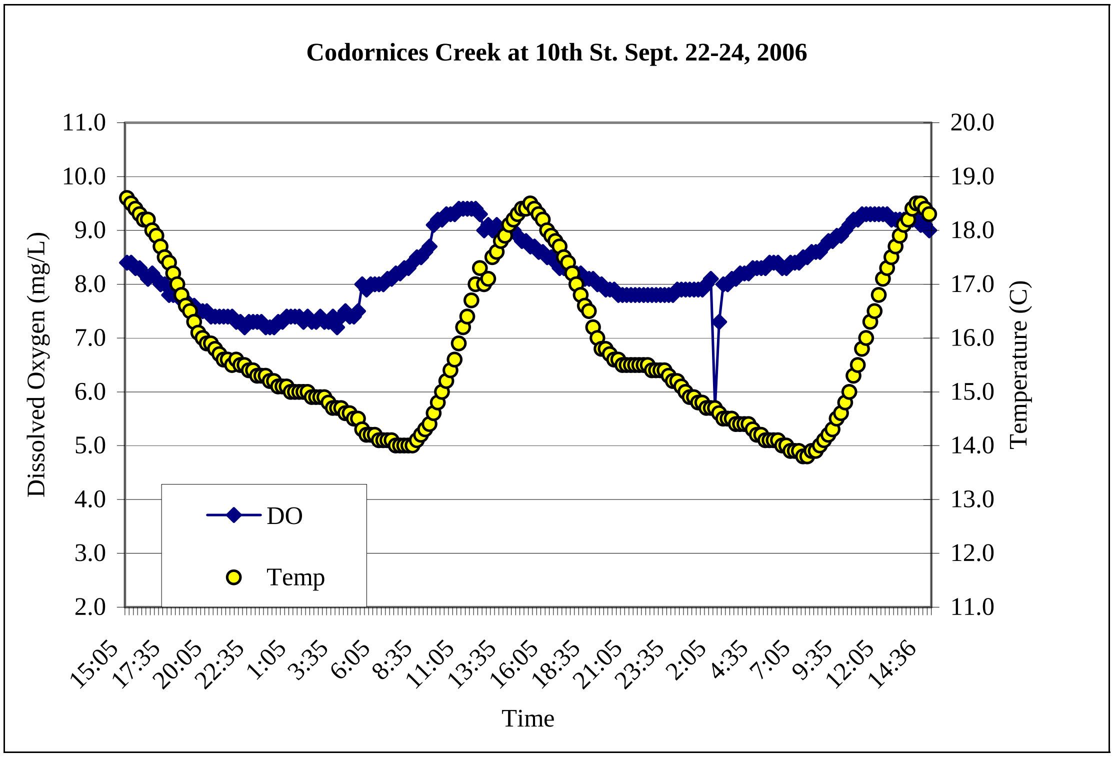
Figures 15-17 show the results of the 48-hour continuous monitoring of dissolved oxygen and temperature in September 2006 at Cornell St, 10th Street and 7th Street, respectively. The meter was also used at Cornell Street in September 2005 with results very similar to that shown in Figure 15. Dissolved oxygen levels ranged more greatly and dropped to lower levels at 10th Street and 7th Street than they did at Cornell Street. Dissolved oxygen levels at 10th Street remained above 7 mg/L for the recorded duration, but at 7th Street dissolved oxygen dropped to less than 5 mg/L during night-time periods. The diurnal fluctuation of temperature was 4.1 degrees Celsius at both 10th Street and 7th Street compared to 1.8 degrees at Cornell Street. These comparisons do not take into account differences in cloud cover or air temperature for the periods of measurement.

The actual ambient dissolved oxygen levels at 10th Street may be lower than those represented in Figure 16 because the meters probe was placed within a microhabitat aerated by a short and steep riffle. The exceptionally low value in the data from 10th Street is an outlier that may represent a brief period of time when a leaf or other debris covered the probe. Afternoon peaks in water temperature were equally high at 10th Street and 7th Street and both represent limitations for *O. mykiss* rearing which are discussed in the next section.

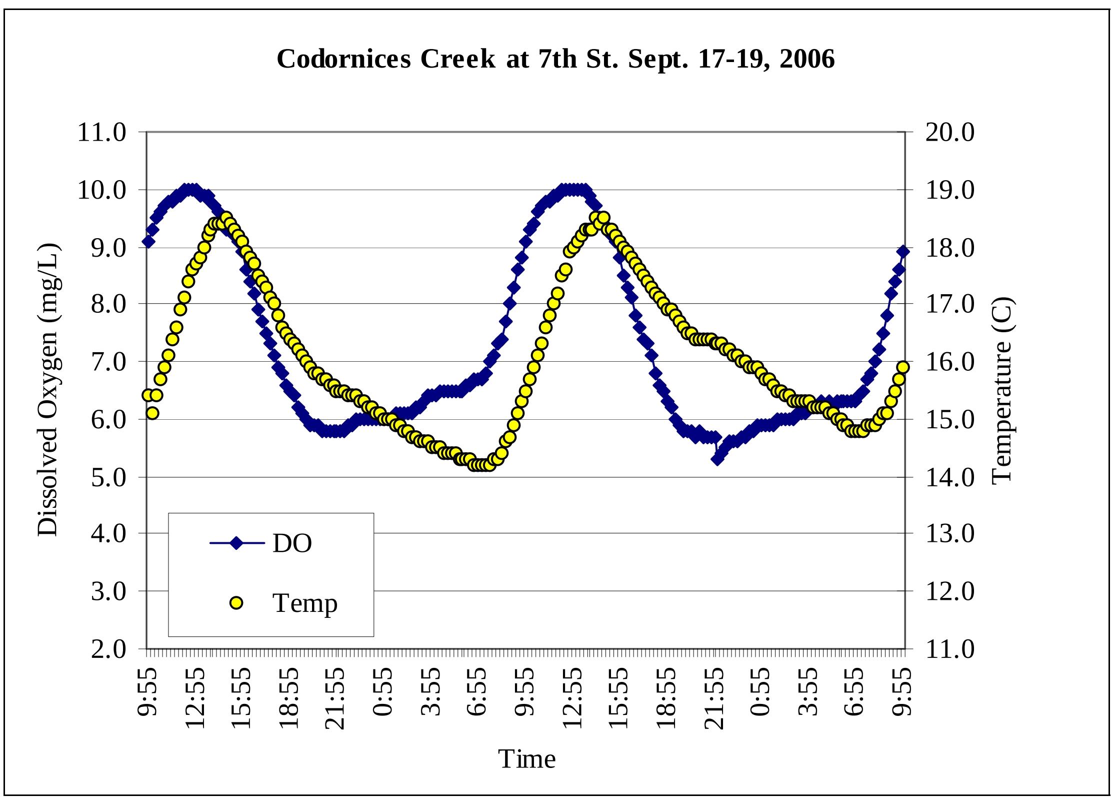
Figure 18 charts dissolved oxygen measurements taken at various microhabitats while walking up lower Codornices Creek from 2nd Street to San Pablo Ave (100 meters above 10th Street) during the hours before dawn and immediately after dawn on September 17, 2006. The actual differences between locations across lower Codornices Creek are confounded by the fact that ambient dissolved oxygen increases during this dawn period. While the results of this exploration lend some support to the hypothesis that low dissolved oxygen is a problem that decreases moving upstream, the data more importantly suggests that the trend in dissolved oxygen is not continuous. The lowest dissolved oxygen values were not near 2nd Street but rather within the recently restored segment of channel between the railroad tracks and 5th Street. Dissolved oxygen exceeded 7 mg/L in locations between 5th and 6th Street (measurements taken at approximately 6:30 am) and then dropped to less than 7 mg/L in the reach between 6th Street and 8th Street (measurements taken at approximately 6:45 am).



Figures 15: Dissolved oxygen and temperature values recorded at 15-minute intervals over 48 hours at Cornell Avenue in September 2006.



Figures 16: Dissolved oxygen and temperature values recorded at 15-minute intervals over 48 hours at 10th Street in September 2006.



Figures 17: Dissolved oxygen and temperature values recorded at 15-minute intervals over 48 hours at 7th Street in September 2006.

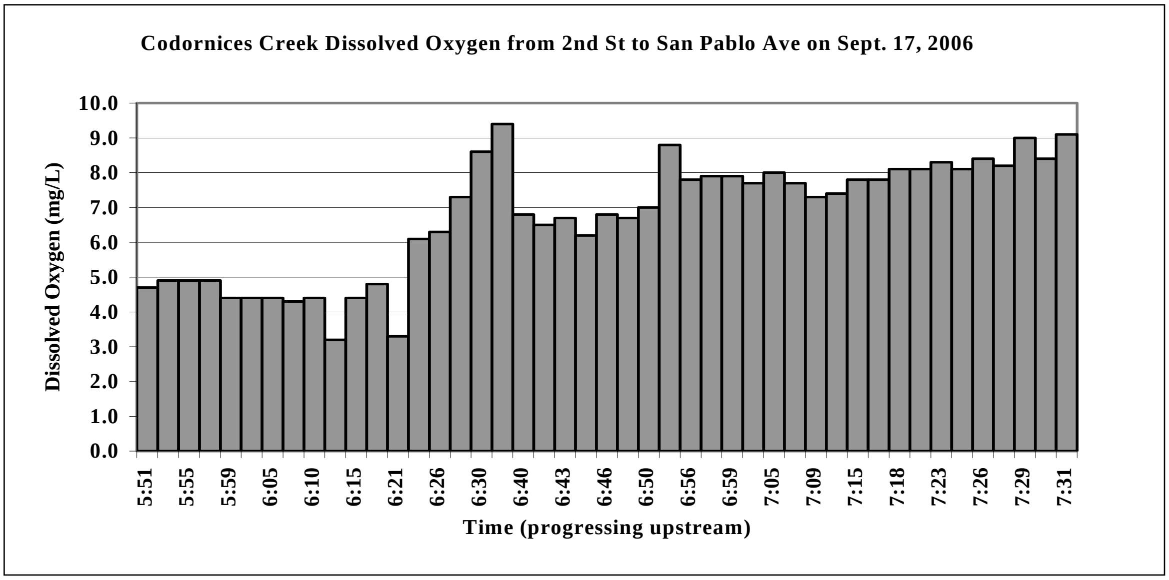


Figure 18. Dissolved oxygen measurements taken at diverse microhabitats in lower Codornices Creek, progressing upstream from 2nd Street to San Pablo Avenue during the pre-dawn period of Sept. 17, 2006. Measurements are not equally spaced.

Temperature Assessment

Water temperature was measured at six locations using continuous recording probes (Hobotemps) in addition to measurements with handheld bulb thermometers during weekly pre-dawn water quality sampling. At total of seven probes were deployed in an arrangement designed to map longitudinal trends in temperature for the fish bearing segments of Codornices Creek. The probe near 6th Street was lost as a result of large-machinery work in the stream channel during the month of October. Figure 19 maps the location of the temperature probes.

Water temperatures recorded near dawn at six water quality monitoring sites (Figure 20) are useful in comparing minimum temperatures among sites. At the four upper sites, dawn recordings were very similar, all peaking near 16.5 °C on July 21 and decreasing to approximately 14.5 °C on October 10. Dawn temperatures at 2nd Street were 1-1.5 °C warmer than for the entire summer. Water temperature at 4th Street was also warmer, but by only 1 °C or less.

Floating weekly average temperature or the 7-day mean water temperature reflects the degree of chronic exposure to elevated water temperature. Sullivan et al. (2000) determined that *O. mykiss* growth is impaired 10% and 20% when floating weekly average temperature exceeds 17°C and 19°C, respectively. Figure 21 charts the floating weekly average temperature for the six sites where temperature was continuously recorded in 2006. These results suggest that while *O. mykiss* growth was impaired at all sites during the late July period of maximum annual temperature, the duration of growth impairment was only one week at upper sites, approximately 6 weeks at 10th Street and more than two months at 4th Street and 2nd Street. Moreover, the degree of impairment was significantly higher at these lower sites.

While dawn temperatures at 10th Street are not higher than upper sites (Figure 20), the high diurnal fluctuation of temperature at 10th Street (Figure 16) indicates some stream warming at this location. Figure 22 charts the daily maximum, average and minimum temperatures at 10th Street, and reveals a daily shift in temperature of 4-5 °C during the first eight weeks of summer. Maximum daily temperatures at 10th Street exceeded 21 °C for approximately 4 weeks.

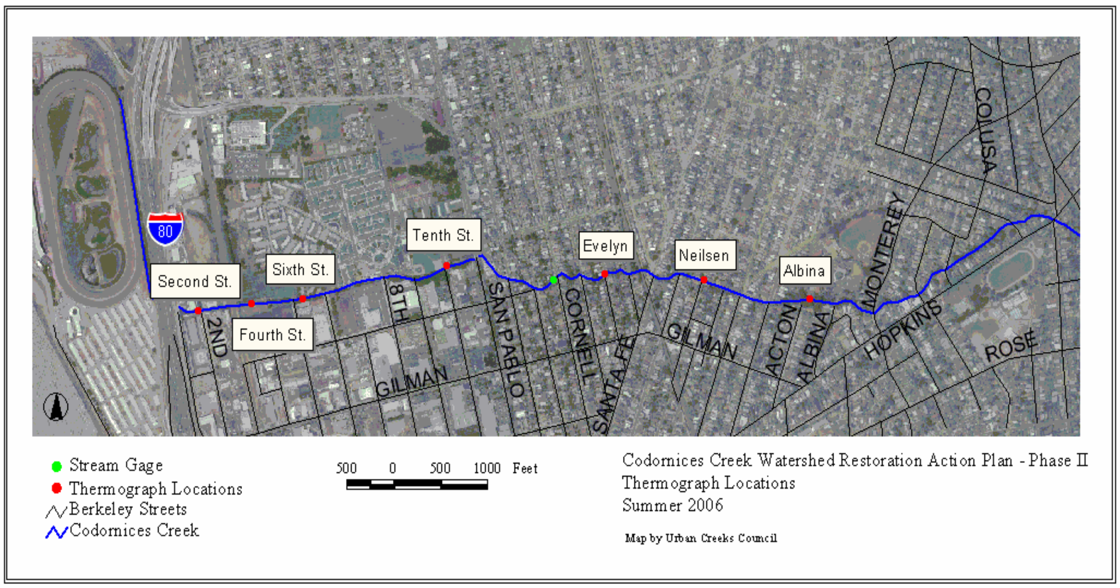
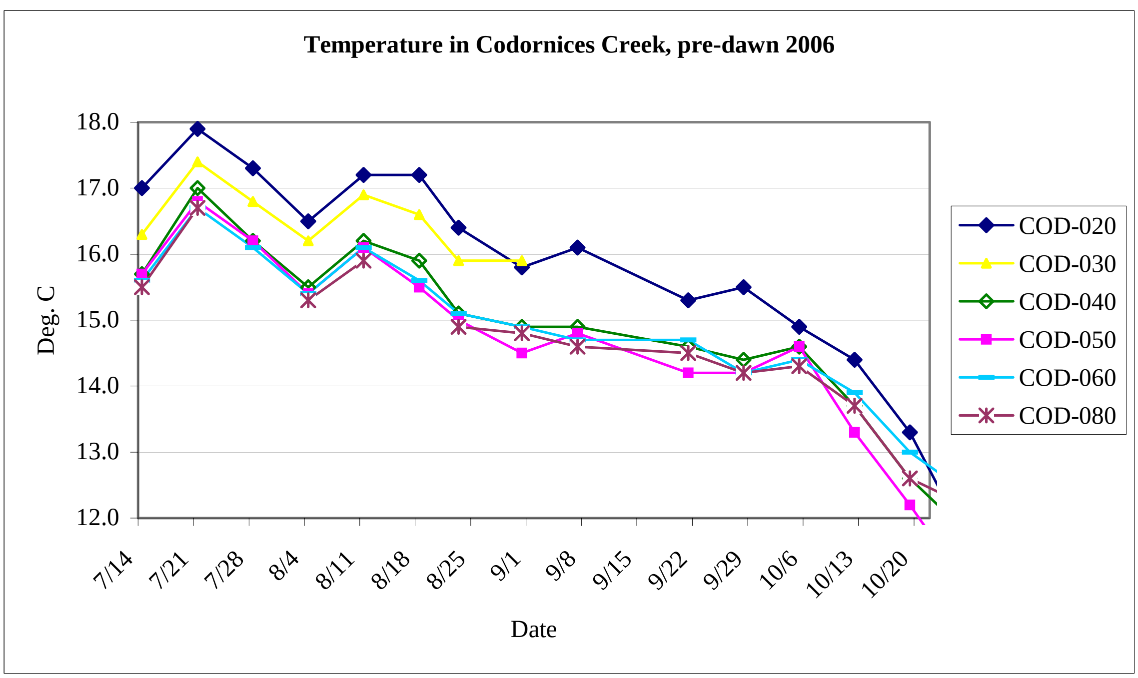
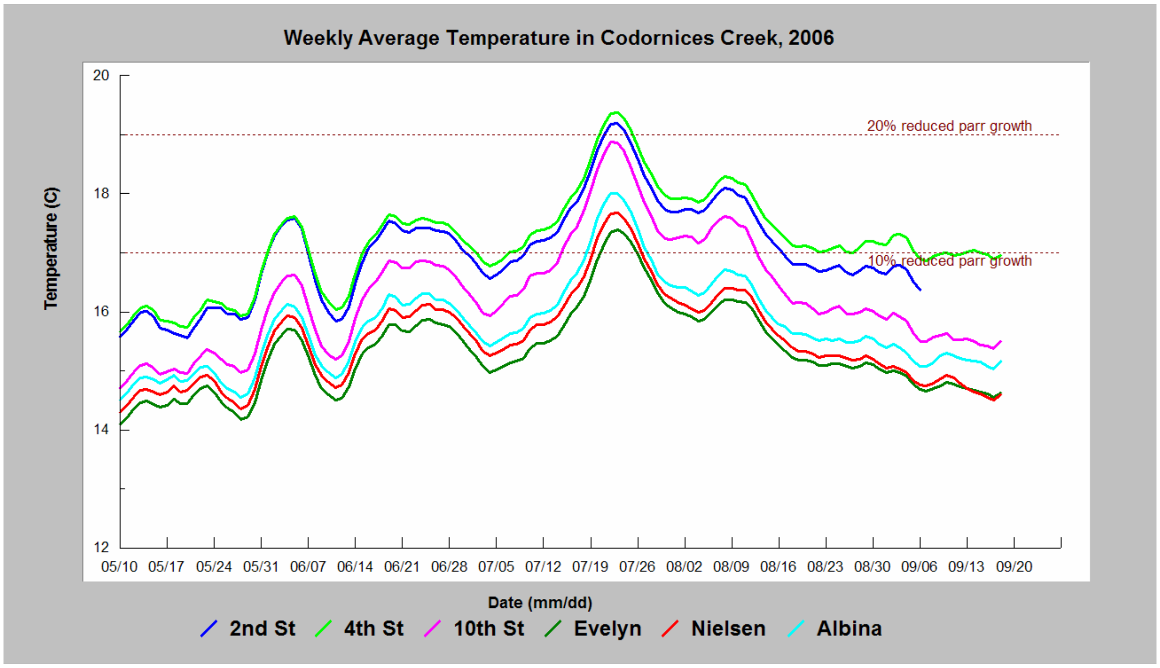


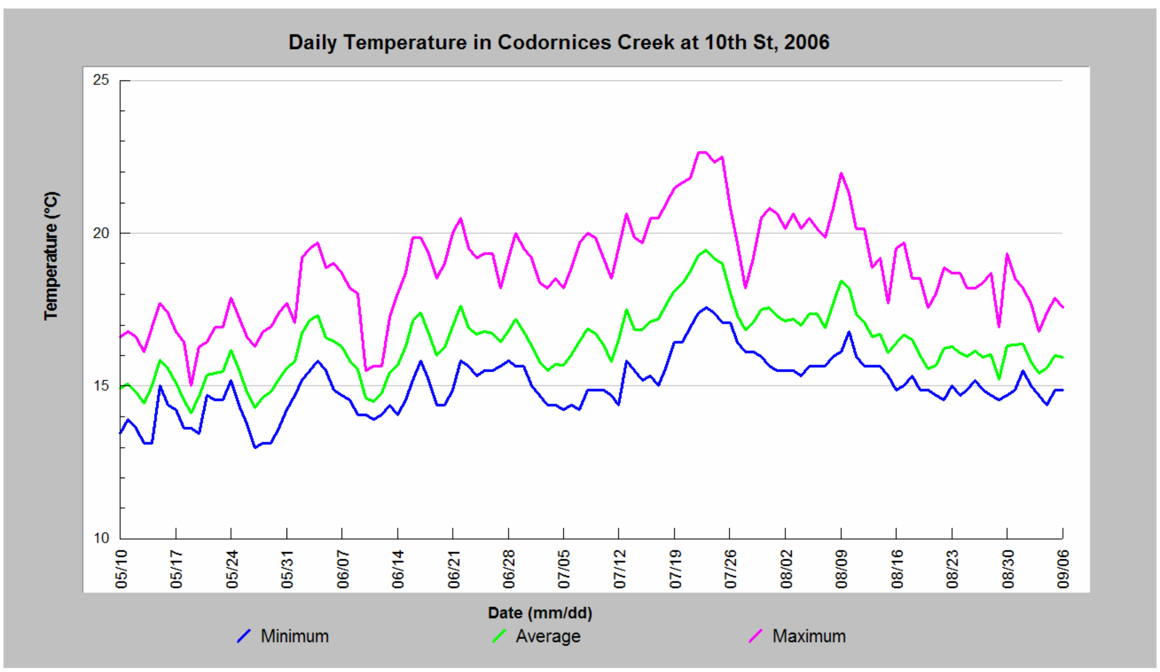
Figure 19. The location of seven temperature probes deployed in Codornices Creek in 2006.



Figures 20: Water temperature recorded near dawn at six Codornices Creek sites in the summer and fall of 2006.



Figures 21: Floating weekly average (7-day) water temperature in Codornices Creek at six locations from May 10 to September 20, 2006. The lines at 17^{o}C and 19^{o}C refer to thresholds for *O. mykiss* growth established by Sullivan et al. (2000).



Figures 22: Daily average, minimum and maximum water temperature in Codornices Creek at 10th Street from May 10 to September 9, 2006.

DISCUSSION AND CONCLUSIONS

More than 200 hours of volunteer assistance for spawning surveys and weekly water quality monitoring made it possible for this project to meet its monitoring goals. Compared to the scheduled activities described in the project Monitoring Plan (Kier Associates 2005a), the actual monitoring accomplished deviated only by omission of a second year of electrofishing. This single omission enabled the team to meet an extremely ambitious monitoring plan within a very tight budget.

The fish population survey of 2005 estimated 504 *O. mykiss* (95% confidence interval: 271-738) in Codornices Creek. The 2005 estimate is probably low, given the likelihood of large trout in several culverts where the electrofishing team was unable to work. While the electrofishing survey did not capture *O. mykiss* greater than 9", trout 10-13" were observed at multiple sites in Codornices Creek during the spawning season. Future efforts to quantify the *O. mykiss* population should make an even greater effort than that reported here to include culverts in the electrofishing survey. Because *O. mykiss* populations can vary 100% between years (Burnett 2001), a general estimate of the *O. mykiss* population for Codornices Creek could not be provided in a range smaller than a low of 135, to a high of 1,474 fish.

The *O. mykiss* population of Codornices Creek is restricted to a 1.3-mile long segment above 5th Street and below the present migration barrier at Albina Avenue. Water quality measurements suggest that poor riparian conditions are impairing fish habitat in lower Codornices Creek. Below 5th Street, stream habitat is unsuitable for salmonids due to low dissolved oxygen and high summer water temperatures. Despite channel restoration and riparian planting between the Union Pacific railroad tracks and 5th Street in 2005, the stream remained without shade, dominated by aquatic vegetation which lowers dissolved oxygen at night. Other short sections of unshaded stream in lower Codornices Creek (6th Street to 8th Street, and 10th Street to San Pablo) also seem to be contributing to the problems of elevated stream temperature and inadequate nighttime dissolved oxygen.

A comparison of data from 10th Street between years suggests that this reach contributed more to temperature and dissolved oxygen problems in 2006 than 2005. In fact, riparian vegetation was thoroughly cleared from the banks for approximately 50 meters downstream of San Pablo Avenue following the floods of December 2005. Increasing pH at the 10th Street site (COD-080) during 2006 may be the result of this removal of canopy. High pH levels can occur when algae and aquatic vegetation use CO_2 for photosynthesis. At higher pH levels, relatively low levels of ammonia can be dangerously toxic to fish.

Stream temperature increased to levels higher than optimum for rearing *O. mykiss*, if only briefly, at locations above San Pablo Avenue. This suggests that restoration efforts below San Pablo Avenue may not be entirely effective in producing suitable rearing temperatures without additional effort being made to increase riparian canopy in upper reaches. If the amount and quality of habitat for *O. mykiss* in Codornices Creek is to be improved, then restoration project managers, creekside residents and City officials will all have to work to protect, maintain and enhance the riparian vegetation that supports a shaded, productive stream.

Other potential sources of water quality impairment in Codornices Creek may be contributing to the low abundance of *O. mykiss* and the low integrity of the BMI community. Low levels of dissolved oxygen in lower Codornices Creek generally limit the ability of sensitive organisms, like most stoneflies and caddisflies, to complete their life cycles. However, the BMI sample results indicate additional impairment.

While metals, diazinon and hydrocarbon pollutants measured by CCWRAP monitoring activities (Kier Associates 2004) do not support the hypothesis of lethal effects to stream biota, the discrete monitoring of these parameters can fail to indicate actual effects on those stream biota which are chronically exposed or exposed at periods other than when samples are taken.

Excess dissolved phosphate and nitrate nutrients have not been monitored in Codornices Creek, but such pollution would have the observed effect of skewing percent dominance by Chironomidae and Oligochaetae. Continued monitoring of BMIs will prove an especially powerful way to measure improvements to aquatic conditions in Codornices Creek over time. Substantial BMI sampling since 2003 provides sufficient data to accurately characterize the stream's baseline conditions. Any significant net improvement to habitat or water quality conditions will be in future BMI data collected using the same standards. More precise interpretation of both the baseline data and future data, and more powerful tools for testing change over time, will be enabled by a regional Index of Biologic Integrity (IBI) currently under development (Arlene Feng, pers. com.). By example, the North Coast IBI (Rhen and Ode 2005) uses data from hundreds of sites throughout the region to statistically derive a formula of metrics that indexes level of impairment.

Consistently applied pebble counts can reveal changes over time in particle size distribution. In order to achieve such information, however, a specific method of pebble count application to the stream channel should be used consistently. CCWRAP results suggest that focusing on pool-riffle transitions may provide enhanced ability to both characterize spawning habitat quality and to detect changes in particle size distribution over time.

V-star may not be suitable for evaluating sediment in Codornices Creek due to geological conditions and unnatural channel constraints different from those of the streams of the North Coast region where this method has been validated. The appropriate use of V-star for evaluating sediment as a limiting factor, or for detecting changes through trend monitoring, depends upon certain conditions within the dynamic process that effects fine sediment deposition in pools. While V-star has been thoroughly studied and validated for natural stream channels flowing through the Franciscan geologic formation, the results of its application in Codornices Creek are difficult to interpret. The Codornices Creek watershed is located on the Franciscan Formation, but the stream channel is strongly influenced by young marine sediments. In addition, Codornices Creek, due to its urbanized location is artificially confined by retaining walls that influence sediment dynamics and diminish fish habitat.

Two hydrologic aspects of urbanization conspire to threaten the stability and productivity of *O. mykiss* populations in Codornices Creek. An extremely high, "flashy" runoff rate (refer again to Figure 6) and a high proportion of artificially confined channel cause more downstream displacement of *O. mykiss* than would occur in a stream with more attenuated runoff, a natural floodplain and off-channel habitats. Given the extraordinary size and frequency of freshets in Codornices Creek during March and early April, it is not surprising that so few *O. mykiss* were found migrating downstream during spring. Until significant enhancement of floodplain and off-channel habitats can be achieved, one must expect the *O. mykiss* population to lose most, if not all of its pre-smolts during stormy springs like that of 2006.

ACKNOWLEDGEMENTS

We are deeply grateful to Emma Gutzler for coordinating our volunteers and for managing data collection with exceptional skill and good cheer. Daniel Dole contributed reliable monitoring of water quality and provided an exceptional example of stewardship by a streamside resident. Angus Mullins provided professional field assistance. David Shaw generously assisted with the use of the continuous dissolved oxygen meter. Bill Lydgate provided expert consultation on the application of V*. Larry Traventi and Tom Keegan provided skilled electrofishing services. Special thanks to John Forte of St. Mary's College High School and Bruce Mackey for conducting spawning surveys. And thanks to the gracious neighbors of Codornices Creek who gave us access through their property.

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RIVERMORPH PARTICLE SUMMARY

River Name: Codornices Creek
Reach Name: 2nd St
Sample Name: CCWRAP Monitoring 2006 BF
Survey Date: 06/20/06

Size (mm)	TOT #	ITEM %	CUM %
0 - 0.062	0	0.00	0.00
0.062 - 0.125	0	0.00	0.00
0.125 - 0.25	0	0.00	0.00
0.25 - 0.50	0	0.00	0.00
0.50 - 1.0	4	4.00	4.00
1.0 - 2.0	5	5.00	9.00
2.0 - 4.0	5	5.00	14.00
4.0 - 5.7	3	3.00	17.00
5.7 - 8.0	9	9.00	26.00
8.0 - 11.3	4	4.00	30.00
11.3 - 16.0	17	17.00	47.00
16.0 - 22.6	20	20.00	67.00
22.6 - 32.0	22	22.00	89.00
32 - 45	8	8.00	97.00
45 - 64	2	2.00	99.00
64 - 90	1	1.00	100.00
90 - 128	0	0.00	100.00
128 - 180	0	0.00	100.00
180 - 256	0	0.00	100.00
256 - 362	0	0.00	100.00
362 - 512	0	0.00	100.00
512 - 1024	0	0.00	100.00
1024 - 2048	0	0.00	100.00
2048 -	0	0.00	100.00

D16 (mm)	5.13
D35 (mm)	12.68
D50 (mm)	16.99
D84 (mm)	29.86
D95 (mm)	41.75
D100 (mm)	90
Silt/Clay (%)	0
Sand (%)	9
Gravel (%)	90
Cobble (%)	1
Boulder (%)	0
Bedrock (%)	0

Total Particles = 100.

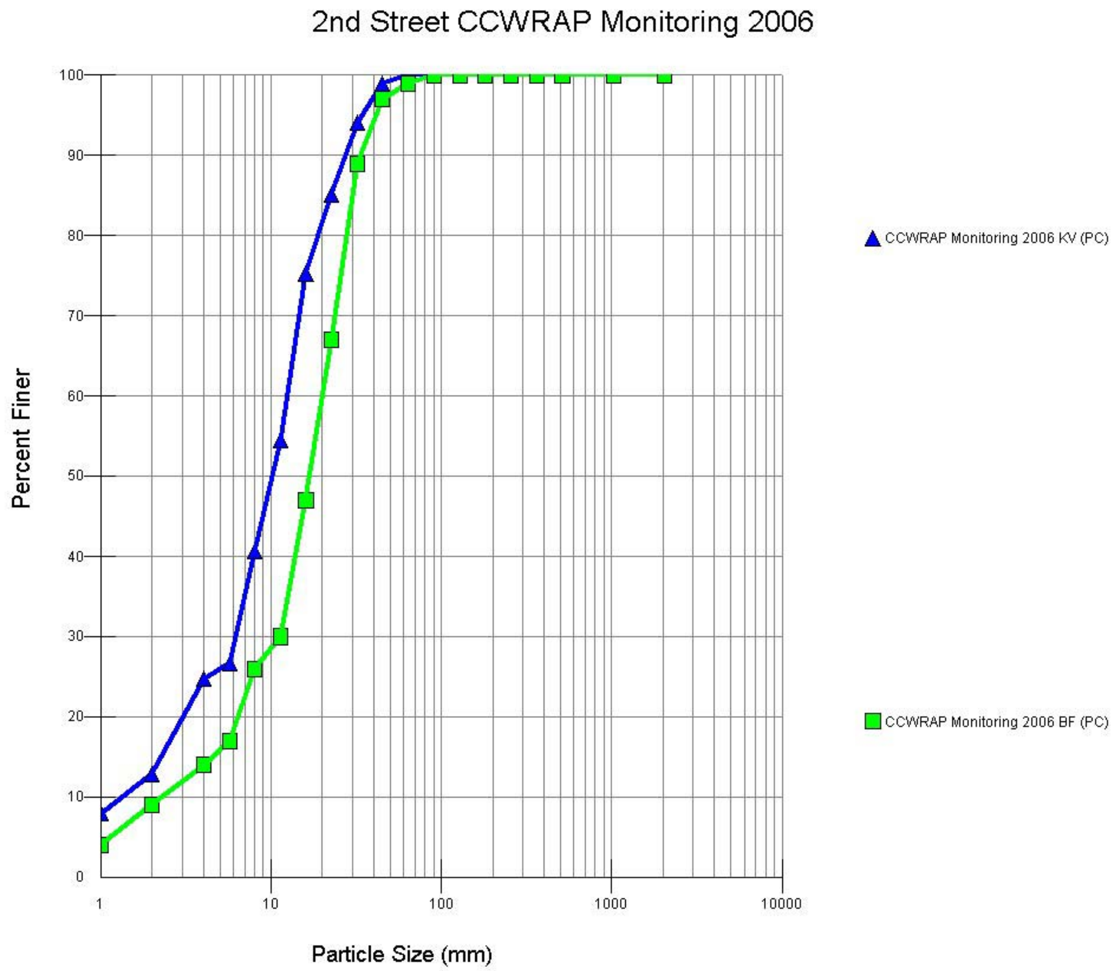
RIVERMORPH PARTICLE SUMMARY

River Name: Codornices Creek
Reach Name: 2nd St
Sample Name: CCWRAP Monitoring 2006 KV
Survey Date: 06/08/06

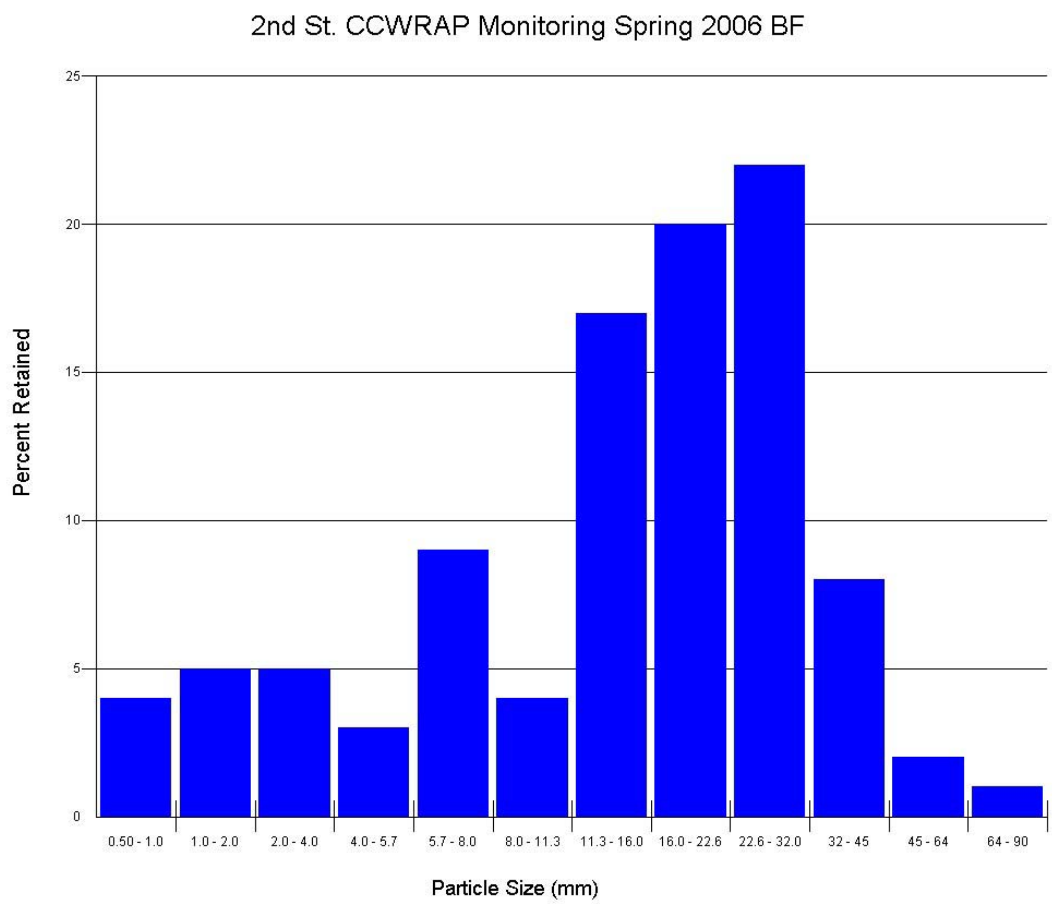
Size (mm)	TOT #	ITEM %	CUM %
0 - 0.062	0	0.00	0.00
0.062 - 0.125	0	0.00	0.00
0.125 - 0.25	0	0.00	0.00
0.25 - 0.50	0	0.00	0.00
0.50 - 1.0	8	7.92	7.92
1.0 - 2.0	5	4.95	12.87
2.0 - 4.0	12	11.88	24.75
4.0 - 5.7	2	1.98	26.73
5.7 - 8.0	14	13.86	40.59
8.0 - 11.3	14	13.86	54.46
11.3 - 16.0	21	20.79	75.25
16.0 - 22.6	10	9.90	85.15
22.6 - 32.0	9	8.91	94.06
32 - 45	5	4.95	99.01
45 - 64	1	0.99	100.00
64 - 90	0	0.00	100.00
90 - 128	0	0.00	100.00
128 - 180	0	0.00	100.00
180 - 256	0	0.00	100.00
256 - 362	0	0.00	100.00
362 - 512	0	0.00	100.00
512 - 1024	0	0.00	100.00
1024 - 2048	0	0.00	100.00
2048 -	0	0.00	100.00

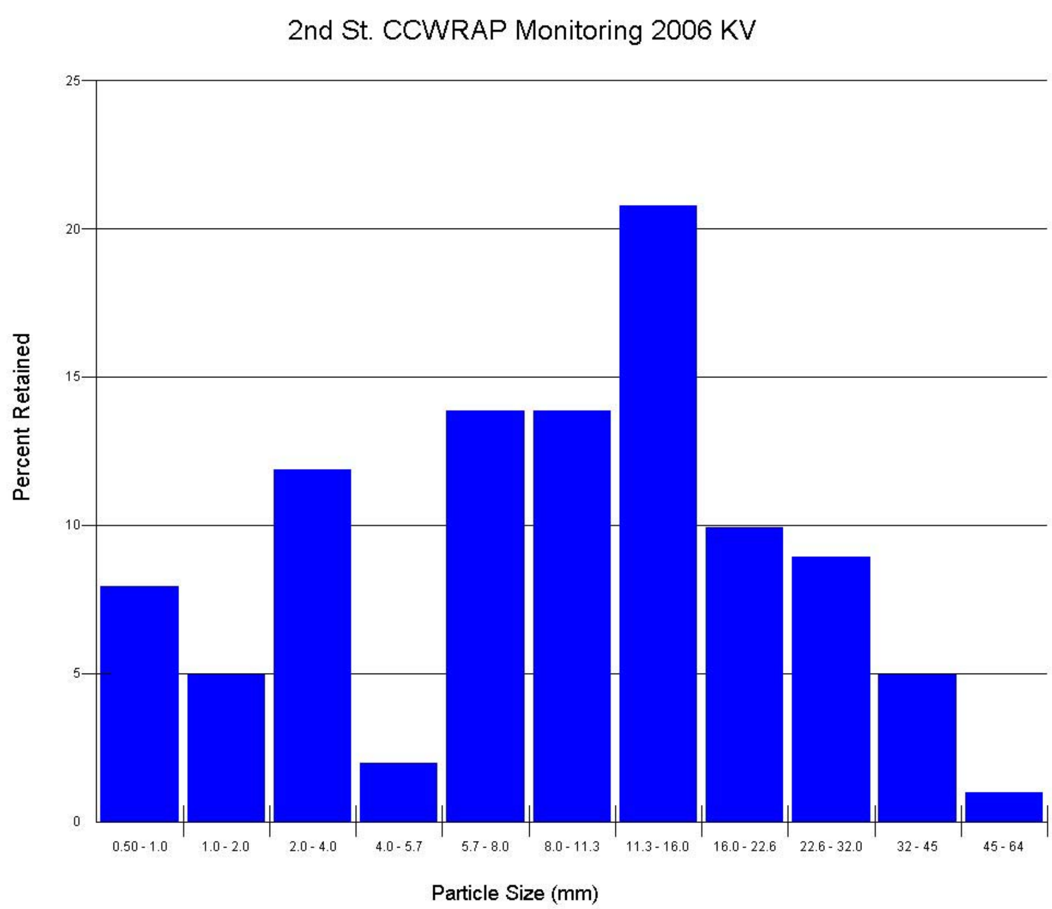
D16 (mm)	2.53
D35 (mm)	7.07
D50 (mm)	10.24
D84 (mm)	21.83
D95 (mm)	34.47
D100 (mm)	64
Silt/Clay (%)	0
Sand (%)	12.87
Gravel (%)	87.13
Cobble (%)	0
Boulder (%)	0
Bedrock (%)	0

Total Particles = 101.



2nd Street CCWRAP Monitoring 2006
Percent Finer
0
10
20
30
40
50
60
70
80
90
100
1
10
100
1000
10000
Particle Size (mm)
CCWRAP Monitoring 2006 KV (PC)
CCWRAP Monitoring 2006 BF (PC)


2nd St. CCWRAP Monitoring Spring 2006 BF
Percent Retained
25
20
15
10
5
0
0.50 - 1.0
1.0 - 2.0
2.0 - 4.0
4.0 - 5.7
5.7 - 8.0
8.0 - 11.3
11.3 - 16.0
16.0 - 22.6
22.6 - 32.0
32 - 45
45 - 64
64 - 90
Particle Size (mm)


2nd St. CCWRAP Monitoring 2006 KV
Percent Retained
25
20
15
10
5
0
0.50 - 1.0
1.0 - 2.0
2.0 - 4.0
4.0 - 5.7
5.7 - 8.0
8.0 - 11.3
11.3 - 16.0
16.0 - 22.6
22.6 - 32.0
32 - 45
45 - 64
Particle Size (mm)

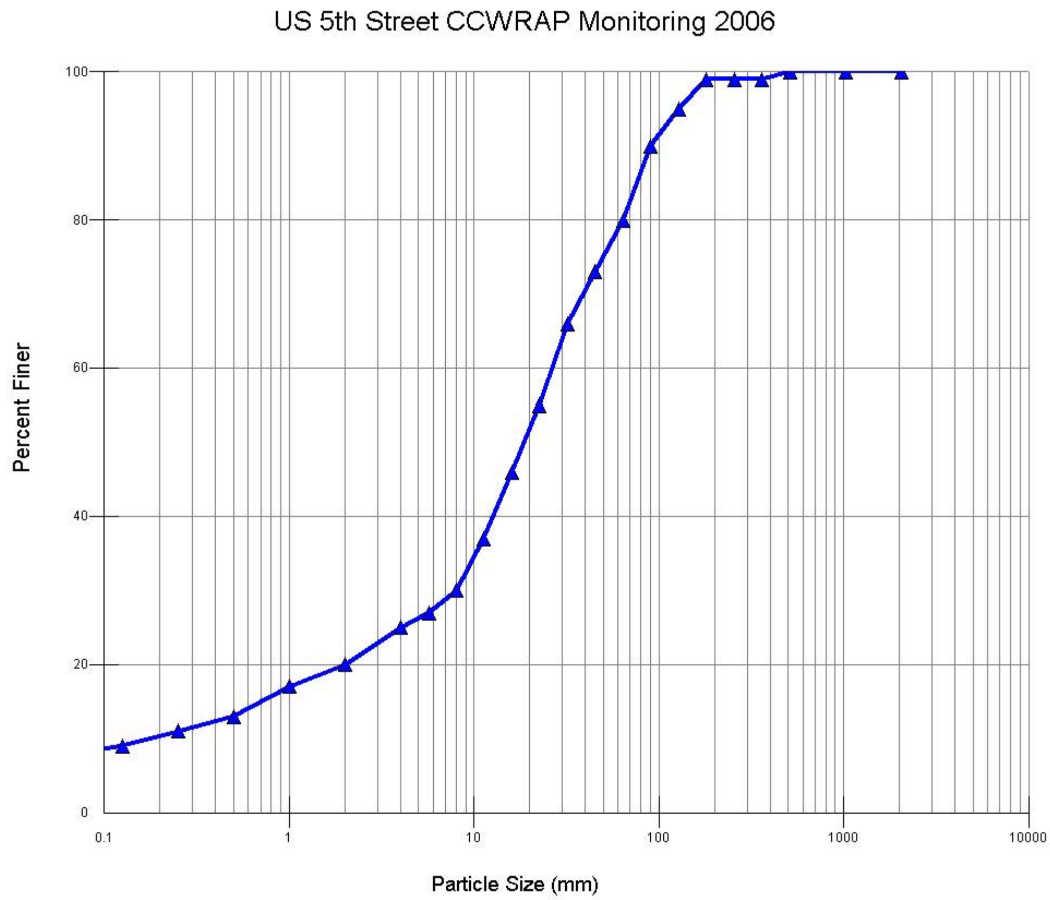
RIVERMORPH PARTICLE SUMMARY

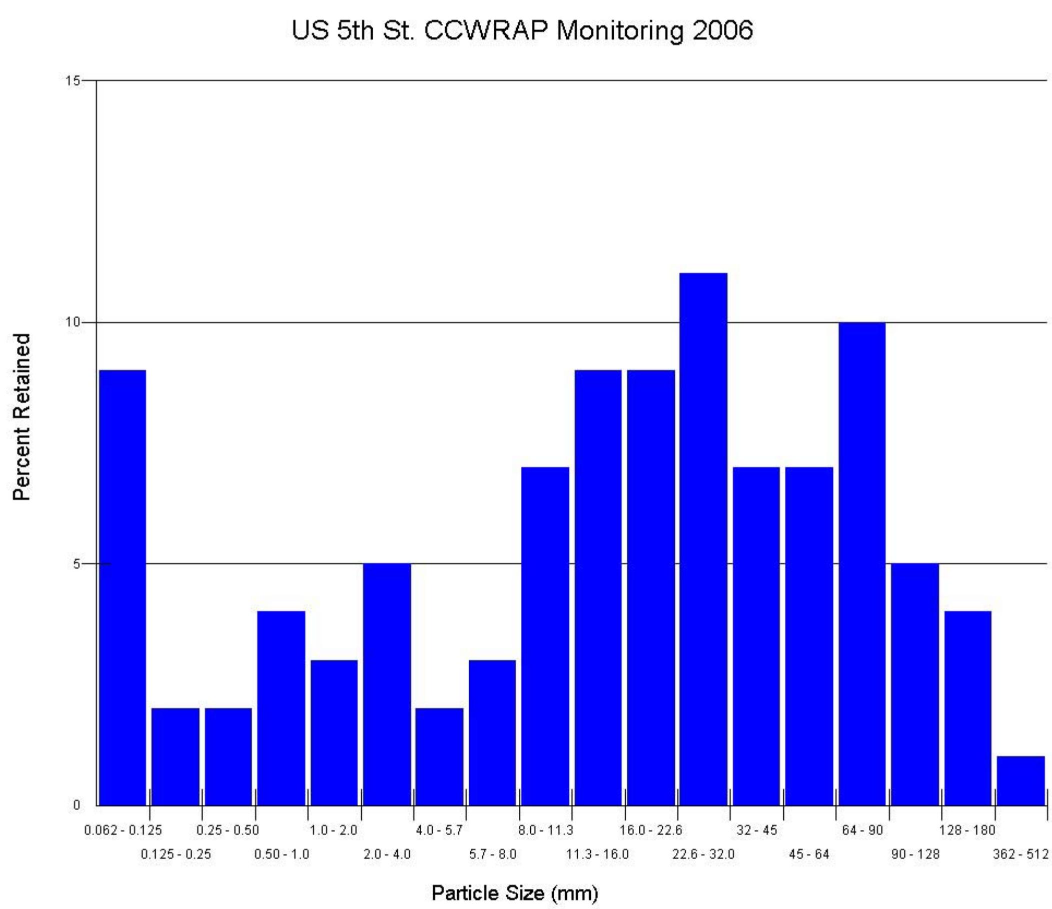
River Name:	Codornices Creek
Reach Name:	US 5th St
Sample Name:	CCWRAP Monitoring 2006
Survey Date:	06/08/06

Size (mm)	TOT #	ITEM %	CUM %
0 - 0.062	0	0.00	0.00
0.062 - 0.125	9	9.00	9.00
0.125 - 0.25	2	2.00	11.00
0.25 - 0.50	2	2.00	13.00
0.50 - 1.0	4	4.00	17.00
1.0 - 2.0	3	3.00	20.00
2.0 - 4.0	5	5.00	25.00
4.0 - 5.7	2	2.00	27.00
5.7 - 8.0	3	3.00	30.00
8.0 - 11.3	7	7.00	37.00
11.3 - 16.0	9	9.00	46.00
16.0 - 22.6	9	9.00	55.00
22.6 - 32.0	11	11.00	66.00
32 - 45	7	7.00	73.00
45 - 64	7	7.00	80.00
64 - 90	10	10.00	90.00
90 - 128	5	5.00	95.00
128 - 180	4	4.00	99.00
180 - 256	0	0.00	99.00
256 - 362	0	0.00	99.00
362 - 512	1	1.00	100.00
512 - 1024	0	0.00	100.00
1024 - 2048	0	0.00	100.00
2048 -	0	0.00	100.00

D16 (mm)	0.88
D35 (mm)	10.36
D50 (mm)	18.93
D84 (mm)	74.4
D95 (mm)	128
D100 (mm)	511.98
Silt/Clay (%)	0
Sand (%)	20
Gravel (%)	60
Cobble (%)	19
Boulder (%)	1
Bedrock (%)	0

Total Particles = 100.


US 5th Street CCWRAP Monitoring 2006
Percent Finer
0
20
40
60
80
100
0.1
1
10
100
1000
10000
Particle Size (mm)


US 5th St. CCWRAP Monitoring 2006
Percent Retained
0
5
10
15
0.062 - 0.125
0.125 - 0.25
0.25 - 0.50
0.50 - 1.0
1.0 - 2.0
2.0 - 4.0
4.0 - 5.7
5.7 - 8.0
8.0 - 11.3
11.3 - 16.0
16.0 - 22.6
22.6 - 32.0
32 - 45
45 - 64
64 - 90
90 - 128
128 - 180
362 - 512
Particle Size (mm)

RIVERMORPH PARTICLE SUMMARY

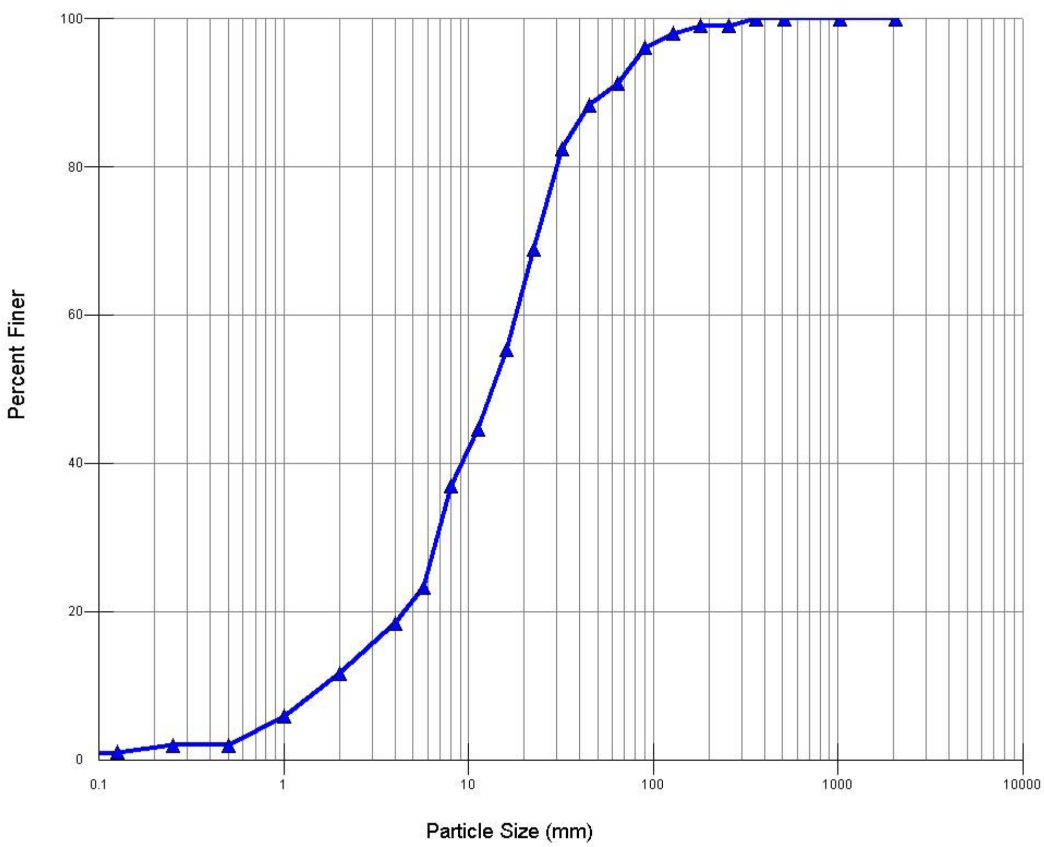
River Name:	Codornices Creek
Reach Name:	UC Village US 8th
Sample Name:	CCWRAP Monitoring 2006
Survey Date:	06/08/06

Size (mm)	TOT #	ITEM %	CUM %
0 - 0.062	0	0.00	0.00
0.062 - 0.125	1	0.97	0.97
0.125 - 0.25	1	0.97	1.94
0.25 - 0.50	0	0.00	1.94
0.50 - 1.0	4	3.88	5.83
1.0 - 2.0	6	5.83	11.65
2.0 - 4.0	7	6.80	18.45
4.0 - 5.7	5	4.85	23.30
5.7 - 8.0	14	13.59	36.89
8.0 - 11.3	8	7.77	44.66
11.3 - 16.0	11	10.68	55.34
16.0 - 22.6	14	13.59	68.93
22.6 - 32.0	14	13.59	82.52
32 - 45	6	5.83	88.35
45 - 64	3	2.91	91.26
64 - 90	5	4.85	96.12
90 - 128	2	1.94	98.06
128 - 180	1	0.97	99.03
180 - 256	0	0.00	99.03
256 - 362	1	0.97	100.00
362 - 512	0	0.00	100.00
512 - 1024	0	0.00	100.00
1024 - 2048	0	0.00	100.00
2048 -	0	0.00	100.00

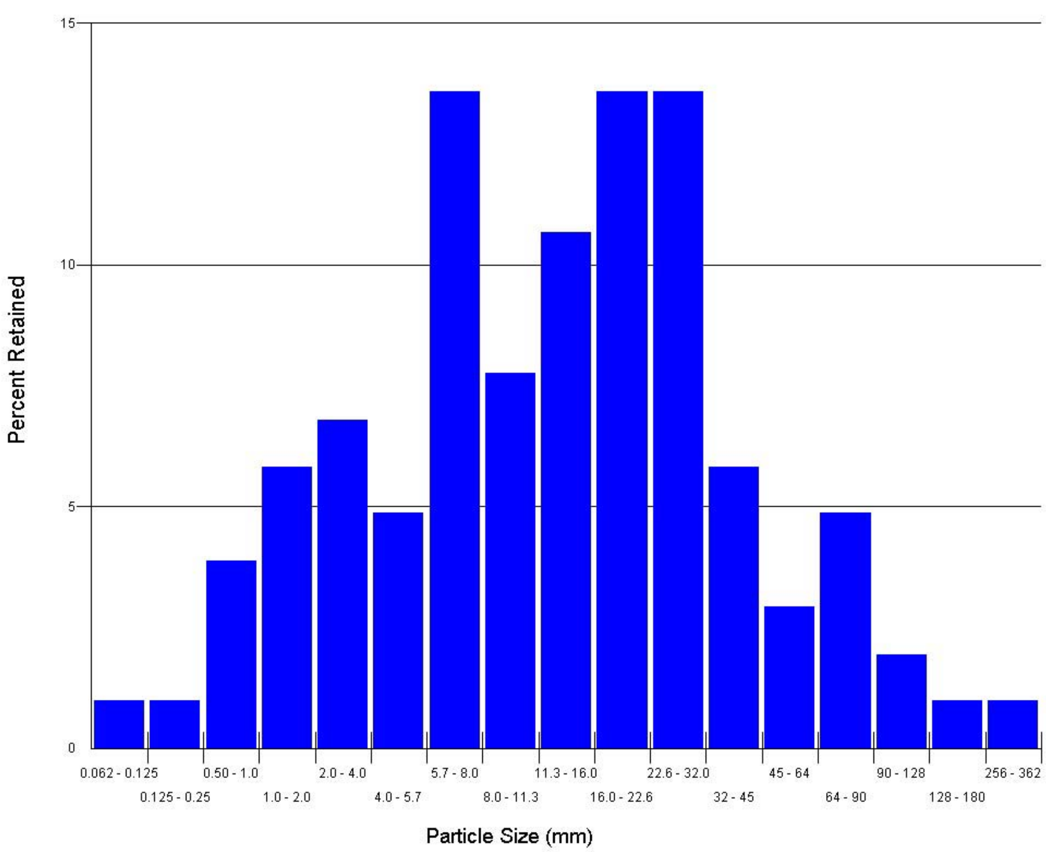
D16 (mm)	3.28
D35 (mm)	7.68
D50 (mm)	13.65
D84 (mm)	35.3
D95 (mm)	84.01
D100 (mm)	361.99
Silt/Clay (%)	0
Sand (%)	11.65
Gravel (%)	79.61
Cobble (%)	7.77
Boulder (%)	0.97
Bedrock (%)	0

Total Particles = 103.

US 8th St. CCWRAP Monitoring 2006



US 8th St. CCWRAP Monitoring 2006



RIVERMORPH PARTICLE SUMMARY

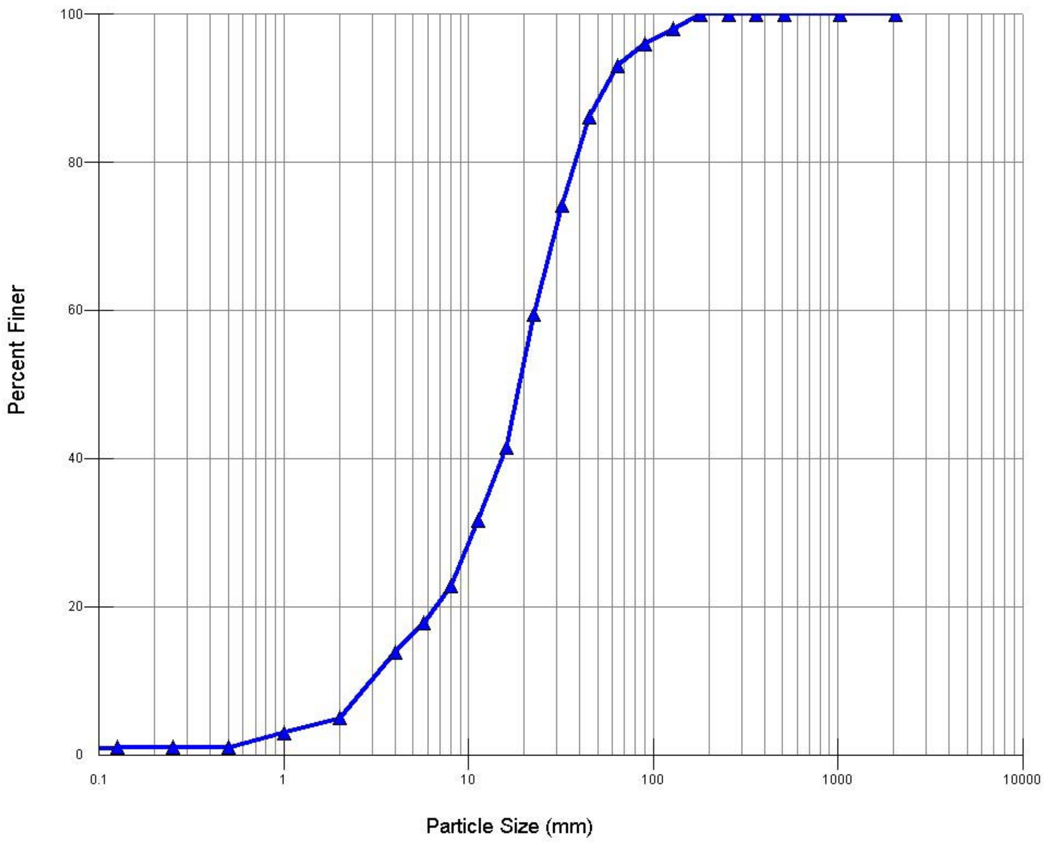
River Name: Codornices Creek
Reach Name: Masonic Avenue
Sample Name: CCWRAP Monitoring 2006
Survey Date: 06/08/06

Size (mm)	TOT #	ITEM %	CUM %
0 - 0.062	0	0.00	0.00
0.062 - 0.125	1	0.99	0.99
0.125 - 0.25	0	0.00	0.99
0.25 - 0.50	0	0.00	0.99
0.50 - 1.0	2	1.98	2.97
1.0 - 2.0	2	1.98	4.95
2.0 - 4.0	9	8.91	13.86
4.0 - 5.7	4	3.96	17.82
5.7 - 8.0	5	4.95	22.77
8.0 - 11.3	9	8.91	31.68
11.3 - 16.0	10	9.90	41.58
16.0 - 22.6	18	17.82	59.41
22.6 - 32.0	15	14.85	74.26
32 - 45	12	11.88	86.14
45 - 64	7	6.93	93.07
64 - 90	3	2.97	96.04
90 - 128	2	1.98	98.02
128 - 180	2	1.98	100.00
180 - 256	0	0.00	100.00
256 - 362	0	0.00	100.00
362 - 512	0	0.00	100.00
512 - 1024	0	0.00	100.00
1024 - 2048	0	0.00	100.00
2048 -	0	0.00	100.00

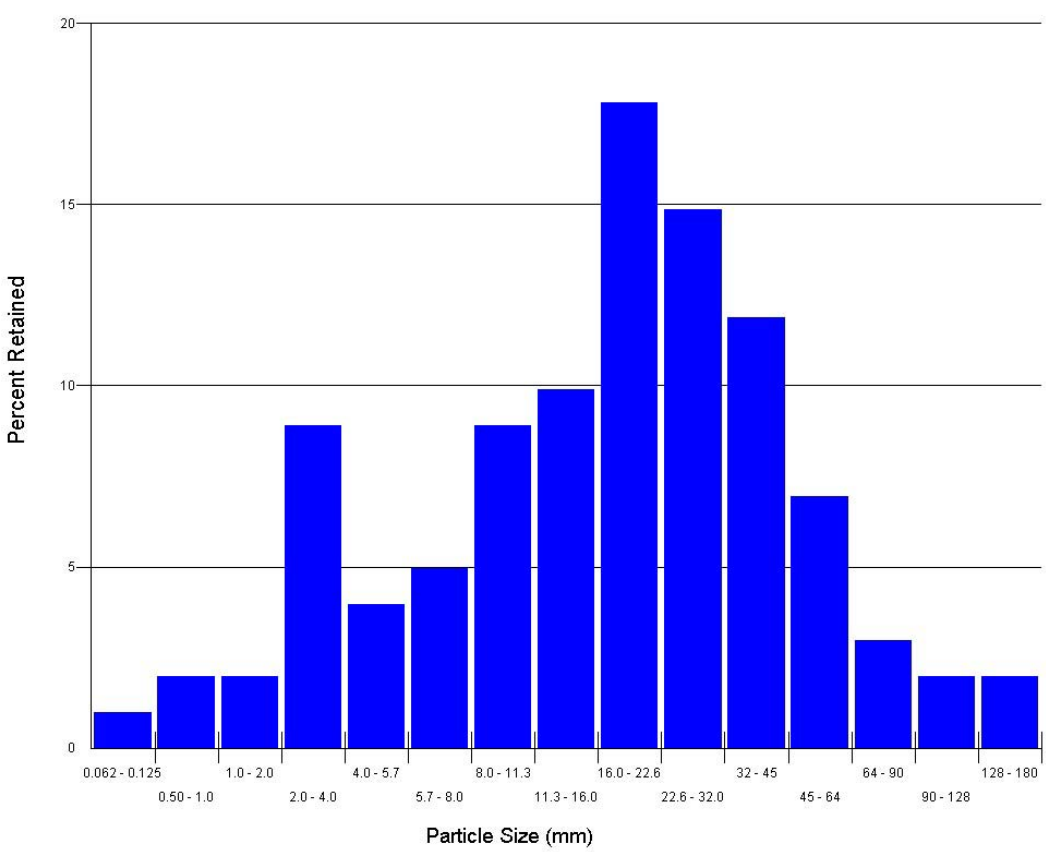
D16 (mm)	4.92
D35 (mm)	12.88
D50 (mm)	19.12
D84 (mm)	42.66
D95 (mm)	80.9
D100 (mm)	180
Silt/Clay (%)	0
Sand (%)	4.95
Gravel (%)	88.12
Cobble (%)	6.93
Boulder (%)	0
Bedrock (%)	0

Total Particles = 101.

Masonic Ave. CCWRAP Monitoring 2006



Masonic Ave. CCWRAP Monitoring 2006



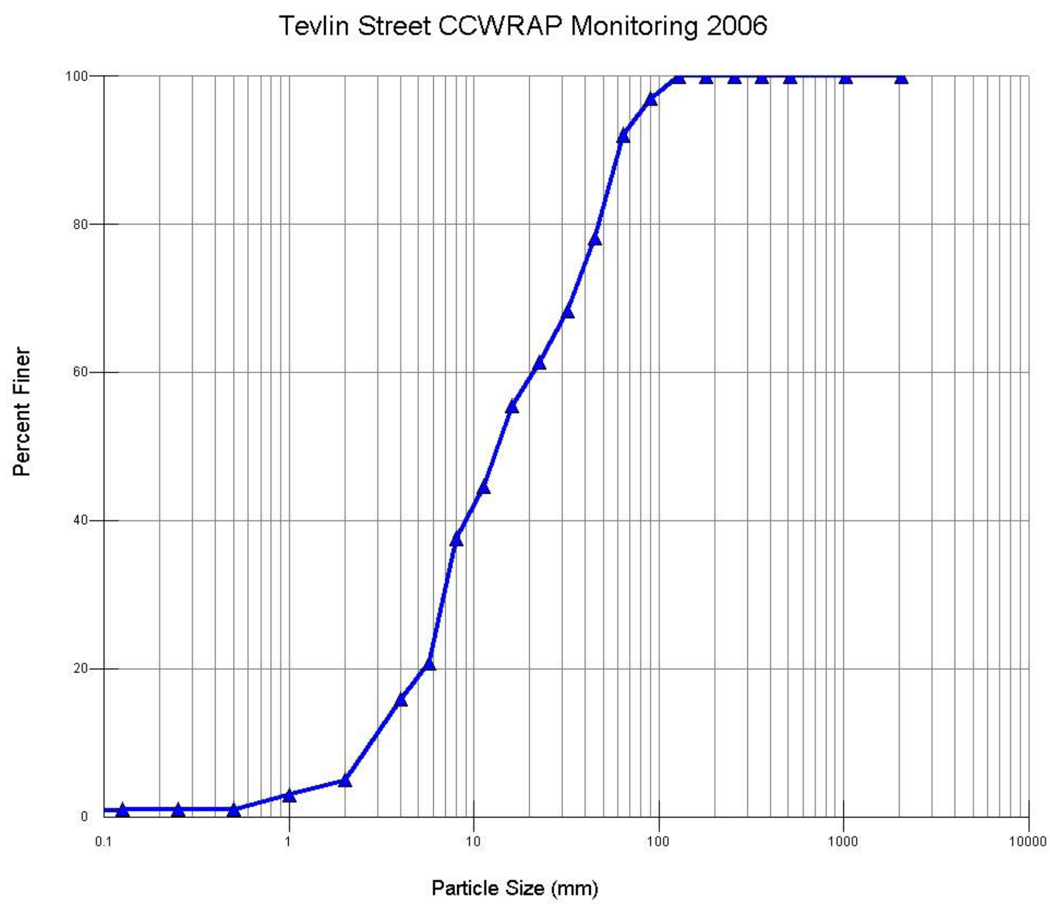
RIVERMORPH PARTICLE SUMMARY

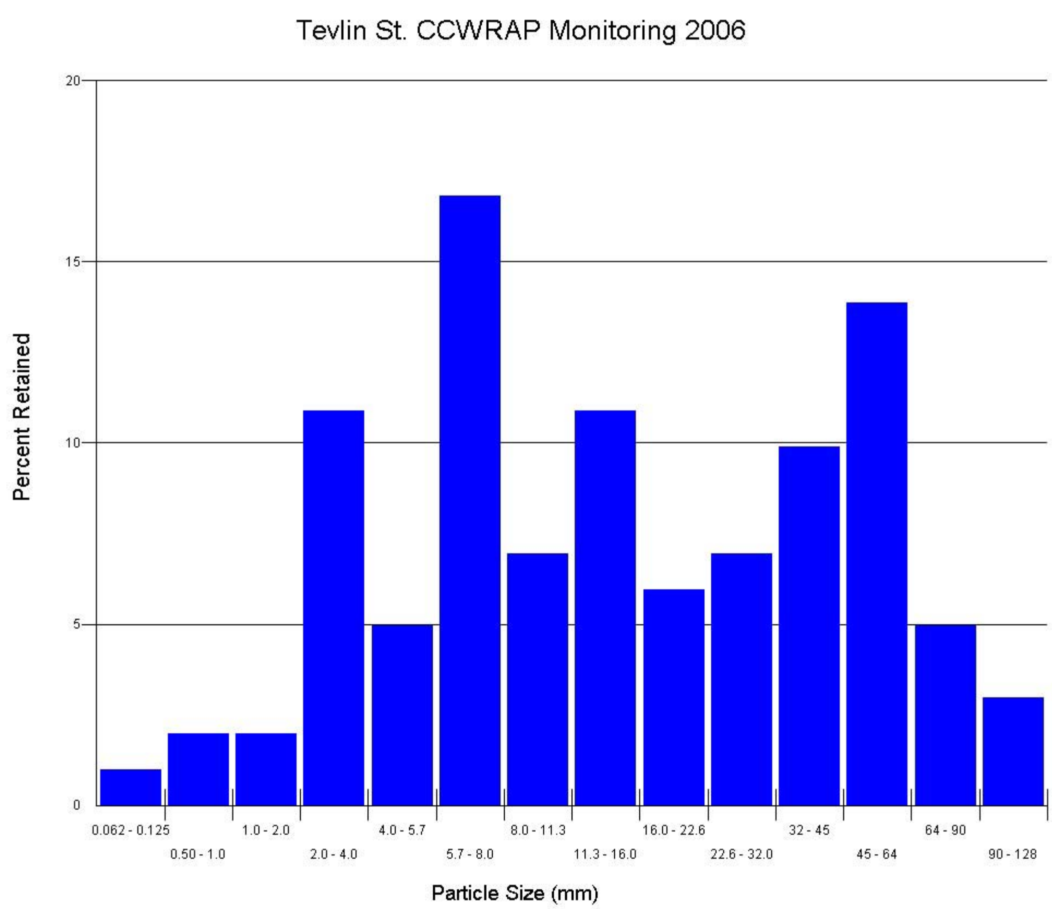
River Name: Codornices Creek
Reach Name: Tevlin
Sample Name: CCWRAP Monitoring 2006
Survey Date: 06/08/06

Size (mm)	TOT #	ITEM %	CUM %
0 - 0.062	0	0.00	0.00
0.062 - 0.125	1	0.99	0.99
0.125 - 0.25	0	0.00	0.99
0.25 - 0.50	0	0.00	0.99
0.50 - 1.0	2	1.98	2.97
1.0 - 2.0	2	1.98	4.95
2.0 - 4.0	11	10.89	15.84
4.0 - 5.7	5	4.95	20.79
5.7 - 8.0	17	16.83	37.62
8.0 - 11.3	7	6.93	44.55
11.3 - 16.0	11	10.89	55.45
16.0 - 22.6	6	5.94	61.39
22.6 - 32.0	7	6.93	68.32
32 - 45	10	9.90	78.22
45 - 64	14	13.86	92.08
64 - 90	5	4.95	97.03
90 - 128	3	2.97	100.00
128 - 180	0	0.00	100.00
180 - 256	0	0.00	100.00
256 - 362	0	0.00	100.00
362 - 512	0	0.00	100.00
512 - 1024	0	0.00	100.00
1024 - 2048	0	0.00	100.00
2048 -	0	0.00	100.00

D16 (mm)	4.05
D35 (mm)	7.64
D50 (mm)	13.65
D84 (mm)	52.92
D95 (mm)	79.34
D100 (mm)	128
Silt/Clay (%)	0
Sand (%)	4.95
Gravel (%)	87.13
Cobble (%)	7.92
Boulder (%)	0
Bedrock (%)	0

Total Particles = 101.


Tevlin Street CCWRAP Monitoring 2006
Percent Finer
0
20
40
60
80
100
0.1
1
10
100
1000
10000
Particle Size (mm)


Tevlin St. CCWRAP Monitoring 2006
Percent Retained
0
5
10
15
20
0.062 - 0.125
0.50 - 1.0
1.0 - 2.0
2.0 - 4.0
4.0 - 5.7
5.7 - 8.0
8.0 - 11.3
11.3 - 16.0
16.0 - 22.6
22.6 - 32.0
32 - 45
45 - 64
64 - 90
90 - 128
Particle Size (mm)

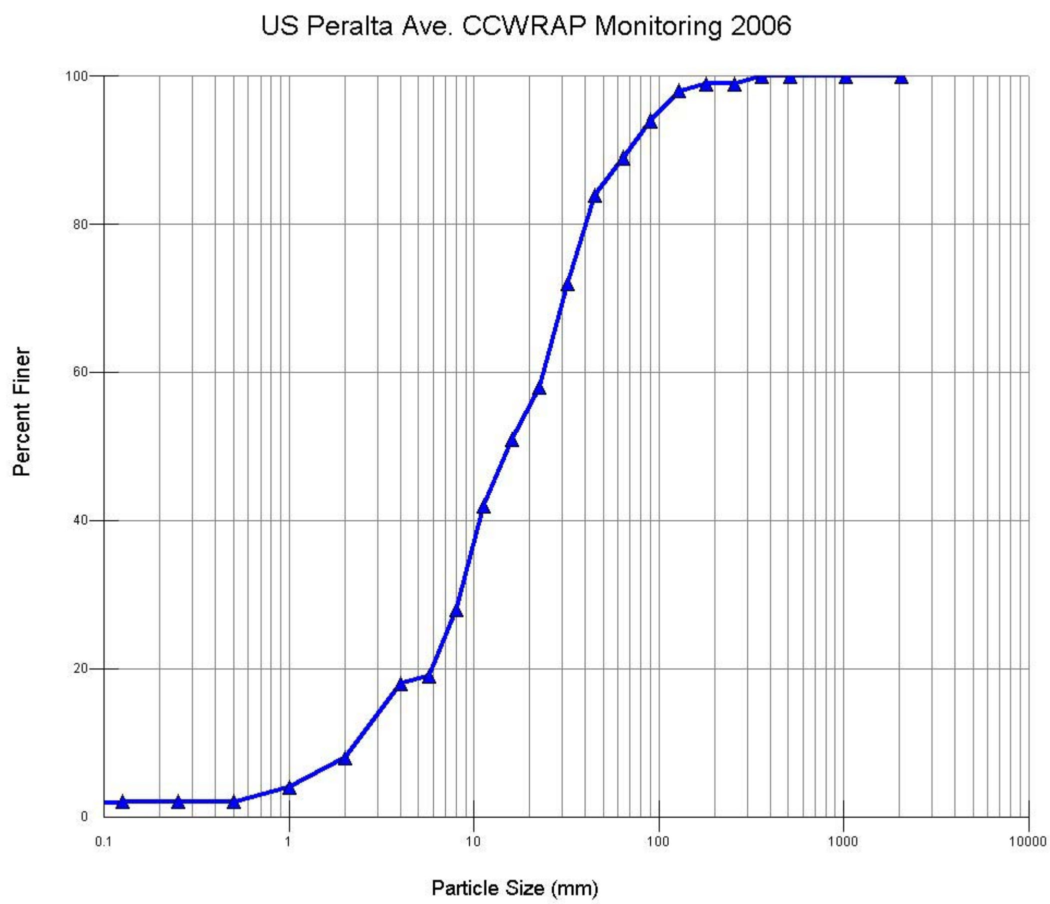
RIVERMORPH PARTICLE SUMMARY

River Name:	Codornices Creek
Reach Name:	US Peralta
Sample Name:	CCWRAP Monitoring 2006
Survey Date:	06/08/06

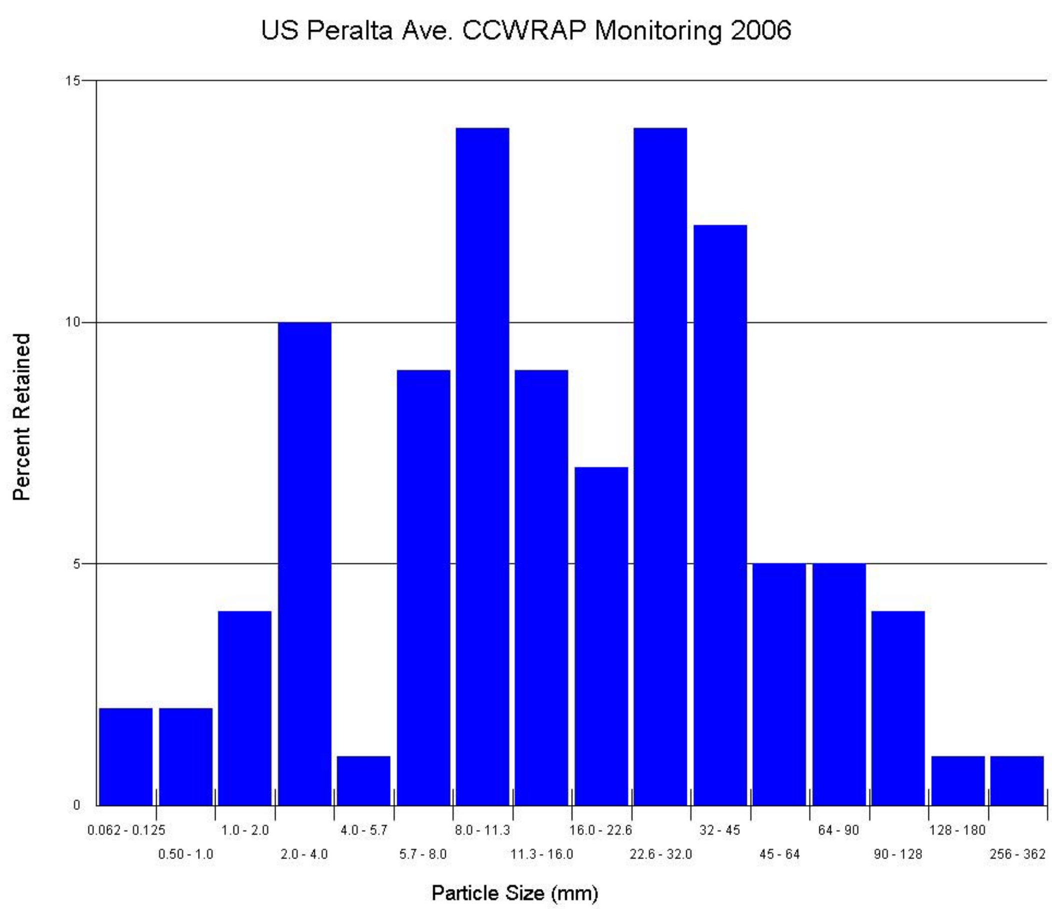
Size (mm)	TOT #	ITEM %	CUM %
0 - 0.062	0	0.00	0.00
0.062 - 0.125	2	2.00	2.00
0.125 - 0.25	0	0.00	2.00
0.25 - 0.50	0	0.00	2.00
0.50 - 1.0	2	2.00	4.00
1.0 - 2.0	4	4.00	8.00
2.0 - 4.0	10	10.00	18.00
4.0 - 5.7	1	1.00	19.00
5.7 - 8.0	9	9.00	28.00
8.0 - 11.3	14	14.00	42.00
11.3 - 16.0	9	9.00	51.00
16.0 - 22.6	7	7.00	58.00
22.6 - 32.0	14	14.00	72.00
32 - 45	12	12.00	84.00
45 - 64	5	5.00	89.00
64 - 90	5	5.00	94.00
90 - 128	4	4.00	98.00
128 - 180	1	1.00	99.00
180 - 256	0	0.00	99.00
256 - 362	1	1.00	100.00
362 - 512	0	0.00	100.00
512 - 1024	0	0.00	100.00
1024 - 2048	0	0.00	100.00
2048 -	0	0.00	100.00

D16 (mm)	3.6
D35 (mm)	9.65
D50 (mm)	15.48
D84 (mm)	45
D95 (mm)	99.5
D100 (mm)	361.99
Silt/Clay (%)	0
Sand (%)	8
Gravel (%)	81
Cobble (%)	10
Boulder (%)	1
Bedrock (%)	0

Total Particles = 100.



US Peralta Ave. CCWRAP Monitoring 2006
Percent Finer
0
20
40
60
80
100
0.1
1
10
100
1000
10000
Particle Size (mm)



US Peralta Ave. CCWRAP Monitoring 2006
Percent Retained
0
5
10
15
0.062 - 0.125
0.50 - 1.0
1.0 - 2.0
2.0 - 4.0
4.0 - 5.7
5.7 - 8.0
8.0 - 11.3
11.3 - 16.0
16.0 - 22.6
22.6 - 32.0
32 - 45
45 - 64
64 - 90
90 - 128
128 - 180
256 - 362
Particle Size (mm)

RIVERMORPH PARTICLE SUMMARY

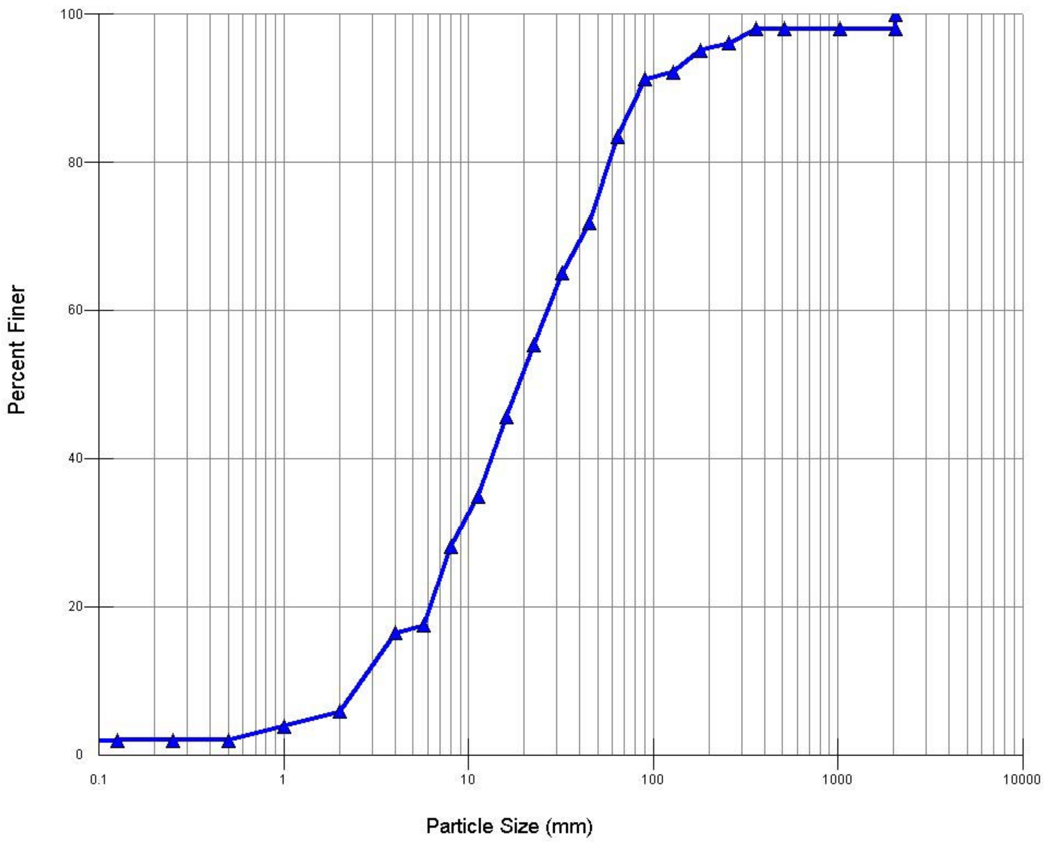
River Name:	Codornices Creek
Reach Name:	St. Mary's College High School
Sample Name:	CCWRAP Monitoring 2006
Survey Date:	06/08/06

Size (mm)	TOT #	ITEM %	CUM %
0 - 0.062	0	0.00	0.00
0.062 - 0.125	2	1.94	1.94
0.125 - 0.25	0	0.00	1.94
0.25 - 0.50	0	0.00	1.94
0.50 - 1.0	2	1.94	3.88
1.0 - 2.0	2	1.94	5.83
2.0 - 4.0	11	10.68	16.50
4.0 - 5.7	1	0.97	17.48
5.7 - 8.0	11	10.68	28.16
8.0 - 11.3	7	6.80	34.95
11.3 - 16.0	11	10.68	45.63
16.0 - 22.6	10	9.71	55.34
22.6 - 32.0	10	9.71	65.05
32 - 45	7	6.80	71.84
45 - 64	12	11.65	83.50
64 - 90	8	7.77	91.26
90 - 128	1	0.97	92.23
128 - 180	3	2.91	95.15
180 - 256	1	0.97	96.12
256 - 362	2	1.94	98.06
362 - 512	0	0.00	98.06
512 - 1024	0	0.00	98.06
1024 - 2048	0	0.00	98.06
2048 -	2	1.94	100.00

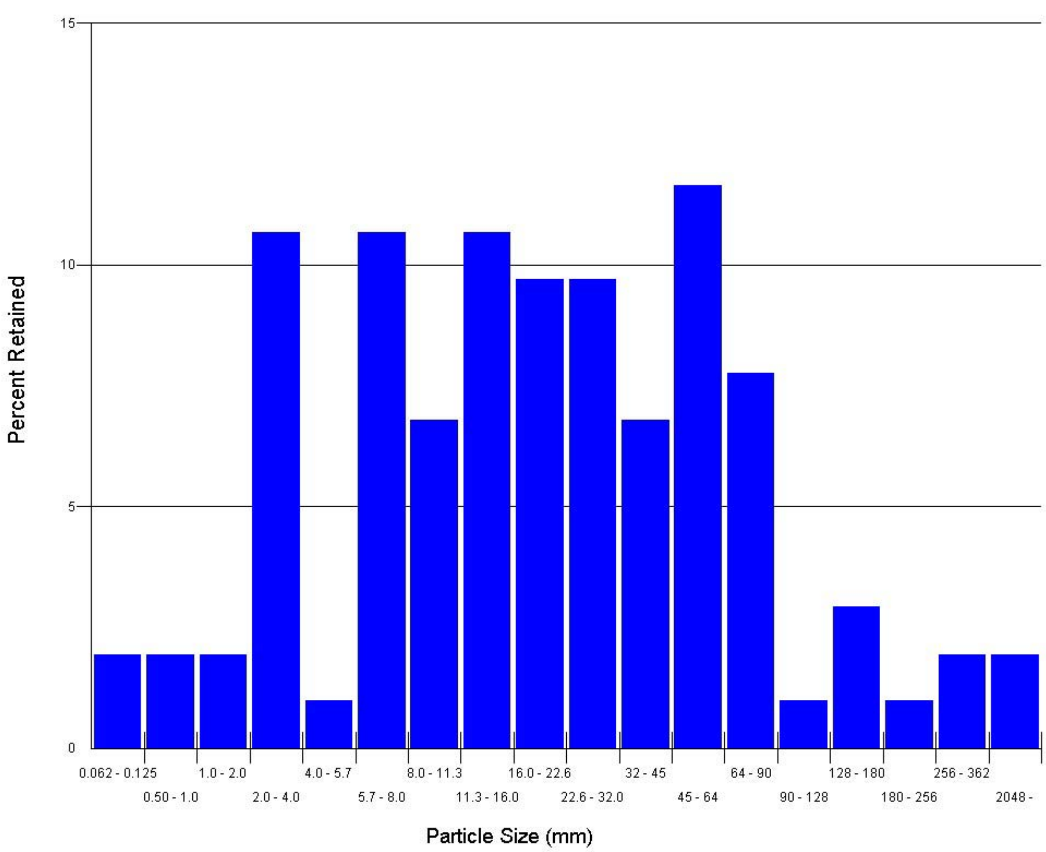
D16 (mm)	3.91
D35 (mm)	11.32
D50 (mm)	18.97
D84 (mm)	65.68
D95 (mm)	177.33
D100 (mm)	2048
Silt/Clay (%)	0
Sand (%)	5.83
Gravel (%)	77.67
Cobble (%)	12.62
Boulder (%)	1.94
Bedrock (%)	1.94

Total Particles = 103.

SMCHS CCWRAP Monitoring 2006



SMCHS CCWRAP Monitoring 2006



RIVERMORPH PARTICLE SUMMARY

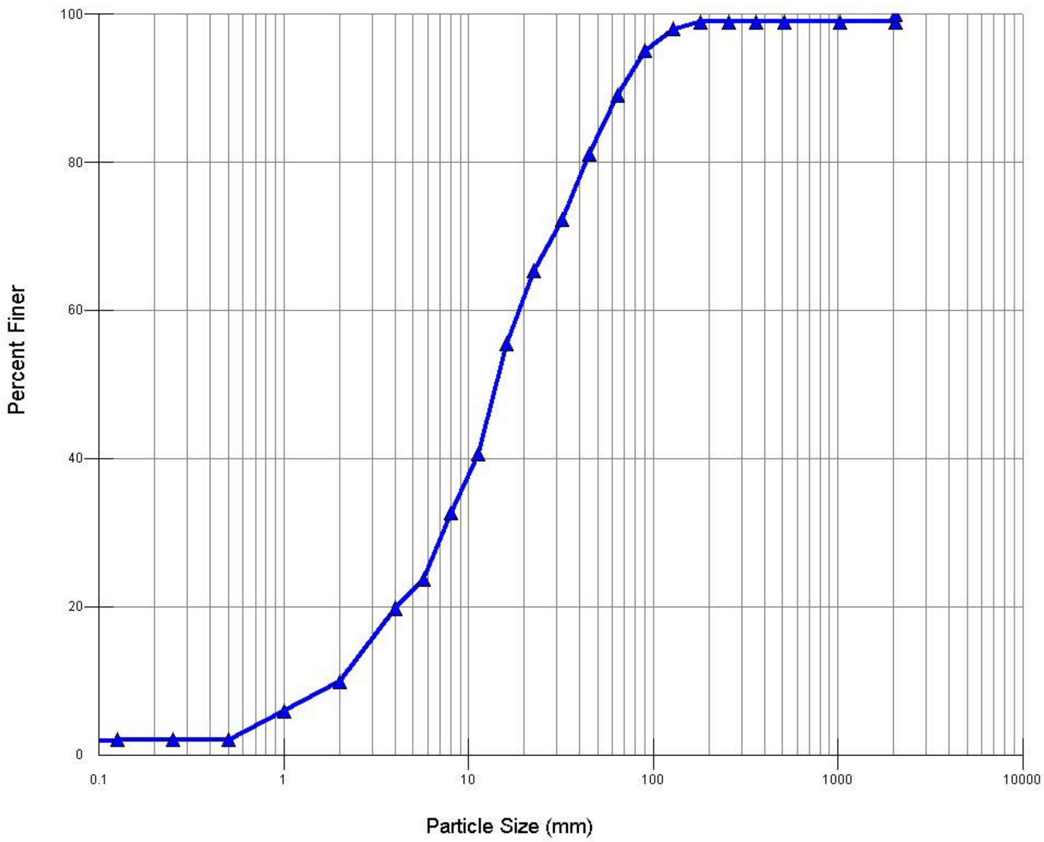
River Name:	Codornices Creek
Reach Name:	US Colusa Avenue
Sample Name:	CCWRAP Monitoring 2006
Survey Date:	06/08/06

Size (mm)	TOT #	ITEM %	CUM %
0 - 0.062	0	0.00	0.00
0.062 - 0.125	2	1.98	1.98
0.125 - 0.25	0	0.00	1.98
0.25 - 0.50	0	0.00	1.98
0.50 - 1.0	4	3.96	5.94
1.0 - 2.0	4	3.96	9.90
2.0 - 4.0	10	9.90	19.80
4.0 - 5.7	4	3.96	23.76
5.7 - 8.0	9	8.91	32.67
8.0 - 11.3	8	7.92	40.59
11.3 - 16.0	15	14.85	55.45
16.0 - 22.6	10	9.90	65.35
22.6 - 32.0	7	6.93	72.28
32 - 45	9	8.91	81.19
45 - 64	8	7.92	89.11
64 - 90	6	5.94	95.05
90 - 128	3	2.97	98.02
128 - 180	1	0.99	99.01
180 - 256	0	0.00	99.01
256 - 362	0	0.00	99.01
362 - 512	0	0.00	99.01
512 - 1024	0	0.00	99.01
1024 - 2048	0	0.00	99.01
2048 -	1	0.99	100.00

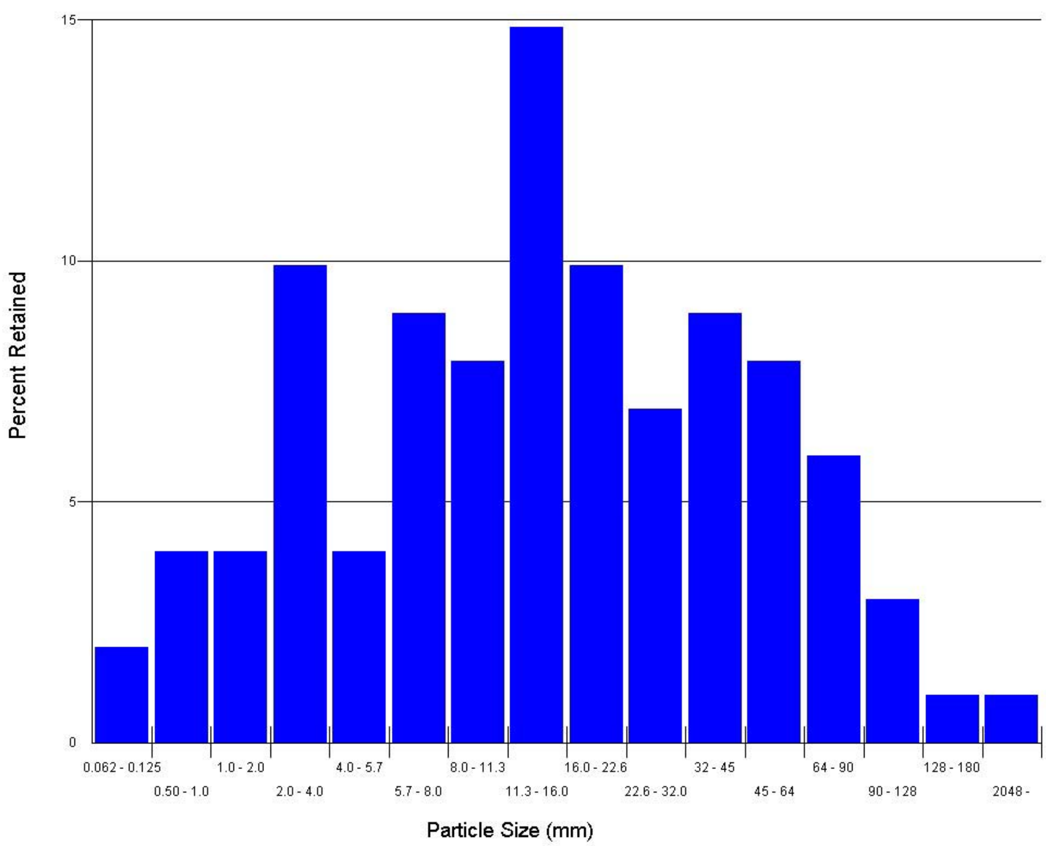
D16 (mm)	3.23
D35 (mm)	8.97
D50 (mm)	14.28
D84 (mm)	51.74
D95 (mm)	89.78
D100 (mm)	2048
Silt/Clay (%)	0
Sand (%)	9.9
Gravel (%)	79.21
Cobble (%)	9.9
Boulder (%)	0
Bedrock (%)	0.99

Total Particles = 101.

US Colusa Ave. CCWRAP Monitoring 2006



US Colusa Ave. CCWRAP Monitoring 2006



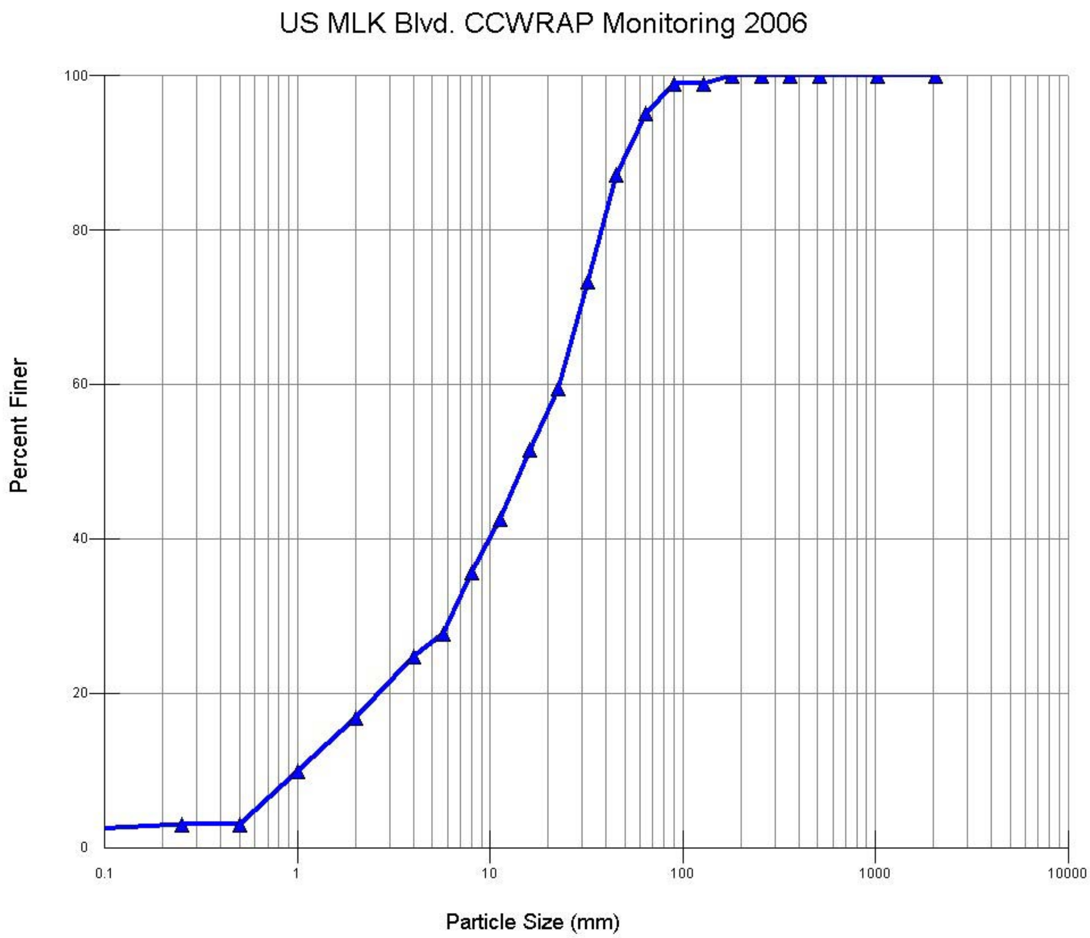
RIVERMORPH PARTICLE SUMMARY

River Name: Codornices Creek
Reach Name: US Martin Luther King Blvd
Sample Name: CCWRAP Monitoring 2006
Survey Date: 06/08/06

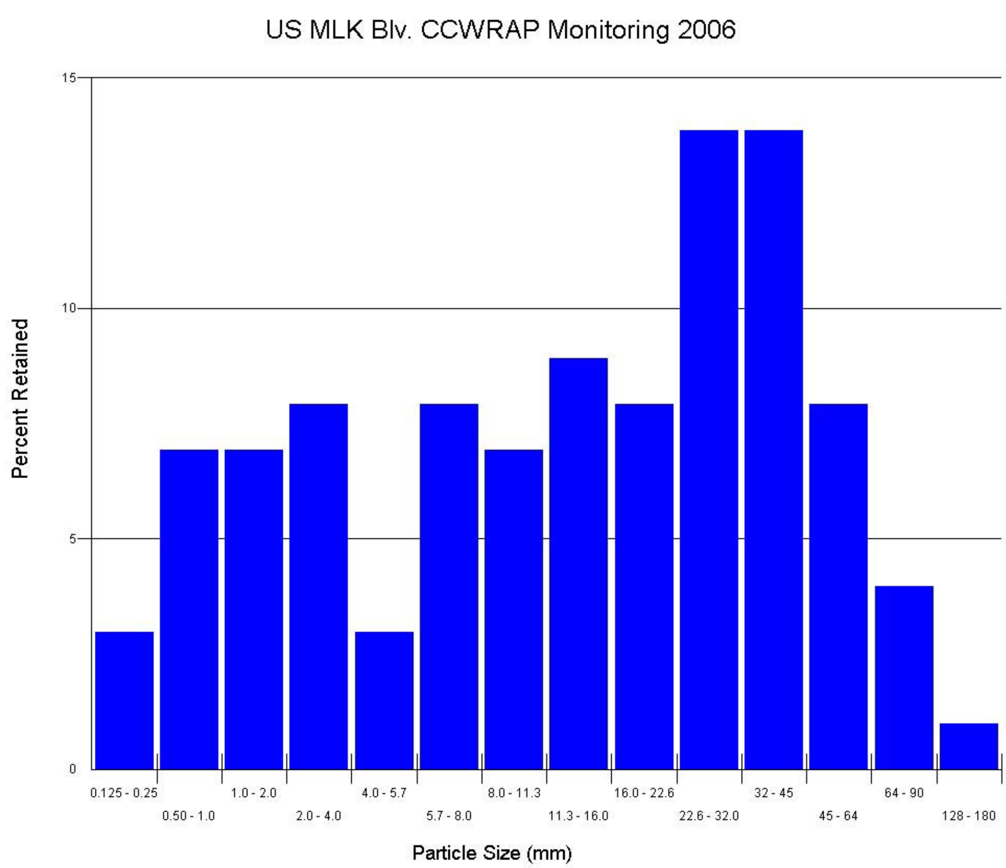
Size (mm)	TOT #	ITEM %	CUM %
0 - 0.062	0	0.00	0.00
0.062 - 0.125	0	0.00	0.00
0.125 - 0.25	3	2.97	2.97
0.25 - 0.50	0	0.00	2.97
0.50 - 1.0	7	6.93	9.90
1.0 - 2.0	7	6.93	16.83
2.0 - 4.0	8	7.92	24.75
4.0 - 5.7	3	2.97	27.72
5.7 - 8.0	8	7.92	35.64
8.0 - 11.3	7	6.93	42.57
11.3 - 16.0	9	8.91	51.49
16.0 - 22.6	8	7.92	59.41
22.6 - 32.0	14	13.86	73.27
32 - 45	14	13.86	87.13
45 - 64	8	7.92	95.05
64 - 90	4	3.96	99.01
90 - 128	0	0.00	99.01
128 - 180	1	0.99	100.00
180 - 256	0	0.00	100.00
256 - 362	0	0.00	100.00
362 - 512	0	0.00	100.00
512 - 1024	0	0.00	100.00
1024 - 2048	0	0.00	100.00
2048 -	0	0.00	100.00

D16 (mm)	1.88
D35 (mm)	7.81
D50 (mm)	15.21
D84 (mm)	42.06
D95 (mm)	63.88
D100 (mm)	179.99
Silt/Clay (%)	0
Sand (%)	16.83
Gravel (%)	78.22
Cobble (%)	4.95
Boulder (%)	0
Bedrock (%)	0

Total Particles = 101.



US MLK Blvd. CCWRAP Monitoring 2006
Percent Finer
Particle Size (mm)
0
20
40
60
80
100
0.1
1
10
100
1000
10000



US MLK Blv. CCWRAP Monitoring 2006
Percent Retained
Particle Size (mm)
0
5
10
15
0.125 - 0.25
0.50 - 1.0
1.0 - 2.0
2.0 - 4.0
4.0 - 5.7
5.7 - 8.0
8.0 - 11.3
11.3 - 16.0
16.0 - 22.6
22.6 - 32.0
32 - 45
45 - 64
64 - 90
128 - 180

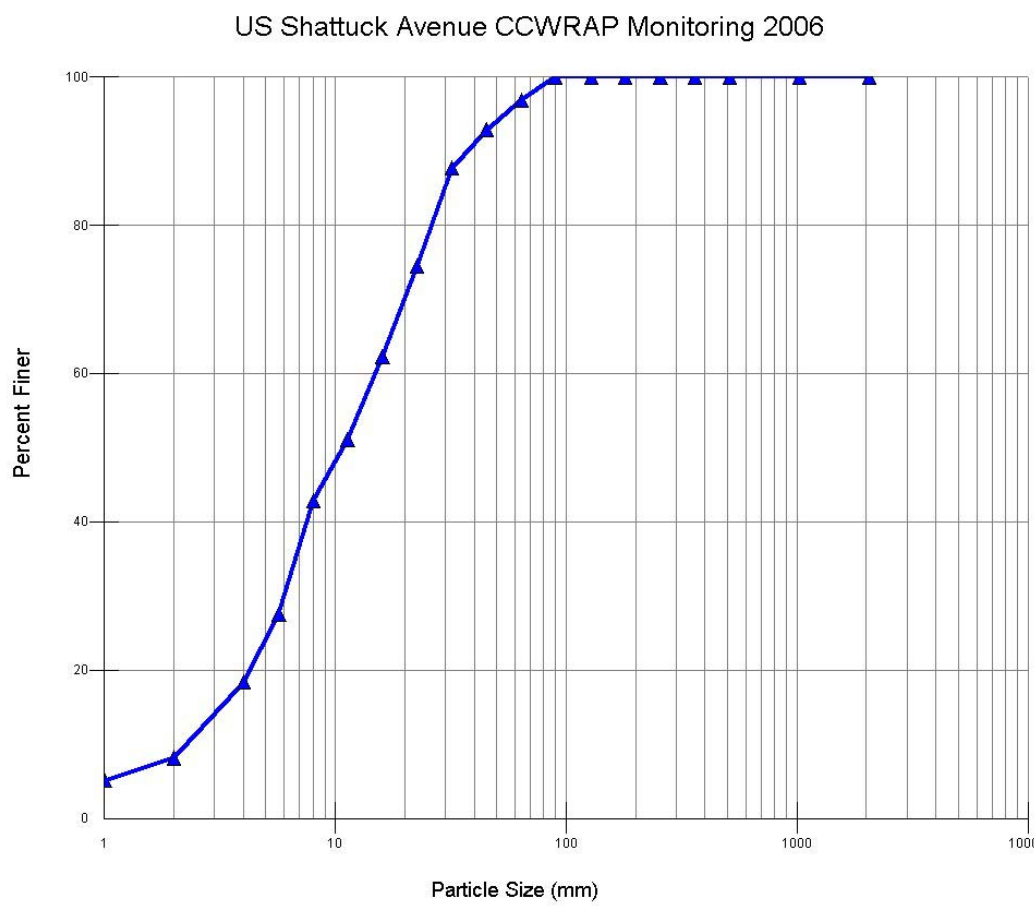
RIVERMORPH PARTICLE SUMMARY

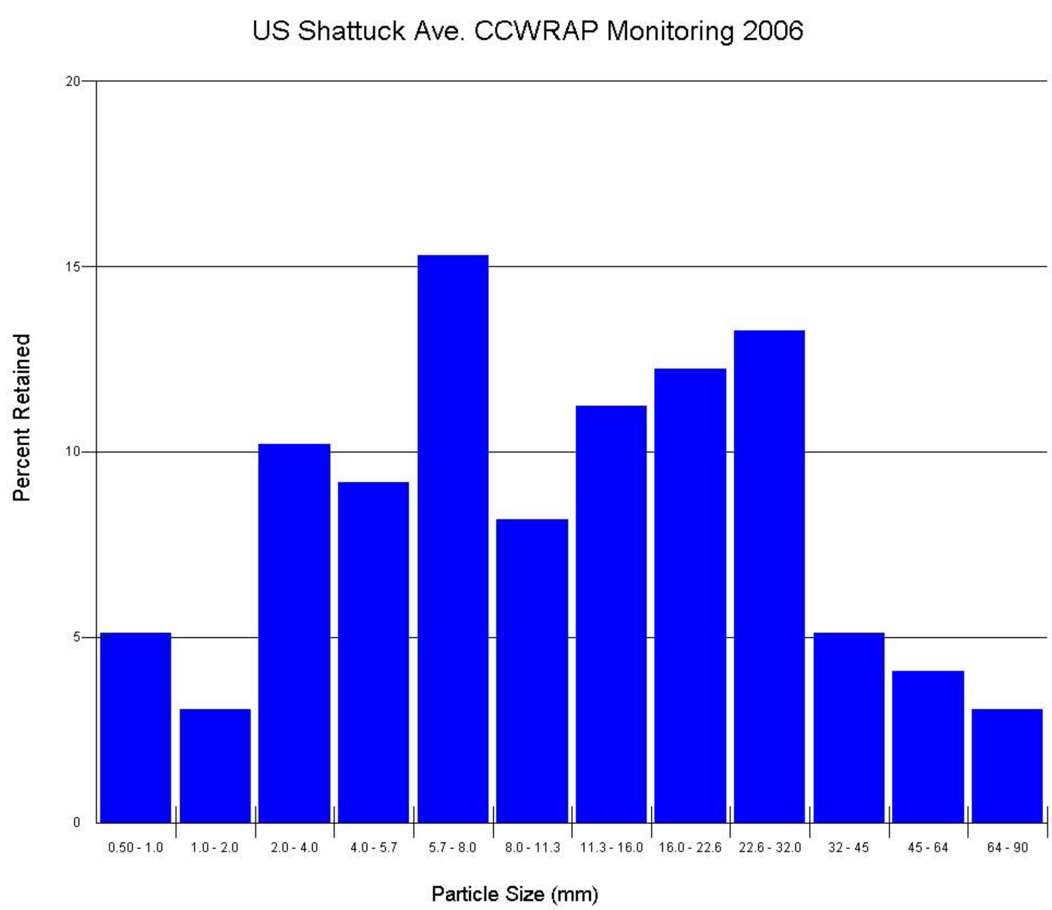
River Name: Codornices Creek
Reach Name: US Shattuck Avenue
Sample Name: CCWRAP Monitoring 2006
Survey Date: 06/08/06

Size (mm)	TOT #	ITEM %	CUM %
0 - 0.062	0	0.00	0.00
0.062 - 0.125	0	0.00	0.00
0.125 - 0.25	0	0.00	0.00
0.25 - 0.50	0	0.00	0.00
0.50 - 1.0	5	5.10	5.10
1.0 - 2.0	3	3.06	8.16
2.0 - 4.0	10	10.20	18.37
4.0 - 5.7	9	9.18	27.55
5.7 - 8.0	15	15.31	42.86
8.0 - 11.3	8	8.16	51.02
11.3 - 16.0	11	11.22	62.24
16.0 - 22.6	12	12.24	74.49
22.6 - 32.0	13	13.27	87.76
32 - 45	5	5.10	92.86
45 - 64	4	4.08	96.94
64 - 90	3	3.06	100.00
90 - 128	0	0.00	100.00
128 - 180	0	0.00	100.00
180 - 256	0	0.00	100.00
256 - 362	0	0.00	100.00
362 - 512	0	0.00	100.00
512 - 1024	0	0.00	100.00
1024 - 2048	0	0.00	100.00
2048 -	0	0.00	100.00

D16 (mm)	3.54
D35 (mm)	6.82
D50 (mm)	10.89
D84 (mm)	29.34
D95 (mm)	54.97
D100 (mm)	90
Silt/Clay (%)	0
Sand (%)	8.16
Gravel (%)	88.78
Cobble (%)	3.06
Boulder (%)	0
Bedrock (%)	0

Total Particles = 98.


US Shattuck Avenue CCWRAP Monitoring 2006
Percent Finer
100
80
60
40
20
0
1
10
100
1000
10000
Particle Size (mm)


US Shattuck Ave. CCWRAP Monitoring 2006
Percent Retained
20
15
10
5
0
0.50 - 1.0
1.0 - 2.0
2.0 - 4.0
4.0 - 5.7
5.7 - 8.0
8.0 - 11.3
11.3 - 16.0
16.0 - 22.6
22.6 - 32.0
32 - 45
45 - 64
64 - 90
Particle Size (mm)

RIVERMORPH PARTICLE SUMMARY

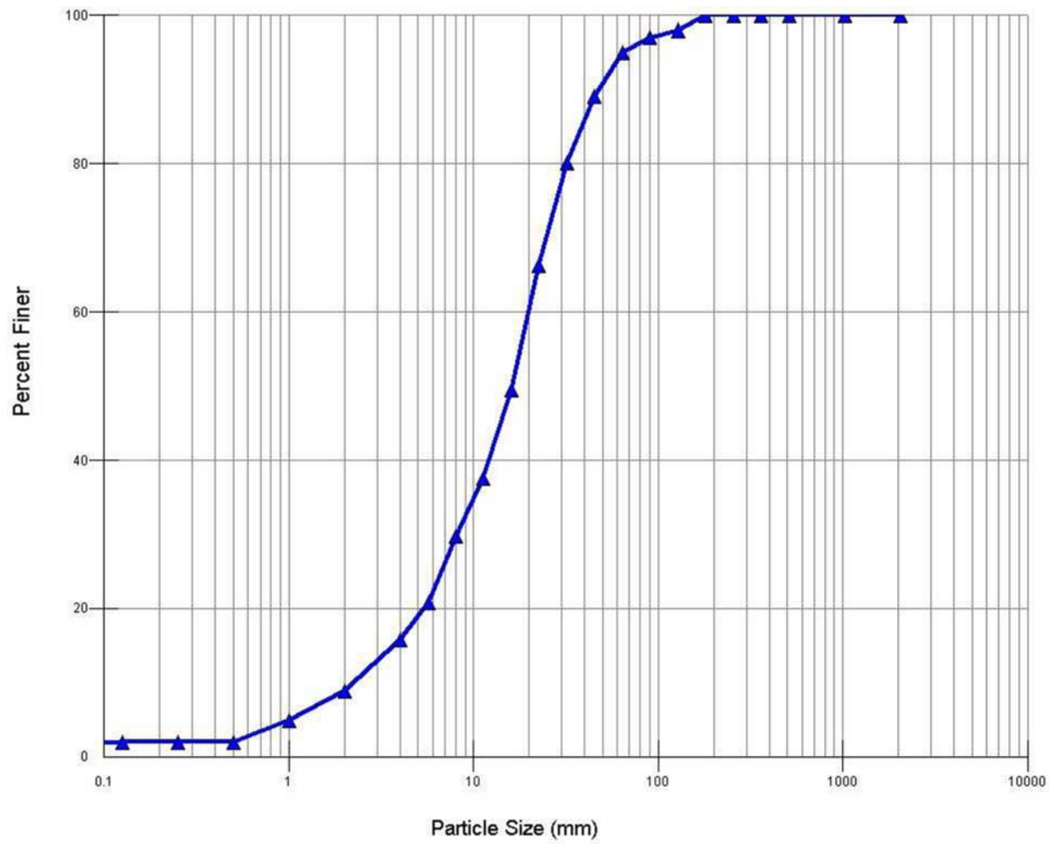
River Name: Codornices Creek
Reach Name: Cod. Creek Park
Sample Name: CCWRAP Monitoring 2006
Survey Date: 06/08/06

Size (mm)	TOT #	ITEM %	CUM %
0 - 0.062	0	0.00	0.00
0.062 - 0.125	2	1.98	1.98
0.125 - 0.25	0	0.00	1.98
0.25 - 0.50	0	0.00	1.98
0.50 - 1.0	3	2.97	4.95
1.0 - 2.0	4	3.96	8.91
2.0 - 4.0	7	6.93	15.84
4.0 - 5.7	5	4.95	20.79
5.7 - 8.0	9	8.91	29.70
8.0 - 11.3	8	7.92	37.62
11.3 - 16.0	12	11.88	49.50
16.0 - 22.6	17	16.83	66.34
22.6 - 32.0	14	13.86	80.20
32 - 45	9	8.91	89.11
45 - 64	6	5.94	95.05
64 - 90	2	1.98	97.03
90 - 128	1	0.99	98.02
128 - 180	2	1.98	100.00
180 - 256	0	0.00	100.00
256 - 362	0	0.00	100.00
362 - 512	0	0.00	100.00
512 - 1024	0	0.00	100.00
1024 - 2048	0	0.00	100.00
2048 -	0	0.00	100.00

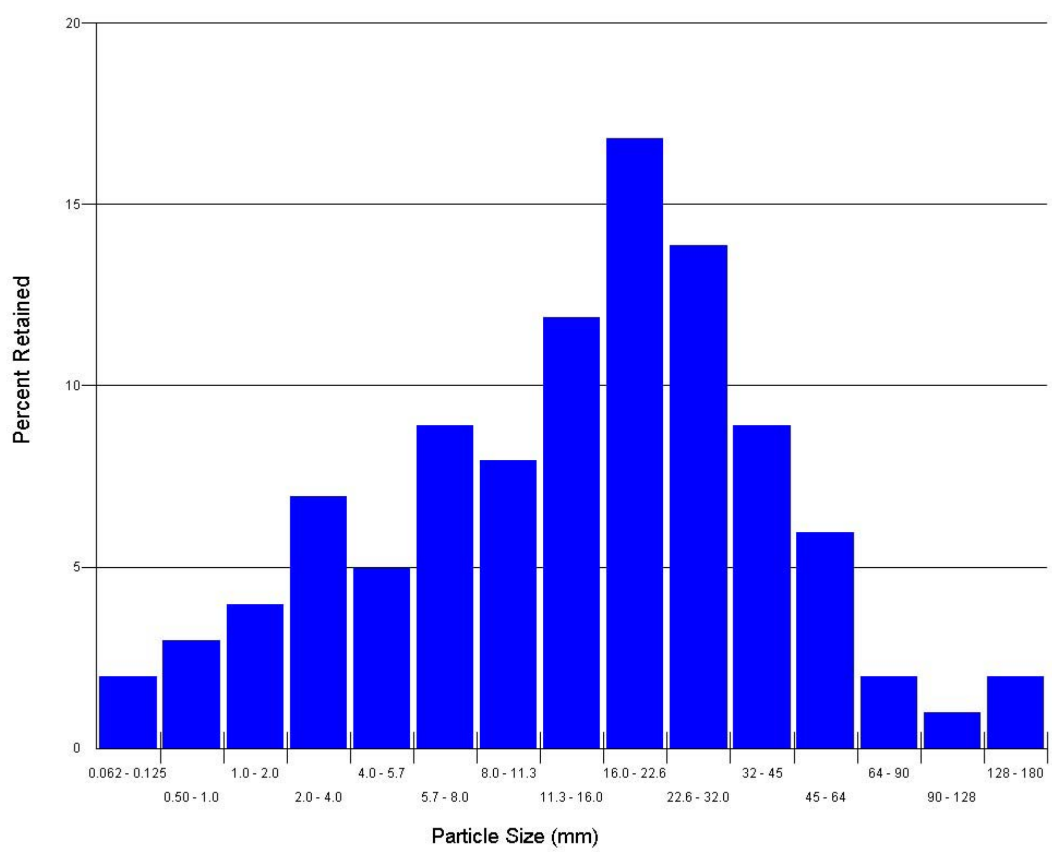
D16 (mm)	4.05
D35 (mm)	10.21
D50 (mm)	16.2
D84 (mm)	37.54
D95 (mm)	63.84
D100 (mm)	180
Silt/Clay (%)	0
Sand (%)	8.91
Gravel (%)	86.14
Cobble (%)	4.95
Boulder (%)	0
Bedrock (%)	0

Total Particles = 101.

Codornices Creek Park CCWRAP Monitoring 2006



Codornices Creek Park CCWRAP Monitoring 2006



Taxa	Tolerance	2nd St	4th St	6th St	10th St	Evelyn	Albina
ARTHROPODA							
INSECTA							
Diptera							
Chironomidae							
Chironominae							
Chironomini	6	21	24	3	2	1	2
Tanytarsini	6	218	174	274	190	78	82
Orthocladiinae	5	192	133	141	172	151	135
Tanypodinae	7						1
Empididae	6						
Tricholinocera	6		1				
Simuliidae							
Simulium	6	16	1	13	6	6	17
Stratiomyidae							
Caloparyphus	7					1	
Tipulidae							
Limonia	6					1	
Tipula	4		1				
Ephemeroptera							
Baetidae							
Baetis	5	19	30	36	72	122	107
Odonata							
Coenagrionidae							
Argia	7				1	4	3
Plecoptera							
Nemouridae							
Malenka	2					1	1
Trichoptera							
Hydroptilidae							
Hydroptila	6	1	2	14	3	13	
Chelicerata							
ARACHNOIDEA							
Acarina							
Hydryphantidae							
Thyadinae	5						1
Lebertioidea	5						1
Lebertiidae							
Lebertia	8			1	1	2	
Sperchontidae							
Sperchon	8	1		1	4	8	5
Crustacea							
MALACOSTRACA							
Amphipoda							
Crangonyctidae							
Crangonyx	4			2			
MOLLUSCA							
GASTROPODA							
Hydrobiidae	8	1	2	1	1	11	10
Physidae							
Physella	8			1	1	1	
Planorbidae							
Menetus	6						1
BIVALVIA							
Pelecypoda							
Sphaeriidae							
Pisidium	8		1			2	3
ANNELIDA							
OLIGOCHAETA	5	31	130	55	53	97	131
Megadrili	5	1	2	1	1	1	1
POLYCHAETA	10		1		1		
PLATYHELMINTHES							
TURBELLARIA							
Tricladida							
Planariidae	4			1		2	
TOTAL SPECIMENS		501	502	544	508	502	501

Benthic Macro Invertebrate taxa, May 2006 Codornices Creek samples and counts per site. Jonathan Lee used the California Standard Taxonomic Effort, which distinguishes most organisms at genus level (italicized here). Orders and higher taxonomic levels appear in bold. Phylla and subphyla are underlined.

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POLYCYCLIC AROMATIC HYDROCARBONS IN CODORNICES CREEK

Introduction and Background

The Codornices Watershed Restoration Action Plan (CCWRAP) is an ongoing effort responding to the request of creekside landowners interested in restoring Codornices Creek stream habitat and its steelhead (*Oncorhynchus mykiss*) population. Original funding for the project resulted in a report (Kier Associates 2004) summarizing CCWRAP Phase 1 activities and available information on the creek's fish population, fish habitat, and identified restoration needs.

CCWRAP 1 included the collection of some water quality, fish, and fish habitat data necessary to develop recommended restoration actions. Recommendations also addressed the collection of additional data necessary to evaluate Codornices Creek fish populations and fish habitat for effective restoration planning. CCWRAP 2 includes a water quality component, focusing on polycyclic aromatic hydrocarbons (PAHs), along with temperature and dissolved oxygen. The purposes of this report are 1) to convey the PAH results; 2) to compare measured concentrations with established water and sediment criteria; and if the criteria are exceeded, 3) to recommend measures that will reduce the concentrations and loads of PAHs to Codornices Creek.

Polycyclic aromatic hydrocarbons are a class of organic compounds consisting of two or more fused benzene rings, sometimes with methyl groups substituted for hydrogen. They are sometimes referred to as the "chicken wire hydrocarbons" because of the linked hexagonal ring structures. There are thousands of different compounds differing in the number and arrangement of rings, and position of substituents on the rings, but about two dozen or so account for most environmental contamination. The molecular structure of the common "light" (2-3 ring) PAHs, and the common “heavy” (4-6 ring) PAHs can be viewed at http://www.nefsc.noaa.gov/nefsc/publications/tm/tm157/tm157struc.htm.

Many PAHs or their metabolites are known to be cytotoxic, mutagenic and/or carcinogenic to aquatic organisms (Eisler, 1987). Water concentrations of PAHs from weathered oil as low as 1 ppb have been found to increase embryo mortality in pink salmon (Heinz et al., 1999).

PAHS can be classified according to origin, as pyrogenic, petrogenic and diagenic. The pyrogenic PAHs result from incomplete combustion of fossil fuel and other organic material; they are found in vehicle emissions, crankcase oil, asphalt, coal tar, creosote, and wood smoke. With 4 or more ring structures, the pyrogenic PAHs are generally more toxic and carcinogenic than the petrogenic PAHs. The mix of pyrogenic PAHs in the environment depends on the starting source material, temperature, and the fuel:air ratio (Benner et al., 1990).

The petrogenic PAHs originate from petroleum products (oil, gasoline, diesel fuel, etc.). They contain a high percentage of naphthalene, and generally consist of 2 or 3 ring structures. The diagenic PAHs are formed by anaerobic decomposition of organic matter in soil or sediment. One of the most common of these is perylene, which can be used as a marker for diagenetic sources (Sanders et al., 2002).

Because the formation of PAHs during combustion is influenced by temperature, ratios of different PAHs can be used to distinguish between pyrogenic, petrogenic and diagenetic sources. A phenanthrene/anthracene ratio of <10 and fluoranthene/pyrene ratio of >1 indicates a pyrogenic source, whereas a phenanthrene/anthracene ratio of >15 and fluoranthene/pyrene ratio of <1 indicates a petrogenic source (Sanders et al., 2002). The source of PAHs may be important information in devising control strategies.

The chemical properties of PAHs and their behavior in the environment vary widely, largely as a function of their molecular weight. Table 1 lists some of the most common PAHs, and their properties. PAHs, especially those of high molecular weight, tend to adsorb onto organic matter and fine sediment, forming a reservoir in the aquatic environment. They bioaccumulate in many invertebrates, increasing the exposure of fish that consume the invertebrates (Johnson et al., 2002). They are generally metabolized by vertebrates, and thus do not accumulate far up the food chain, although PAH metabolites may accumulate in the livers of fish. Linder et al. (1985) give a Biological Concentration Factor (BCF)[1] for 72-h exposure of rainbow trout to anthracene of 4,400 to 9,200; Gerhart and Carlson (1978) give a BCF in liver for 10-day exposure of rainbow trout to Benzo(a)pyrene of 182-920.

There have been a number of efforts to develop water quality and sediment quality criteria for PAHs. Di Toro et al. (2000) developed criteria for water and tissue, based on the compounds’ octanol-water partition coefficient (K_{ow}). The values range from 0.5 mg/l for Dibenz(a,h)anthracene to 530 mg/l for Acenapthylene. De Toro and McGrath (2000) developed criteria for sediments (expressed as μmol/g of organic carbon), and compared their criteria to

[1] BCF is the ratio (unitless) of the concentration of a substance in the test organism to its concentration in the water.

guidelines developed by USEPA and others. Table 1 shows the threshold values for both water and sediment developed by Di Toro and colleagues, expressed as concentration in the organic carbon fraction.

In developing thresholds to protect estuarine fish, Johnson et al. (2002) used “hockey stick” regressions to establish criteria for total PAH threshold effect levels in sediment. They concluded that a sediment quality guideline of 1 ppm (1000 ppb) would protect estuarine fish against several important health effects, including degenerative lesions, spawning inhibition, and reduced egg viability.

Data are available on PAH concentrations in sediments around San Francisco Bay, showing the 85 percentile for concentration for 23 individual PAHs, as well as for “light” (2-3 ring compounds) and “heavy” (4-6 ring compounds) (Gandesbery and Hetzel, 1998). The data for sediments samples with > 40 percent fines and < 40 percent fines are treated separately. The 85th percentile values (that is, the concentration equaled or exceeded in 15 percent of the samples) are shown in Table 1. Some data are also available for stormwater runoff concentrations (Woodward Clyde Consultants, 1991).

POLYCYCLIC AROMATIC HYDROCARBONS: CHARACTERISTICS, AND CRITERIA FOR SEDIMENT AND WATER						
		Sediment				Water
Compound	MW, g/mol	$C_{s,oc}$, µmol/g in Organic Carbon[2]	Threshold Conc. In Organic C, ppm	Sediment ERL, ppb[3]	85th Percentile in SFBay Fine Sed., ppb[4]	Chronic Threshold, ppb[5]
Acenaphthylene	152.20	5.03	770	44.0	31.7	527.7
Naphthalene	128.19	5.09	650	160.0	55.8	322.0
1-Methylnaphthalene	142.20	5.31	760	70.0	12.1	126.7
2-Methylnaphthalene	142.20	5.32	760	16.0	19.4	121.0
Acenaphthene	154.21	5.39	830	---	26.6	95.1
Fluorene	166.20	5.48	910	19.0	25.3	66.2
2,6-Dimethylnaphthalene	156.23	5.56	870	---	12.1	44.0
Anthracene	178.20	5.64	1010	85.3	88	35.6
Phenanthrene	178.20	5.66	1010	240.0	237	32.4
2,3,5-Trimethylnaphthalene	170.26	5.80	990	---	9.8	16.6
Pyrene	202.26	5.83	118	665.0	665	17.2
1-Methylphenanthrene	192.26	5.89	1130	---	31.7	---
Fluoranthene	202.26	5.92	1200	600.0	514	12.2
Benzo[*a*]anthracene	228.29	6.23	142	261.0	244	3.8
Chrysene	228.29	6.25	1430	384.0	289	3.5
Benzo[*a*]pyrene	252.31	6.47	1630	430.0	412	1.6
Perylene	252.31	6.49	1640	---	145	---
Benzo[*e*]pyrene	252.32	6.49	1640	---	294	1.5
Benzo[*b*]fluoranthene	252.32	6.56	1660	---	371	1.1
Benzo[*k*]fluroranthene	252.32	6.58	1660	---	258	---
Benzo[*ghi*]perylene	276.34	6.70	1850	---	310	---
Dibenz[*a,h*]anthracene	278.35	6.82	1900	63.4	32.7	0.5
Indeno[1,2,3-*cd*]pyrene	276.34	6.83	1890	---	382	---
		.				
Total Heavy				1700	3060	
Total Light				552	434	
Total				4022	3390	

[2] Di Toro and McGrath, 2000
[3] Long, et al., 1995. ERL is "Effect Range-Low"
[4] Gandesbury and Hetzel, 1998
[5] Di Toro et al., 2000

Methods

Two water samples were collected during the first major runoff event of fall 2005. Samples were collected in clean laboratory-supplied glass bottles, at the BART crossing, and at 2nd St., at about 8:00 PM on 11/7/05. Sampling virtually coincided with the hydrograph peak. Conductivity was measured at the time of sampling.

On two occasions (11/30/05 and 5/9/06), sediment samples were collected at three sites: 2nd St., 4th St. (in the middle of the restored reach), and just above the railroad culverts, at the lower end of the restored. Samples were taken from lower banks, where fine-grained organic-rich sediment could be found. In the lab, large twigs, leaves and roots were picked out, and the samples were stirred thoroughly, and subdivided. Subsamples were then transferred to laboratory-supplied glass jars, stored on ice, and delivered within 24 hrs to Torrent Laboratory in Milpitas. The remaining portion of each sample was then frozen for subsequent analysis for Total Organic Carbon (TOC) and percent silt plus clay by ETS Laboratory in Petaluma. These parameters are necessary to provide a basis for comparing PAH concentrations with established criteria.

Torrent Laboratory measured the PAH concentrations using Gas Chromatography/Mass Spectrometry (GC/MS; EPA Method 8270C). In order to remove the interference of dissolved organic matter, the samples were cleaned up prior to analysis by Solid Phase Extraction (EPA 3535M). When the sediment samples from 11/30/05 were analyzed, this clean-up method was not available, and the samples had to be diluted, which raised the method detection limit (MDL). When the clean-up method became available, the frozen fall samples were redivided, and sub-samples reanalyzed by Torrent Lab. The reporting limit for the individual PAH compounds is given as 0.020 mg/kg (ppm), or 20 ppb for sediment, and 10 ppb for water.[6]

In addition to the water and sediment samples collected in this project, the State Water Resources Control Board's Surface Water Ambient Monitoring Program (SWAMP; see: http://www.waterboards.ca.gov/swamp/) collected 3 water samples and 1 sediment sample from Codornices Creek in WY 2005. The results for those samples are reported here, along with the TOC and particle size analysis for calculation of the appropriate criteria. The Reporting Limit for the laboratory that is analyzing the SWAMP samples is 0.005 ppb for both sediment and water.

Results and Discussion

The two water samples that we collected in the "first flush" event of November 2005 did not have concentrations exceeding the MDL. The SWAMP samples, however, had detectable levels of a number of compounds. Table 2 shows the results from the SWAMP water samples, compared with the "Chronic Effects Level" established by Long et. al., 1995. None of the measured concentrations come close to the chronic threshold.

[6] 1 mg/kg = 1 part per million (ppm), or 1000 parts per billion (ppb)

Table 2. PAH concentrations in the waters of Codornices Creek. The three samples are from the SWAMP program. The two samples from this study were all below the detection limit. The "Chronic Threshold" shows the water quality criteria of Di Toro et al. (2000). None of the criteria were exceeded in the SWAMP PAH samples.

	Concentration in Water, µg/L			
	Chronic Threshold	1/10/2005	4/12/2005	6/12/2005
Acenaphthene	95.1	0.024	0.026	0.038
Acenaphthylene	527.7	ND	ND	ND
Anthracene	35.6	ND	ND	ND
Benz(a)anthracene	3.8	ND	ND	ND
Benzo(a)pyrene	1.6	ND	ND	ND
Benzo(b)fluoranthene	1.1	ND	ND	0.014
Benzo(e)pyrene	1.5	ND	ND	0.010
Benzo(g,h,i)perylene	---	ND	ND	0.015
Benzo(k)fluoranthene	---	ND	ND	ND
Chrysene	3.5	ND	ND	0.007
Dibenz(a,h)anthracene	0.5	ND	ND	ND
Dimethylnaphthalene, 2,6-	44.0	ND	ND	0.007
Fluoranthene	12.2	ND	0.005	0.018
Fluorene	66.2	0.015	0.013	0.021
Indeno(1,2,3-c,d)pyrene	---	ND	ND	ND
Methylnaphthalene, 1-	126.7	0.036	0.040	0.045
Methylnaphthalene, 2-	121.0	0.046	0.056	0.040
Methylphenanthrene, 1-	---	ND	ND	ND
Naphthalene	322.0	0.361	0.417	0.235
Perylene	---	ND	ND	ND
Phenanthrene	32.4	0.012	0.011	0.025
Pyrene	17.2	ND	ND	0.015
Trimethylnaphthalene, 2,3,5-	16.6	ND	ND	ND

Table 3 shows the PAH concentrations in sediment samples from Codornices Creek. The data include one SWAMP sample, and 6 samples from this study, for 3 locations and two sampling dates. The results are compared with the "Effect Range-Low" criteria developed by Long et al. (1995).

Table 3. PAH concentrations in bed sediment from Codornices Creek, compared with "Effect Range-Low" criteria of Long et al. (1995).

		Sediment Concentration, ppb dry wt.						
		4/12/05	11/30/2005			5/9/2006		
	Effect Range-Low	SWAMP	2nd St.	4th St.	RR Culverts	2nd St.	4th St.	RR Culverts
Acenaphthene	---	4.92	ND	ND	ND	ND	ND	ND
Acenaphthylene	44.0	2.00	ND	ND	ND	ND	ND	ND
Anthracene	85.3	11.6	ND	ND	ND	ND	27.0	ND
Benz(a)anthracene	261.0	25.0	22.0	ND	ND	ND	87.0	ND
Benzo(a)pyrene	430.0	29.40	21.00	ND	ND	ND	60.00	ND
Benzo(b)fluoranthene	---	43.10	31.00	ND	ND	ND	50.00	ND
Benzo(e)pyrene	---	32.50	--	--	--	--	--	--
Benzo(g,h,i)perylene	---	38.70	ND	ND	ND	ND	33.00	ND
Benzo(k)fluoranthene	---	14.80	ND	ND	ND	ND	48.00	ND
Chrysene	384.0	28.0	40.0	ND	ND	21.0	98.0	ND
Dibenz(a,h)anthracene	63.4	11.4	ND	ND	ND	ND	ND	ND
Dimethylnaphthalene, 2,6-	---	3.44	--	--	--	--	--	--
Fluoranthene	600.0	65.10	72.0	ND	25.00	27.00	180.00	23.00
Fluorene	19.0	5.83	ND	ND	ND	ND	ND	ND
Indeno(1,2,3-c,d)pyrene	---	29.60	ND	ND	ND	ND	42.00	ND
Methylnaphthalene, 1-	70.0	3.54	ND	ND	ND	ND	ND	ND
Methylnaphthalene, 2-	16.0	6.68	ND	ND	ND	ND	ND	ND
Methylphenanthrene, 1-	---	5.54	--	--	--	--	--	--
Naphthalene	160.0	9.76	62.0	ND	ND	ND	ND	ND
Perylene	---	15.50	--	--	--	--	--	--
Phenanthrene	240.0	35.10	28.0	ND	ND	ND	82.00	ND
Pyrene	665.0	71.20	96.0	21.00	27.00	31.00	160.00	21.00
Trimethylnaphthalene, 2,3,5-	---	ND	--	--	--	--	--	--

Since PAHs are relatively insoluble in water, but soluble in lipids, the biological impact of PAHs in sediment depends on their individual behavior. The most important variable characterizing this behavior is the octanol-water partition coefficient (K_{ow}), that is, tendency of a compound to dissolve preferentially in octanol in a two-phase water-octanol system at equilibrium. Di Toro et al. (2000) used this variable, the log of which is directly related to molecular weight, to derive biological criteria for the concentration of PAHs in the organic carbon fraction of sediment. Table 4 shows the concentrations of PAHs in the organic carbon fraction of the Codornices Creek samples, compared with the Di Toro criteria. Note that all of the measured concentrations in the organic carbon fraction of the Codornices Creek sediments are two to three orders of magnitude below the Di Toro criteria.

Table 4. PAH concentrations in the organic carbon fraction of sediment from Codornices Creek, compared with the criteria developed by Di Toro et al. (2000).

		Concentration in Organic Carbon Fraction, ppm						
		4/12/05	11/30/2005			5/9/2006		
	Criteria, ppm in OC	SWAMP	2nd St.	4th St.	RR Culverts	2nd St.	4th St.	RR Culverts
Acenaphthene	831.2	0.75	ND	ND	ND	ND	ND	ND
Acenaphthylene	765.6	0.30	ND	ND	ND	ND	ND	ND
Anthracene	1005.0	1.76	ND	ND	ND	ND	0.42	ND
Benz(a)anthracene	1422.2	3.79	0.31	ND	ND	ND	1.35	ND
Benzo(a)pyrene	1632.4	4.45	0.29	ND	ND	ND	0.93	ND
Benzo(b)fluoranthene	1655.2	6.53	0.43	ND	ND	ND	0.78	ND
Benzo(e)pyrene	1637.6	4.92	--	--	--	--	--	--
Benzo(g,h,i)perylene	1851.5	5.86	ND	ND	ND	ND	0.51	ND
Benzo(k)fluoranthene	1660.3	2.24	ND	ND	ND	ND	0.74	ND
Chrysene	1426.8	4.24	0.55	ND	ND	0.37	1.52	ND
Dibenz(a,h)anthracene	1898.3	1.73	ND	ND	ND	ND	ND	ND
Dimethylnaphthalene, 2,6-	868.6	0.52	--	--	--	--	--	--
Fluoranthene	1197.4	9.86	1.00	ND	0.28	0.48	2.79	0.45
Fluorene	910.8	0.88	ND	ND	ND	ND	ND	ND
Indeno(1,2,3-c,d)pyrene	1887.4	4.48	ND	ND	ND	ND	0.65	ND
Methylnaphthalene, 1-	755.1	0.54	ND	ND	ND	ND	ND	ND
Methylnaphthalene, 2-	756.5	1.01	ND	ND	ND	ND	ND	ND
Methylphenanthrene, 1-	1132.4	0.84	--	--	--	--	--	--
Naphthalene	652.5	1.48	0.86	ND	ND	ND	ND	ND
Perylene	1637.5	2.35	--	--	--	--	--	--
Phenanthrene	1008.6	5.32	0.39	ND	ND	ND	1.27	ND
Pyrene	1179.2	10.79	1.33	0.23	0.30	0.55	2.48	0.41
Trimethylnaphthalene, 2,3,5-	987.5	ND	--	--	--	--	--	--

It is useful to compare the concentrations of PAHs in Codornices Creek sediment not only with established sediment criteria, but also with ambient sediment concentrations elsewhere in the Bay Area. Table 5 shows the Codornices Creek concentrations in the fine sediment fraction (< 0.0625 mm), that is, the silt plus clay fraction. These can be compared with the 85th percentile for PAHs in the sediment in San Francisco Bay (Gandesbery and Hetzel, 1998). In the SWAMP sample, 8 individual PAHs equaled or exceeded the 85th percentile, and in our samples, one PAH exceeded the 85th percentile. The exceedences are indicated with shading in table 5.

Table 5. Codornices PAH concentrations in the fine sediment fraction compared with the 85th percentile concentrations in San Francisco Bay sediment, from Gandesbery and Hetzel (1998).

	85th Percentile in SF Bay Fine Sediment	PAH Concentration in Sediment, ppb 4/12/05 SWAMP	11/30/2005 2nd St	11/30/2005 4th St.	11/30/2005 RR Culverts	5/9/2006 2nd St.	5/9/2006 4th St.	5/9/2006 RR Culverts
Acenaphthene	27	28	ND	ND	ND	ND	ND	ND
Acenaphthylene	32	11	ND	ND	ND	ND	ND	ND
Anthracene	88	67	ND	ND	ND	ND	33	ND
Benz(a)anthracene	244	144	54	ND	ND	ND	107	ND
Benzo(a)pyrene	412	169	52	ND	ND	ND	74	ND
Benzo(b)fluoranthene	371	248	76	ND	ND	ND	61	ND
Benzo(e)pyrene	294	187	--	--	--	--	--	--
Benzo(g,h,i)perylene	310	222	ND	ND	ND	ND	41	ND
Benzo(k)fluoranthene	258	85	ND	ND	ND	ND	59	ND
Chrysene	289	161	99	ND	ND	73	120	ND
Dibenz(a,h)anthracene	33	66	ND	ND	ND	ND	ND	ND
Dimethylnaphthalene, 2,6-	12	20	--	--	--	--	--	--
Fluoranthene	514	374	178	ND	58	94	221	28
Fluorene	25	34	ND	ND	ND	ND	ND	ND
Indeno(1,2,3-c,d)pyrene	382	170	ND	ND	ND	ND	52	ND
Methylnaphthalene, 1-	12	20	ND	ND	ND	ND	ND	ND
Methylnaphthalene, 2-	19	38	ND	ND	ND	ND	ND	ND
Methylphenanthrene, 1-	32	32	--	--	--	--	--	--
Naphthalene	56	56	153	ND	ND	ND	ND	ND
Perylene	145	89	--	--	--	--	--	--
Phenanthrene	237	202	69	ND	ND	ND	101	ND
Pyrene	665	409	237	31	63	108	197	26
Trimethylnaphthalene, 2,3,5-	10	ND	--	--	--	--	--	--
Total PAHs	3390	2832	917	31	121	276	1066	54

Because the mixture of PAHs in a given sample is influenced by the temperature at which they are produced, it is possible to infer from a sample whether the source is from combustion (pyrogenic) or from fossil fuel (petrogenic) (Sanders et al., 2002). Table 6 shows the ratios for phenanthrene: anthracene and fluoranthene: pyrene that are typical of both sources. For several of the samples, at least one of the constituents in the ratios was below the detection limit, so a ratio could not be calculated. For the fluoranthene: pyrene ratio, the break between pyrogenic and petrogenic is 1.0, and the values are clustered around this value. For the phenanthrene: anthracene ratio that we have for two samples, the values are well below the break, indicating a predominant pyrogenic source. For all but one of the samples, the total naphthalenes are low or non-detectable, indicating that spilled gasoline is not a significant source. The SWAMP water sample of 6 /12/05 was an exception; it showed a high percentage of napthalenes, but the fluoranthene:pyrene ratio was >1, indicating a pyrogenic source. In short, the results suggest that pyrogenic sources (atmospheric deposition of particles from diesel exhaust, wood smoke, burned or heated crankcase oil, and runoff from asphalt) are more important than petrogenic sources (spilled gasoline), but the latter may be episodically important. The pyrogenic material most likely enters the creek through wash-off of atmospheric deposition onto the land surface, rather than point-source spills.

It is worth noting that some PAHs are diagenetic, that is, they occur naturally as a result of organic matter decomposition in anaerobic environments. One of these is perylene, which can be used as a marker of diagenetic sources (Sanders et al., 2002). Unfortunately, Torrent Laboratory did not include perylene in its list of analytes, but in the SWAMP sediment sample, perylene accounted for 3 percent of the total PAHs; it was not detected in the 3 SWAMP water samples. The very limited data do not suggest that diagenetic sources are significant in Codornices Creek relative to the petrogenic and pyrogenic sources.

Table 6. Indicators of PAH origins in water and sediment of Codornices Creek. Phen/Ant is the Phenanthrene:Anthracene ratio and Flu/Pyr is the fluoranthene: pyrene ratio.

	Date	Matrix	Phen/Ant ratio	Flu/Pry ratio	Pct. Total Naph
Pyrogenic			<10	>1	low
Petrogenic			>15	<1	high
SWAMP	4/12/05	Sediment	3.0	0.91	5.9
	6/12/05	Water	--	1.22	66.8
2nd St.		Sediment	--	0.75	16.7
4th St.		Sediment	--	--	ND
RR Culverts	11/30/05	Sediment	--	0.93	ND
2nd St.		Sediment	--	0.87	ND
4th St.		Sediment	3.0	1.13	ND
RR Culverts	5/9/06	Sediment	--	1.10	ND

<u>Summary and Conclusions</u>

In order to determine whether or not the concentrations of PAHs in Codornices Creek are likely to be damaging to aquatic organisms, we sampled water and sediment from the creek. Two water samples from an early runoff event in November 2005, and six sediment samples from three locations and two dates (November and May) were analyzed for 18 PAH compounds. The sediment samples were also analyzed for total organic carbon (TOC) and percent fines (silt plus clay), in order to provide a basis for comparison with published sediment quality criteria. In addition, data from the Regional Water Quality Control Board's SWAMP program (three water samples and one sediment sample) were considered in this study.

We found no exceedences for either water or sediment of the published quality criteria, although concentrations of some compounds in the sediment of creek are high relative the sediment samples from San Francisco Bay. The mix of compounds identified in Codornices Creek suggests a primarily pyrogenic source, with occasional episodic input from petroleum sources. The likely pyrogenic sources include vehicle emissions, runoff from fresh asphalt, used crankcase oil, wood smoke and creosote.

It must be recognized that our sample size is very small, and absence of evidence of a problem is not evidence of absence of a problem. We cannot rule out the possibility that PAHs are an episodic problem for aquatic life in Codornices Creek. To identify exceedences of water and sediment quality criteria, however, might require a much more intensive (and costly) sampling program. Such a program does not seem warranted at this time. Future work on water quality problems in Codornices Creek should focus on parameters that are now known to be a problem, including temperature and dissolved oxygen, as well as chloramines associated with accidental discharge municipal water.

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Crew	Date	Time	Station	Temp_C	pH	Cond (uS/mg)	DO (mg/l)
EG01	9/15/2005	6:52	COD-020	14.9	7.7	670	4.48
EG01	9/15/2005	6:42	COD-060	14.2	7.9	640	8.08
EG01	9/15/2005	6:24	COD-080	14	8.1	630	8.42
GR01	9/22/2005	6:45	COD-020	15.3	7.8	610	3.67
GR01	9/22/2005	13:37	COD-020	18	8	560	7.71
GR01	9/22/2005	7:38	COD-030	15.2	8.1	590	6.5
GR01	9/22/2005	13:47	COD-030	16.6	8	570	7.7
GR01	9/22/2005	7:23	COD-040	14.4	8	580	7.2
GR01	9/22/2005	7:00	COD-050	14.4	8.2	560	7.55
GR01	9/22/2005	14:50	COD-050	16.9	8.5	560	7.5
GR01	9/22/2005	6:30	COD-060	14.7	8	560	7.62
GR01	9/22/2005	6:15	COD-080	14.5	8.2	540	9.45
DD01	9/29/2005	6:47	COD-020	14.8	**7.4**	700	3.94
DD01	9/29/2005	7:10	COD-030	14.8	7.8	680	6.52
DD01	9/29/2005	7:25	COD-050	13.8	8.1	650	8.14
DD01	9/29/2005	7:37	COD-060	14.4	8.1	660	7.8
DD01	9/29/2005	7:50	COD-080	14.2	8.4	640	9.32
DD02	10/6/2005	6:34	COD-020	13.3	7.4	610	4.58
DD02	10/6/2005	6:48	COD-030	14	**7.7**	600	6.86
DD02	10/6/2005	6:17	COD-040	13.3	8	540	8.32
DD02	10/6/2005	7:22	COD-050	13.7	7.6	560	7.47
DD02	10/6/2005	7:07	COD-060	13.4	8	520	8.73
EG02	10/14/2005	6:51	COD-030	14.5	7.8	670	7.56
EG02	10/14/2005	6:37	COD-050	13.6	8	630	9.13
EG02	10/14/2005	6:28	COD-060	14.1	7.9	640	8.36
EG02	10/14/2005	7:04	COD-080	13.7	7.6	640	4.84
EG02	10/14/2005	6:15	COD-080	14	8	590	8.92
DD03	10/20/2005	6:45	COD-020	15	7.7	670	3.69
DD03	10/20/2005	7:00	COD-030	15.2	7.9	670	6.16
DD03	10/20/2005	6:25	COD-050	14.5	8.2	610	7.69
DD03	10/20/2005	7:35	COD-060	14.6	8.1	620	7.06
DD03	10/20/2005	7:20	COD-080	14.5	8.2	600	8.01
DD04	10/27/2005	6:55	COD-020	13.4	7.6	540	3.91
DD04	10/27/2005	6:40	COD-030	13.9	7.6	540	6.16
DD04	10/27/2005	6:25	COD-050	13.2	7.8	480	8.38
DD04	10/27/2005	7:35	COD-060	13.5	8	560	7.64
DD04	10/27/2005	7:20	COD-080	13.4	8.1	580	9.59
DD05	11/3/2005	6:20	COD-020	11.8	7.8	660	5.26
DD05	11/3/2005	6:05	COD-030	12.6	8	620	7.13
DD05	11/3/2005	5:55	COD-050	12	8.1	560	8.75
DD05	11/3/2005	6:35	COD-060	12.7	8.2	630	8.15
DD05	11/3/2005	6:55	COD-080	12.5	8.4	610	9.41
DD06	11/10/2005	6:15	COD-020	13.2	7.7	600	6.68
DD06	11/10/2005	6:00	COD-030	13.7	7.8	600	7.14
DD06	11/10/2005	5:40	COD-050	13.2	8	540	8.8
DD06	11/10/2005	6:53	COD-060	13.5	8	600	8.2
DD06	11/10/2005	6:35	COD-080	13.5	8.2	590	9.53
EG21	7/14/2006	5:10	COD-020	17.0	7.8	690	3.88
EG21	7/14/2006	5:14	COD-030	16.3	8.0	720	7.44
EG21	7/14/2006	5:26	COD-040	15.7	8.1	700	8.32
EG21	7/14/2006	5:00	COD-050	15.7	8.1	690	7.15
EG21	7/14/2006	5:35	COD-060	15.6	8.3	670	8.59
EG21	7/14/2006	5:45	COD-080	15.5	8.3	680	9.07
DD21	7/21/2006	5:50	COD-020	17.9	7.7	720	2.92

Crew	Date	Time	Station	Temp_C	pH	Cond (uS/mg)	DO (mg/l)
DD21	7/21/2006	5:38	COD-030	17.4	8.0	730	6.94
DD21	7/21/2006	5:25	COD-040	17.0	8.0	720	7.50
DD21	7/21/2006	5:10	COD-050	16.8	7.8	700	6.54
DD21	7/21/2006	6:05	COD-060	16.7	8.1	720	7.98
DD21	7/21/2006	6:17	COD-080	16.7	8.2	690	8.28
DD22	7/28/2006	5:19	COD-020	17.3	7.4	670	3.45
DD22	7/28/2006	5:28	COD-030	16.8	7.5	700	7.37
DD22	7/28/2006	5:37	COD-040	16.2	7.7	700	8.00
DD22	7/28/2006	5:12	COD-050	16.2	7.8	680	7.15
DD22	7/28/2006	5:48	COD-060	16.1	7.7	660	8.41
DD23	8/4/2006	5:51	COD-020	16.5	7.8	690	3.34
DD23	8/4/2006	5:42	COD-030	16.2	7.9	700	7.42
DD23	8/4/2006	5:27	COD-040	15.5	7.9	660	8.15
DD23	8/4/2006	5:15	COD-050	15.4	7.6	630	7.26
DD23	8/4/2006	6:05	COD-060	15.4	8.1	680	8.54
DD23	8/4/2006	6:17	COD-080	15.3	8.2	680	8.42
KR21	8/11/2006	5:06	COD-020	17.2	7.7	670	3.28
KR21	8/11/2006	5:17	COD-030	16.9	7.7	670	7.30
KR21	8/11/2006	5:22	COD-040	16.2	7.9	660	7.78
KR21	8/11/2006	5:32	COD-050	16.1	7.9	670	6.50
KR21	8/11/2006	5:39	COD-060	16.1	7.9	640	8.41
KR21	8/11/2006	5:45	COD-080	15.9	7.9	650	8.30
KR22	8/18/2006	2:17	COD-020	17.2	7.9	660	3.87
KR22	8/18/2006	2:21	COD-030	16.6	7.9	660	8.42
KR22	8/18/2006	2:28	COD-040	15.9	8.1	630	7.95
KR22	8/18/2006	2:32	COD-050	15.5	8.1	640	6.22
KR22	8/18/2006	2:39	COD-060	15.6	8.2	670	8.53
EG22	8/23/2006	5:39	COD-020	16.4	7.9	680	4.24
EG22	8/23/2006	5:53	COD-030	15.9	7.9	670	7.34
EG22	8/23/2006	6:04	COD-040	15.1	8.2	690	9.10
EG22	8/23/2006	6:12	COD-050	15.0	8.2	670	8.24
EG22	8/23/2006	6:23	COD-060	15.1	8.3	670	9.34
EG22	8/23/2006	6:30	COD-080	14.9	8.4	620	9.63
DD24	8/31/2006	6:18	COD-020	15.8	8.1	630	3.74
DD24	8/31/2006	6:05	COD-030	15.9	8.3	720	2.06
DD24	8/31/2006	5:53	COD-040	14.9	8.4	640	8.70
DD24	8/31/2006	5:42	COD-050	14.5	8.1	610	8.60
DD24	8/31/2006	6:34	COD-060	14.9	8.4	650	8.93
DD24	8/31/2006	6:44	COD-080	14.8	8.4	650	9.06
DD25	9/7/2006	6:15	COD-020	16.1	**8.2**	630	4.60
DD25	9/7/2006	6:05	COD-040	14.9	8.5	610	8.70
DD25	9/7/2006	5:50	COD-050	14.8	8.2	580	8.06
DD25	9/7/2006	6:35	COD-060	14.7	8.4	600	9.02
DD25	9/7/2006	6:50	COD-080	14.6	8.4	590	9.05
DD26	9/21/2006	6:25	COD-020	15.3	7.8	630	4.82
DD26	9/21/2006	6:10	COD-040	14.6	8.3	670	8.32
DD26	9/21/2006	5:55	COD-050	14.2	**8.5**	620	8.36
DD26	9/21/2006	6:40	COD-060	14.7	8.3	680	8.81
DD26	9/21/2006	6:50	COD-080	14.5	8.3	670	9.29
DD27	9/28/2006	6:20	COD-020	15.5	8.0	660	5.24
DD27	9/28/2006	6:05	COD-040	14.4	8.3	590	8.58
DD27	9/28/2006	5:55	COD-050	14.2	8.4	560	9.02
DD27	9/28/2006	6:35	COD-060	14.2	8.3	660	8.88
DD27	9/28/2006	6:48	COD-080	14.2	8.4	660	9.17

Crew	Date	Time	Station	Temp_C	pH	Cond (uS/mg)	DO (mg/l)
DD28	10/5/2006	6:25	COD-020	14.9	8.2	400	4.77
DD28	10/5/2006	6:15	COD-040	14.6	8.5	210	10.23
DD28	10/5/2006	6:00	COD-050	14.6	8.6	210	10.16
DD28	10/5/2006	6:45	COD-060	14.4	8.2	210	10.33
DD28	10/5/2006	6:55	COD-080	14.3	8.3	210	10.45
DD29	10/12/2006	6:45	COD-020	14.4	8.2	650	5.37
DD29	10/12/2006	6:30	COD-040	13.7	8.4	660	8.84
DD29	10/12/2006	6:20	COD-050	13.3	8.7	630	9.20
DD29	10/12/2006	7:00	COD-060	13.9	8.3	680	8.94
DD29	10/12/2006	7:10	COD-080	13.7	8.4	670	9.22
DD30	10/19/2006	6:40	COD-020	13.3	8.1	630	5.96
DD30	10/19/2006	6:25	COD-040	12.6	8.3	620	8.96
DD30	10/19/2006	6:15	COD-050	12.2	8.7	600	9.31
DD30	10/19/2006	6:55	COD-060	13.0	8.3	630	9.41
DD30	10/19/2006	7:08	COD-080	12.6	8.3	660	9.76
DD31	10/26/2006	6:55	COD-020	11.7	7.7	630	6.44
DD31	10/26/2006	6:45	COD-040	11.8	8.1	610	8.57
DD31	10/26/2006	6:35	COD-050	11.0	8.4	560	9.64
DD31	10/26/2006	7:10	COD-060	12.4	7.9	650	9.30
DD31	10/26/2006	7:20	COD-080	12.2	8.1	620	9.55
DD32	11/2/2006	6:00	COD-020	13.7	8.1	560	7.46
DD32	11/2/2006	5:50	COD-040	13.9	8.3	450	9.32
DD32	11/2/2006	5:40	COD-050	14.0	8.4	420	9.57
DD32	11/2/2006	6:15	COD-060	14.0	8.3	430	9.32
DD32	11/2/2006	6:27	COD-080	14.0	8.3	420	9.62