■ Interagency Ecological Program for the San Francisco Estuary ■

IEP NEWSLETTER

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Of Interest to Managers

Pete Hrodey (USFWS), Pete_Hrodey@fws.gov

This issue's Quarterly Highlights includes updates on water project operations in the Delta as well as egg production and other activities at the delta smelt Fish Conservation and Culture Lab. This section also includes summaries of the Delta Juvenile Fish Monitoring Program and the first spring Kodiak trawl survey for 2008.

Kate Le (DWR) and Andy Chu (DWR) summarize Central Valley Project (CVP) and State Water Project (SWP) operations in the Delta for the last three months of Water Year 2007 and the first three months of WY 2008. Both periods were dry compared to the corresponding periods in WY2006. During July-September 2007, the CVP's Jones Pumping Plant diverted a comparatively steady 125 m^3 s^{-1}, whereas the SWP pumping ranged between 125 and 200 m^3 s^{-1}. SWP pumping increased from mid-July through August under its Joint Point of Diversion agreement with the CVP, whereas SWP pumping was reduced during September in part to reduce Delta salinity. Project operations during October-December 2007 successfully achieved all applicable Bay-Delta water quality standards. In late December, the projects began restricting exports in accordance with the Interim Remedial Order issued by Judge Wanger to protect delta smelt.

Theresa Rettinghouse (UC Davis) reports that the Fish Conservation and Cultural Lab experienced successful strip spawning during Spring 2007. The Lab also initiated family group and single pair matings for genetic studies. Because of the extremely low number of delta smelt collected during the fall mid-water trawl surveys in 2007, no wild fish were collected this spring. Consequently, the Lab will use 2-year old natural origin fish collected during the fall of 2006 as broodstock for the 2008 hatchery population. Spawning of wild delta smelt began some two months earlier this year compared to 2007. For more details, visit the Lab's new website at www.fishconservation.org.

Jason Hanni (USFWS) reports the results of the Delta Juvenile Fish Monitoring Program for July through September 2007. Trawling was conducted three times a week in the San Joaquin River at Mossdale and at Sherwood Harbor in the Sacramento River. Sampling at Chipps Island was suspended during this period to avoid taking any delta smelt. During the same period, 569 beach seine samples were collected at 52 stations, mostly in the lower Sacramento and San Joaquin rivers and in the Delta. Julio Adib-Samii (DFG) summarizes the delta smelt catch for the first Spring Kodiak Trawl survey of the year conducted January 7 – 11, 2008. Of the 132 individuals caught, 60% were concentrated in the lower Sacramento River near Decker Island and 21% were collected in the Sacramento Deep Water Ship Channel. Fish of both sexes were on average longer than at the same time last year and appeared to be healthier with ample fat reserves and full stomachs. None had mature gonads.

This issue's Contributed Papers section features a series of short articles written and reviewed by UC Davis students enrolled in a course entitled *Hydrology of San Francisco Bay and Delta* taught by Dr. David Schoellhamer of the US Geological Survey's Sacramento District Office. The articles compare hydrologic and water quality conditions in the Bay-Delta catchment during water years 2006 and 2007. Kara Carr's summary of rainfall and snow water equivalent data documents how much wetter than normal 2006 was, whereas 2007 was a relatively dry year. Kristy Ross describes how flows and reservoir storage in the Sacramento River catchment differed between these two years and how they compared with historic conditions. Matt Zelin and Jimmy Pan provide similar analyses for flows in the San Joaquin River and Bay area streams, respectively. David Rheinheimer's analysis of diversions from the Delta indicates that diversions were generally higher in 2006 than in 2007 and that total exports during both years were higher than the 1995-2007 average. In June 2007, pumping at the SWP facility ceased altogether to minimize take of delta smelt. Erik Loboschefsky's analysis of tidally-averaged water flow data for the Delta documents generally higher net seaward flows during 2006. Nevertheless, flows in Old and Middle rivers during July-October 2006 were below normal.

Christina Connell documents how coastal upwelling and water temperature 18 nautical miles offshore from the Golden Gate differed between 2006 and 2007. Upwelling during both years was generally stronger than historically, whereas mean sea surface temperature was warmer than usual during 2006 and cooler than the usual in 2007. Tess Weathers provides a summary of meteorological conditions at three stations in the Bay area during 2006 and 2007. Her analysis shows considerable temporal and spatial variation in barometric pressure, wind speed and wind direction. Nina Noujdina's analysis of hourly water level data for six stations in the Bay documents generally higher levels during 2006 than 2007. Differences between the two years were greatest at the most landward station (Port Chicago) and smallest at the South Bay stations. Erin Hestir documents how salinity in the Bay responded to the higher flow conditions in 2006. Salinity was generally lower at all stations in 2006, whereas vertical stratification was higher in 2006. Jason White reports that suspended sediment concentration throughout the Bay was lower than average in 2007. Xizao Yang's analysis of surface water temperature along the axis of the estuary documents lower temperatures at most stations during 2007. The exception was South Bay, where temperatures were warmer during 2007. Mary Cheng describes how phytoplankton biomass (as measured by chlorophyll concentration) varied among the main subembayments of the Bay and how conditions in 2006 and 2007 differed from each other and from historical values. Chlorophyll concentration in South Bay was generally higher than average during both years.

IEP Quarterly Highlights

DELTA WATER PROJECT OPERATIONS (July through September 2007)

Kate Le (DWR), kle@water.ca.gov

During the July through September 2007 reporting period, San Joaquin River flow ranged between 25 and 37 cubic meters per second (883 cfs and 1,300 cfs), Sacramento River flow ranged between 340 and 600 cubic meters per second (12,000 cfs to 21,186 cfs), and the Net Delta Outflow Index (NDOI) ranged between 70 and 220 cubic meters per second (2,472 cfs and 7,768 cfs) as shown in Figure 1. San Joaquin River flow was stable and low during this period due to dry conditions. Sacramento and NDOI flow patterns were consistent and overall had similar highs and lows, but differ by as low as 236 cubic meters per second and as high as 420 cubic meters per second as shown in Figure 1. Sacramento flows were much higher than San Joaquin. However, all the rivers and outflow levels were lower this year compared to the previous year as a result of a dry year condition.

Exports during the July through September 2007 period were typical at both water projects, but more stable at CVP than SWP. The CVP pumping was approximately 125 cubic meters per second throughout the period, whereas SWP pumping fluctuated between 125 and 200 cubic meters per second. The increased pumping during mid-July through late August at SWP was for joint point of diversion. The SWP reduced exports in late August through September due to salinity concerns in the Delta and low demands from the water contractors.

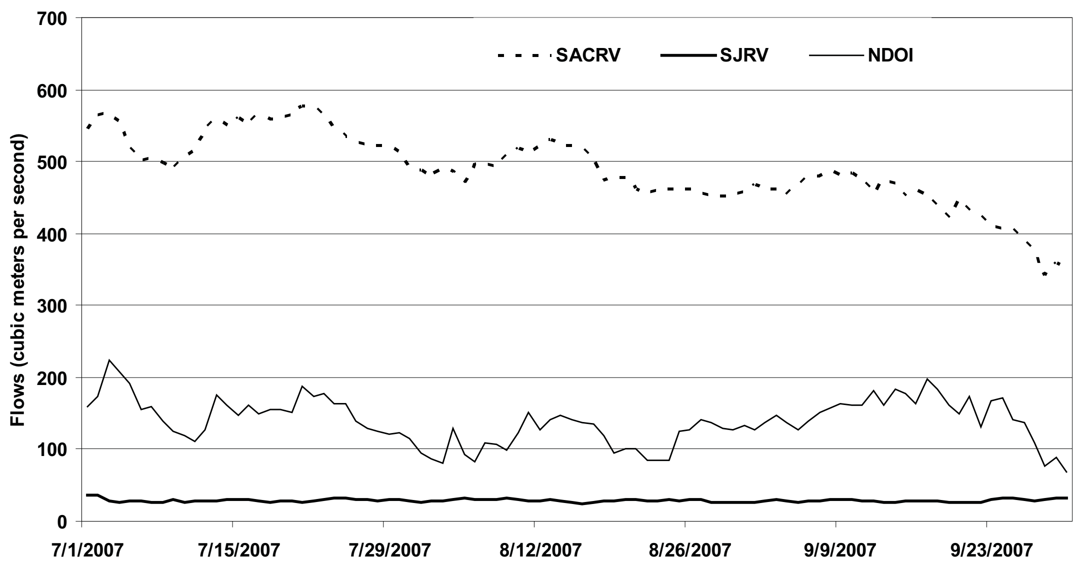

Figure 1 July - September 2007 Sacramento River, San Joaquin River, and Net Delta Outflow Index flows

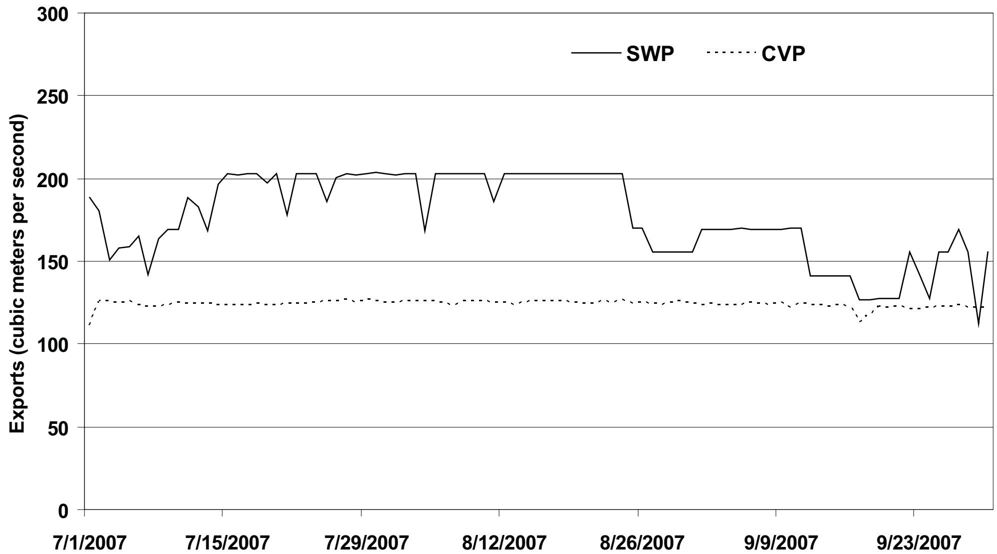

Figure 2 July through September 2007 State Water Project and Central Valley Project Exports

DELTA WATER PROJECT OPERATIONS (October through December 2007)

Kate Le and Andy Chu (DWR), kle@water.ca.gov

Hydrological conditions in the Delta region were slightly below normal during the months of October through December 2007. In Figure 1, San Joaquin River (SJR) average daily flow ranged between 30 and 66 cubic meters per second (1,059 cfs and 2,331 cfs). Sacramento River (SACR) daily average flow ranged between 236 and 469 cubic meters per second (8,333 cfs to 16,560 cfs). Daily Net Delta Outflow Index (NDOI) ranged between 72 and 480 cubic meters per second (2,542 cfs and 16,949 cfs). As shown in Figure 1, the outflow increases appeared to be a direct response to the precipitation events.

Project operations in the Delta during the October through December 2007 period were primarily conducted to meet the Bay-Delta Standards (see Figure 2). The minimum monthly outflow for October was 113 cubic meters per second (4,000 cfs) and for November and December 127 cubic meters per second (4,500 cfs). The 7-day average outflow must be within 28 cubic meters per second (1,000 cfs) of the monthly standards. Other flow and water quality standards for the Delta are also listed in Figure 2.

Exports patterns shown in Figure 3 were coordinated between the Projects to first ensure compliance with Bay Delta Standards. No significant plant maintenance activities or power outages occurred during these months. In regards to the export restrictions due to fishery actions, Projects did begin in late December to operate to the Interim Remedial Order by Judge Wanger for Delta Smelt.

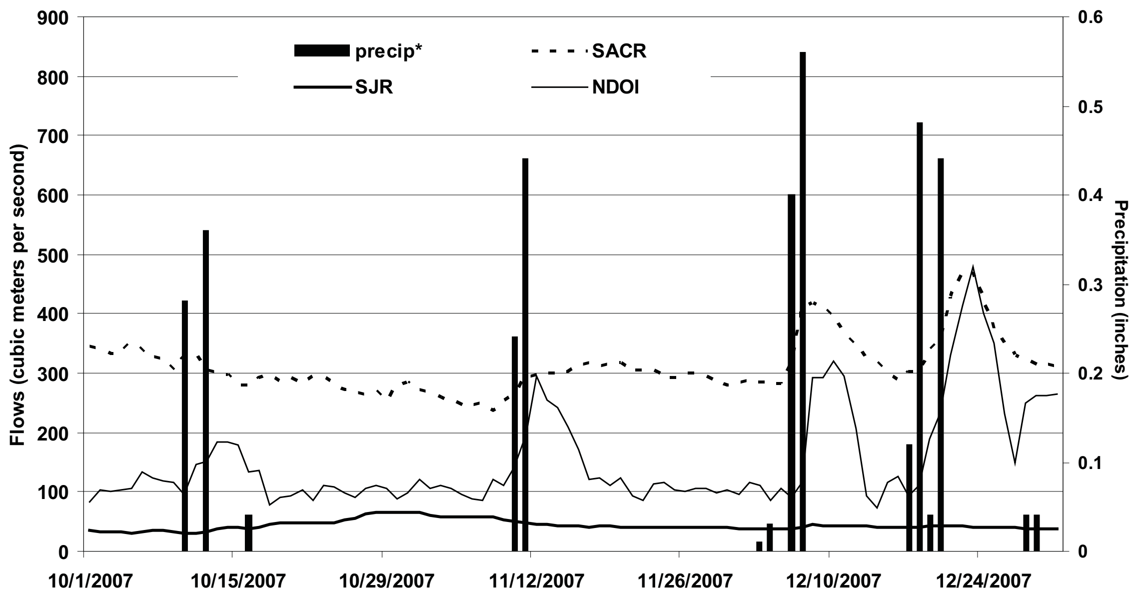

Figure 1 October through December 2007 Sacramento River, San Joaquin River, Net Delta Outflow Index flows, and Stockton Fire Station Precipitation

DRAFT

Bay-Delta Standards

DRAFT

Contained in D-1641

CRITERIA	Oct 07	Nov 07	Dec 07
FLOW/OPERATIONAL			
• Fish and Wildlife			
SWP/CVP Export Limits			
Export/Inflow Ratio	65%		
Minimum Outflow - mon.	4000 cfs	4500 cfs	4500 cfs
- 7 day avg.	3000 cfs	3500 cfs	3500 cfs
River Flows:			
@ Rio Vista - min. mon. avg.	4000 cfs	4500 cfs	4500 cfs
- 7 day average	3000 cfs	3000 cfs	3500 cfs
@ Vernalis: Base -min. mon. avg.			
- 7 day average			
Pulse	*1000 cfs		
Delta Cross Channel Gates	* Up to an additional 28 TAF	Conditional: For Nov-Jan period, DCC gates may be closed for up to a total of 45 days	
WATER QUALITY STANDARDS			
• Municipal and Industrial			
All Export Locations	<= 250 mg/l Cl		
Contra Costa Canal	<= 150 mg/L Cl for 165 days (All days have been met)		
• Agriculture			
Southern Delta	30-day running average EC <= 1.0 mS		
• Fish and Wildlife			
San Joaquin River Salinity			
Suisun Marsh Salinity	19 mS/cm	15.5 mS/cm - Eastern / 16.5 - Western Marsh st	15.5 mS/cm

Water Year Classification: Dry (Based on 05/01/2007 forecast)
SVI (40-30-30 @ 50%) = 6.2 (DRY) Apr 8RI: 1.730 MAF
SJV (60-20-20 @75%) = 1.9 (CRITICAL)

Figure 2 October through December 2007 Bay-Delta Standard

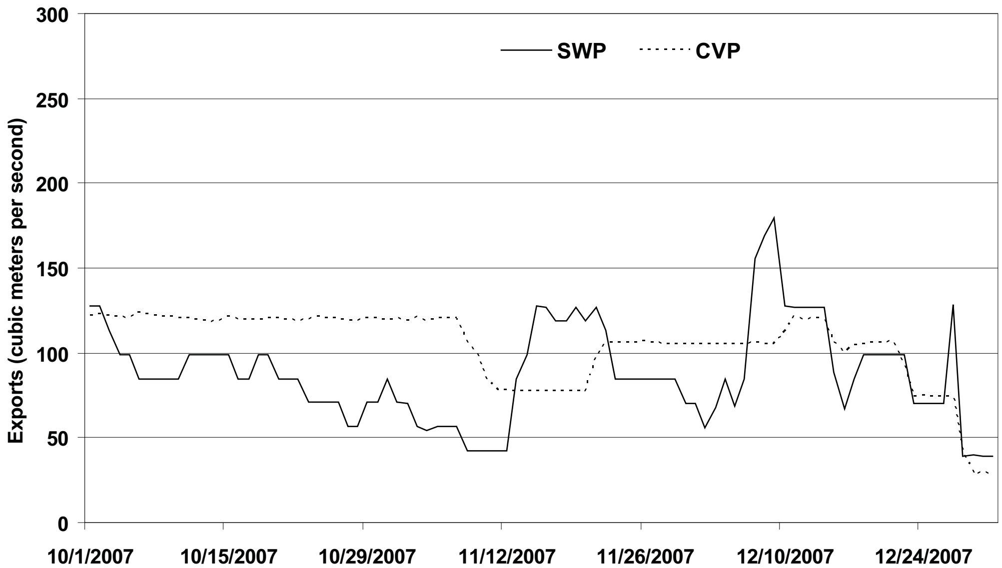

Figure 3 October through December 2007 State Water Project and Central Valley Project Exports

Delta Smelt Egg Production for 2007 & Initiation of Selective Matings for Genetic Analysis at the Fish Conservation and Culture Lab (FCCL), Fall 2007

Theresa Rettinghouse (UC Davis),
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At the beginning of the spawning season, on March 1, 2007, we had a total of 1589 wild delta smelt remaining from those collected in Dec. 2006, available for manual expression and in-vitro fertilization (strip spawning). Assuming 1:1 sex ratio, we had an estimated 795 female broodfish. This year the females were separated prior to spawning, into one of two different temperature controlled tanks. The warmed female tank was maintained at 12.1-16.4°C and the cooler female tank at 8.8-14.7°C from February 1 – March 23, 2007. We wanted to know if advancing the seasonal increase in temperature, by about a month would accelerate gonadal maturation. Measurements and counts of resulting larvae from warm and cold females were tracked for comparisons of fish health and survival. Photographs were also taken of the eggs for size comparisons in collaboration with B. Bennett (UC Davis, Bodega Marine Lab).

Each week females were checked for egg maturity and the ripe females from each tank were strip spawned and then moved to a tank designated for “spent females”. After March 23, 2007, females were combined back into one “colder water” tank and held below 15°C; low temperatures improve fish survival through the spawning season. The complete spring spawning season resulted in a total of 337,717 eggs acquired from 326 wild delta smelt females. The average number of eggs per female was 1,036.

This year we also initiated specific genetic multi-family groups and single pair matings for genetic analysis. Fork lengths and weights were logged and fin clips were taken from wild delta smelt parents for DNA analysis. Eggs from each mating (1 female x 2 males); 32 females and 60 males total, were sampled. The eggs from 3-7 females from each separate spawning date were pooled together to create 4 multi-family groups and the offspring were reared in separate tanks. Eggs, larvae and juveniles were sampled and preserved in 95% Ethanol for B. May (UC Davis) to assess the relative genetic contributions at the later life stages. Samples were also preserved in Bouins for S. Teh (UC Davis) and 70% Ethanol for B. Bennett (UC Davis, Bodega Marine Lab) at the same life stages. Four single crosses were also performed (1 female x 1 male) and all eggs were preserved in 95% Ethanol for B. May on the third day for genetic analysis.

Pre–Spawning Season Update and Number of Delta Smelt Provided for Research in 2007 from the Fish Conservation and Culture Lab (FCCL), Winter 2008

Theresa Rettinghouse (UC Davis), trettinghouse@earthlink.net

The Fish Conservation and Culture Lab normally collects delta smelt, in the lower Sacramento River, during the winter months to provide natural origin fish (NOR) for broodstock to produce hatchery origin fish (HOR). This year, due to the decline in the wild delta smelt population, our lab did not collect smelt. We will be using 2-year old (NOR), collected in the fall of 2006 as broodstock for the 2008 HOR-F1 population. These fish have grown significantly and now show a noticeable size and weight variation between the sexes compared to the collection data from the previous year (Table 1).

This year the spawning season for the wild delta smelt began on Dec 14, two months earlier than last year's first spawn on Feb 16, 2007. We stripped 3 females in late December and early January. The eggs from each female were fertilized by only one male. The fork length and weight were logged for both sexes and fin clips of each smelt were preserved in 95% ethanol for DNA analysis. The average fecundity of the 2-yr old NOR (n=3) is 5,033 eggs. This data shows a substantial increase in fecundity compared to the 1-yr old NOR during the 2007 spawning season (1,036; n=326).

The FCCL supports delta smelt research by supplying eggs and live fish of all life stages to several academic and governmental agencies. During the 2007 calendar year, 74,641 specimens were provided (Table 2). Our newly created FCCL website can be found at www.fishconservation.org. The website will be updated frequently with new information.

Table 1 Growth of wild delta smelt Dec 2006 - Jan 2008

	Collection 12/5 - 12/7/06	*1 year spawning 3/2 -5/11/07*	*2 year spawning 12/1/07 - 1/08/08*
Fork length (mm) - Male	53 (n=102)	65 (n=60)	81 (n=18)
Fork length (mm) - Female	53 (n=102)	65 (n=86)	97 (n=10)
Weight (g) - Male	1.33	2.17 (n=60)	5.82 (n=18)
Weight (g)- Female	1.33	2.36 (n=32)	9.95 (n=10)
Fecundity - Average eggs per female		1036 (n=326)	5033 (n=3)

Table 2 Total number of each life stage of cultured (HOR) delta smelt provided January - December 2007

Project	*Agency*	*Eggs*	*Larvae <20mm*	*Juveniles 20 - 50mm*	*Adults >50mm cultured 2006**	*Adults>50mm cultured 2007*	*Total*
CHTR - Fish release study	DWR - Padilla,CDFG - Fujiumura, Morinaka, Afentoulis				5856	0	5856
Toxicity test	UCD - Werner/Connon		2785	3180	1	0	5966
Fish health and condition	UCD- Bennett	6450	140	100	0	0	6690
Histology	UCD - Teh	18180	380	160	0	1401	20121
Pit tag facility evaluation	USFW - Castillo				485	0	485
Prey selection study	SFSU- Kimmerer/Sullivan		4056	1724	0	0	5780
Refugia - backup population	LSNFH - Rueth					90	90
Fish Screen efficiency	USBR - TFCF				4269	12990	17259
Maturation studies	UCD	1640			0	0	1640
Genetic analysis	UCD - May	4800	5278	676	0	0	10754
Subtotals		31070	12639	5840	10611	14481	
Total fish provided in 2007							74641

Delta Juvenile Fish Monitoring Program

Jason Hanni (USFWS) Jason_hanni@fws.gov

The Delta Juvenile Fish Monitoring Program (DJFMP) of the US Fish and Wildlife Service (USFWS), Stockton Office, has monitored the relative abundance and distribution of juvenile Chinook salmon (*Onchorynchus tshawyscha*) in the lower Sacramento and San Joaquin rivers and in the Delta for the Interagency Ecological Program since the 1970s (USFWS, 2006). The program expanded in the early 1990s to monitor other juvenile fish species.

Trawling

For the reporting period (07/01/07 through 09/30/07), Kodiak trawling was conducted at Mossdale (San Joaquin River RM 54) and midwater trawling was conducted at Sherwood Harbor (Sacramento River RM 55) regularly three days a week. Sampling at Chipps Island (Suisun Bay RM 18) was suspended during this reporting period due to concerns of take for the endangered delta smelt; however, it was resumed beginning the first week in October.

At Sherwood Harbor, unmarked Chinook salmon comprised the majority of the catch. A total of 68 unmarked salmon were captured during the reporting period. Of the unmarked Chinook salmon caught at Sherwood Harbor, 57 were fall-run sized, and 11 were late fall-run sized. Mossdale did not capture any salmon. No fin-clipped salmon were recovered at either sampling location during the sampling period.

During this reporting period, the DJFMP conducted 388 trawls at Mossdale and 379 at Sherwood Harbor. Weekly and total catch per unit effort (CPUE; in fish/10,000 m^3) for all fish species and salmon races were calculated. We captured 11,587 fish while trawling: 116 fish representing 12 different species at Sherwood Harbor, and 11,471 fish of 23 different species at Mossdale. At Mossdale, inland silversides (*Menidia beryllina*; n = 7,577; total CPUE = 32.75 fish/10,000 m^3) were the most abundant, followed by threadfin shad (*Dorosoma petenense;* n = 1,873 fish; total CPUE = 8.10 fish/10,000 m^3) (Table 1). At Sherwood Harbor, species other than unmarked salmon were caught in very low numbers. American Shad (*Alosa sapidissima;* n = 23 fish; total CPUE = 0.12 fish/10,000 m^3) had the second highest occurrence during the sampling period.

Table 1 Percent of catch of the most abundant fish species captured between 07/01/07 and 09/30/07 at Sherwood Harbor mid-water trawl and Mossdale Kodiak trawl

Station	*Individuals*	*Chinook Salmon*	*American Shad*	*Inland Silverside*	*Threadfin Shad*
Sherwood Harbor	n	68	23	10	-
(n=116)	% of catch	58.62	19.82	8.62	-
Mossdale	n	-	-	7577	1873.00
(n=11,471)	% of catch	-	-	66.05	16.33

Beach seine

For the reporting period (07/01/07 through 09/30/07), the DJFMP collected a total of 569 beach seine samples at 52 sites (see USFWS, 2006 for site map). We conducted 91 seines on the lower Sacramento River (7 sites), 69 seines on the San Joaquin River (7 sites), 351 seines in the Delta (29 sites), and 58 seines within San Pablo and San Francisco Bays (9 sites). The Lower Sacramento, Delta, and San Joaquin sites were typically sampled once per week, and Bay sites were sampled every other week.

A total of 43,587 fish representing 52 species were captured in beach seines during the sample period: 3,815 fish from the lower Sacramento River, 26,109 fish from the Delta, 11,683 fish from the San Joaquin River, and 1,980 fish from the Bay region.

Sacramento suckers (*Catostomus occidentalis*) were the most prevalent species in the lower Sacramento River catch (n = 1,163 fish; total CPUE = 0.52 fish/m^3) followed by inland silversides; (n = 821 fish; total CPUE = 0.36 fish/m^3) (Table 2). In the San Joaquin seine, inland silversides; (n = 9,758; total CPUE = 4.51 fish/m^3) followed by red shiners (*Cyprinella lutrensis*; n = 1,612 fish; total CPUE = 0.75 fish/m^3) were the most abundant species caught. In the Delta, which comprises North Delta seine, Central Delta seine, and South Delta seine inland silversides; (n = 20,892 fish; total CPUE = 1.32 fish/m^3) were the most abundant species. Threadfin shad were the next most abundant; (n=1276; total CPUE = 0.08 fish/m^3). Top smelt (*Antherinops affinis*; n = 1,512 fish; total CPUE = 0.24 fish/m^3), while yellowfin goby (*Acanthogobius flavimanus*; n = 105 fish; total CPUE = 0.03 fish/m^3) were the most abundant fish caught in the Bay seines.

Five salmon were recovered in the beach seines during this reporting period. Two fall-run sized fish were captured in the lower Sacramento region, and three late fall-run sized salmon were caught in the Delta region. There were no marked (adipose fin-clipped) Chinook salmon recovered in seines during this reporting period. No salmon were recovered from the San Joaquin River or Bay region seines during the reporting period.

Summary Report for Spring Kodiak Trawl 2008 Survey 1

Julio Adib-Samii (DFG)JadibSamii@water.ca.gov

Survey 1 of the 2008 Spring Kodiak Trawl was conducted from 1/7 to 1/11. This delta-wide survey sampled 40 stations from the Napa River to Stockton on the San Joaquin River, and up to Walnut Grove on the Sacramento River including the Sacramento Deep Water Shipping Channel. A map of the Spring Kodiak Trawl sampling stations can be viewed at our website: (www.delta.dfg.ca.gov/data/skt).

A total of 132 adult delta smelt were collected during Survey 1 from a wide geographic distribution, with the highest concentration (n=79) of fish coming from the lower Sacramento River just downstream of Decker Island. The second highest concentration of fish (n=28) was collected in the Sacramento Deep Water Channel. Delta-wide, 76 males (57.6 % of catch) and 54 females (40.9 % of catch) were collected, and for 2 fish (1.5 % of catch) sex could not be determined. This 2008 catch of 132 delta smelt was slightly higher than the catch for Survey 1 of 2007 which was 109. Additionally, 2008 Survey 1 catch distribution shows a more easterly pattern of occurance than that of 2007, where the highest concentration of delta smelt was in Montezuma Slough (n=38).

We examined all 2008 Survey 1 delta smelt for gonadal maturation and found no mature fish. We categorized delta smelt gonads into one of six stages; where Stage 4 represents a ripe female and Stage 5 represents a ripe male (further details of gonadal stages can be viewed at www.delta.dfg.ca.gov/data/skt). The majority of females (63 %) collected were Stage 2, while 37 % of the females were Stage 3 (pre-spawn). The vast majority (92.1 %) of males was Stage 3 and 1 male was Stage 4 (pre-spawn). With regards to both sexes, gonadal maturation and staging seem to be congruous with environmental factors, such as water temperature and seasonality.

In Survey 1 2008, general fish size and condition seemed exceptionally good compared to 2007. Females were on average 5 mm larger in 2008 (average = 67mm) than in 2007 (average = 62mm). Males on average were substantially larger in 2008 (average = 66.9mm) than in 2007 (average = 60.2 mm). Additionally, 2008 fish seem to be healthier exhibiting large fat reserves and full stomachs. Several females examined from the lower Sacramento River showed full gut tracts occupied by the amphipod *Corophium* spp. Please look for more information in later editions of this newsletter.

Hydrology of San Francisco Bay and Watershed, Water Years 2006 and 2007

David H. Schoellhamer (dschoell@ucdavis.edu)

Introduction

Hydrology is the study of the properties and distribution of water. California has two distinct hydrologic seasons: a wet season from late autumn to early spring with the remainder of the year being dry. Thus, the water year, which begins on October 1 and ends on September 30, is a convenient period to study hydrology because it begins in the dry season, includes a single wet season, and ends in the dry season.

The purpose of this series of short articles is to describe the hydrology of San Francisco Bay and its watershed during water years (WY) 2006 and 2007. The articles describe precipitation and surface water flows in the watershed (Figure 1), flows and diversions in the Sacramento – San Joaquin River Delta (Figure 2), meteorology, water levels, salinity, suspended sediment, temperature, and chlorophyll-a in San Francisco Bay (Figure 3), and temperature and upwelling offshore in the Pacific Ocean (Figure 3). Temporal variation and spatial distribution are described and WY2006 and WY2007 conditions are compared to historical conditions and to each other. Comparison of the two water years is instructive because WY2006 was wetter than normal and WY2007 was drier than normal (Carr, this issue). All data are available to the public from online sources. Due to the breadth of the subject matter and quantity of data available, the articles provide highlights of the hydrology of the Bay, Delta, Ocean, and watershed rather than in-depth analysis. Water managers and scientists may find that the articles are a convenient resource to access hydrologic conditions in WY2006 and WY2007. A previous set of articles described WY2005 (Schoellhamer 2007).

Figure 1 Central Valley watershed that drains to San Francisco Bay. Selected rivers, reservoirs, and streamflow gages are shown.

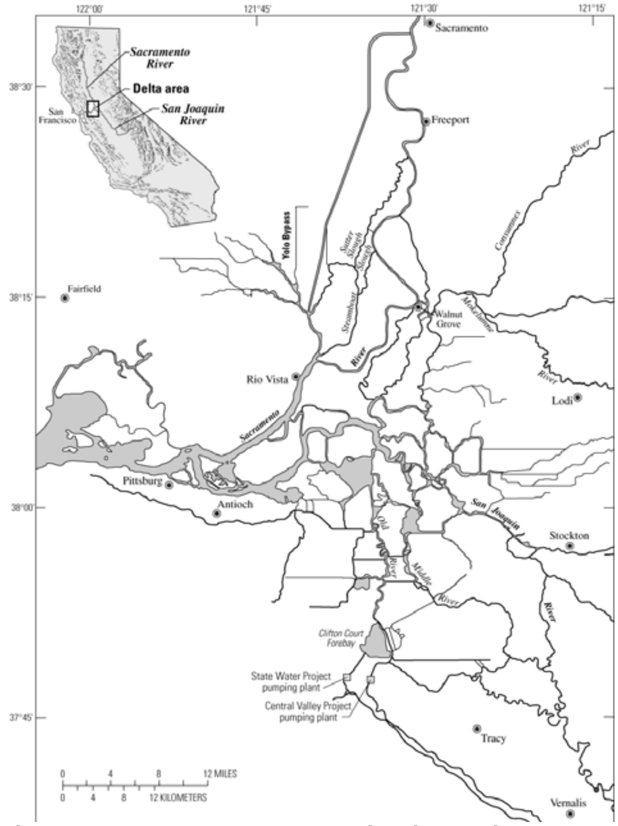

Figure 2 Sacramento-San Joaquin River Delta

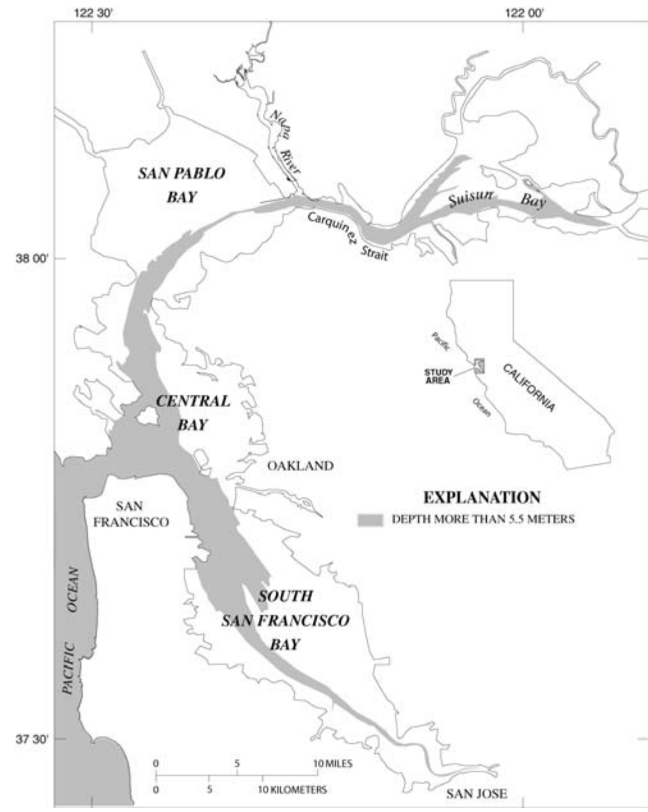

Figure 3 San Francisco Bay and the offshore Pacific Ocean

These articles were written and reviewed by the students enrolled in the class *Hydrology of San Francisco Bay and Delta* that I taught at UC Davis in Fall 2007. The students also downloaded and processed the data presented in these articles. I would like to thank the many individuals, organizations, and agencies who serve the public by collecting and disseminating hydrologic data and Roger Fujii, Neil Ganju, John Largier, Lester McKee, Cathy Ruhl, Ted Sommer, and Doug Thompson for their assistance.

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Schoellhamer, D.H., 2007, Introduction to the Hydrology of San Francisco Bay and Watershed, Water Year 2005: Interagency Ecological Program Newsletter, v. 20, no. 3, p. 9-10.

Precipitation in the San Francisco Bay Watershed, Water Years 2006 and 2007

Kara J. Carr (kjcarr@ucdavis.edu)

Precipitation data indicate that water year (WY) 2006 was wetter than normal and WY 2007 was drier than normal. Monthly averages of rainfall (CDEC 2007a) were evaluated for 13 river basins (5 in the Sacramento region, 6 in the San Joaquin region and 2 in the San Francisco region). Snowpack data (CDEC, 2007b), in the form of snow water equivalent as inches of water (SWE), were evaluated in 11 river basins; 6 basins in the Sacramento River region, and 5 basins in the San Joaquin River region (Figure 1, Schoellhamer, this issue). Snowpack is of particular importance because it contributes 40 percent of the annual water supply for the watershed (Roos, 1989).

In general, 2006 was wetter than normal, with above average rainfall values for December, March and April for the entire watershed. December had the maximum monthly rainfall for all areas considered. Rainfall values were well below average in October for the Sacramento region, and in February for the San Joaquin region. Figure 1 presents average monthly rainfall in the Sacramento region for WY 2006, WY 2007, and historical averages. The figure includes data from all 5 river basins and illustrates the trends seen throughout the watershed.

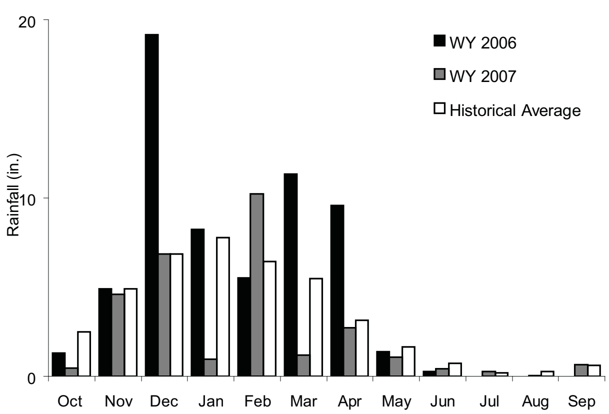

Figure 1 Rainfall and historic monthly averages for the period of record (varies by basin) for the Sacramento region (CDEC 2007a).

Quite the opposite of 2006, WY 2007 was a drier than average year with peak monthly rainfall occurring in February. This peak represents the only monthly value higher than the historical average. Rainfall was close to or below average for the remainder of the water year with marked low values in October, January and March for the Sacramento and San Francisco regions, and in November, January and March in the San Joaquin Region.

Snow water equivalent peaked in May for WY 2006 at 50 inches (183% of the historical average, Figure 2). Above average SWE occurred for most of the WY 2006, with March being the only exception. The above average SWE and its peak after April 1 provided a large benefit to reservoir management, allowing for larger than average snow melt to be distributed in the dry season. In the north, SWE was well above average for April and May, and in the south SWE was well above average for February, April, and May. For the 2 basins reporting, SWE was above average in June as well.

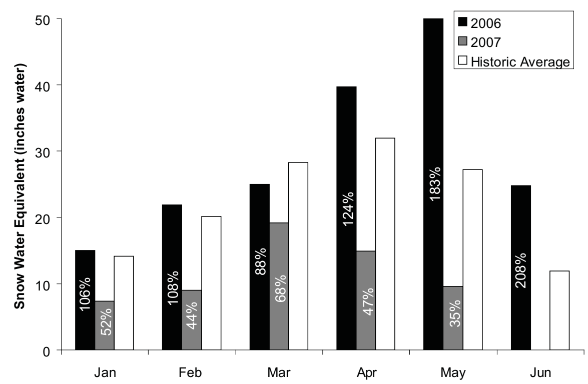

Figure 2 Unweighted mean of SWE and historic monthly averages for the period of record (varies by basin) for the San Francisco Bay watershed. Percentages denote percentage of historic average (CDEC 2007b).

In WY 2007, monthly SWE values were below average throughout the year for all basins reported. SWE peaked in March 2007, at just over 19 inches (68% of the historic average). These below average values are significant as there is a heavy dependence on reservoirs and snow pack for water management in the region. (Knowles and Cayan, 2004). Note the representation of zero SWE for June of 2007 may be due to lack of reported values, and does not necessarily indicate zero SWE.

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Sacramento River Flows, Water Years 2006 and 2007

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Flows within the Sacramento River Basin were significantly higher in water year (WY) 2006 than in 2007 (USGS 2007). When compared to the historical means (1949-2006), most flows in WY 2006 were greater than historical averages as contrasted to the below average flows in WY2007. The difference in the magnitude of flows between these two years can be attributed to precipitation, as flows are directly related to rainfall. WY 2006 was a wet year with precipitation values 150% above normal and WY 2007 was relatively dry, with precipitation values 68% below normal (DWR 2007). While the watershed is large, covering approximately 27,000 square miles and accounting for 26% of California's total runoff (DWR 2007), temporal variation in flows throughout the watershed are similar because temporal variation in precipitation is similar. Tributaries within the basin exhibit similar flows to those of the lower Sacramento River, as depicted in Figure 1.

The monthly average flows for WY 2006 were above historical averages (except for November), with the greatest peak flows occurring in late December/early January and in April. Although February's monthly average was above the historical mean, it was the driest month of the wet season (January – April), as shown in Figure 1. The Sutter and Yolo bypasses were used in WY 2006, with large flows recorded at Fremont, Colusa, Moulton, and Tisdale weirs. The Sacramento Weir was opened on December 31, 2005 and remained open until January 9, 2006.

Conversely, flows in WY 2007 were below monthly historical averages for all months, except July and August, (Table 1). The two peak flows in WY 2007 occurred in February and March and were less than half of WY 2006's largest peaks. These trends are clearly shown in Figure 1 with flows at Freeport (USGS 11447650). The Freeport gauge is located in the lower Sacramento River and measures most outflows from the basin. The Yolo Bypass near Woodland (USGS 11453000) also transports water from the basin, however, in WY 2007, only minimal flows entered the bypass.

The large inflows into the dams in WY 2006 corresponded with similar outflows, as it was necessary for reservoirs to provide flood storage for anticipated future inflows. A large snowpack in WY 2006 resulted in above average dam storage and summer flows greater than historical averages. Reservoirs within the basin, such as Shasta, Oroville, New Bullards Bar and Folsom, all exhibited similar storage changes.

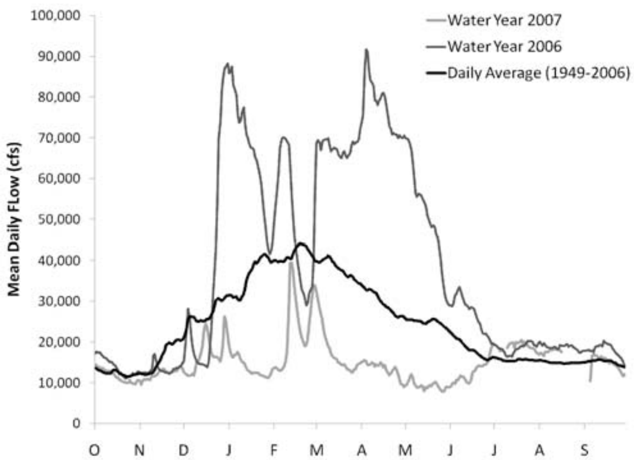

Figure 1 - Mean daily discharge in the Sacramento River at Freeport for water years 2006 and 2007. The historical averages from 1949 to 2006 are also shown.

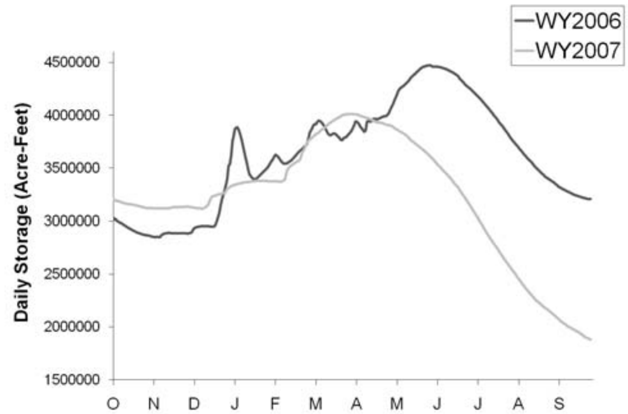

Figure 2 - Water storage behind Shasta Dam. The dam held approximately 500,000 acre-feet more storage in WY 2006 than in WY 2007 and peaked later in the year.

Table 1 - Average monthly flow data for water years 2006, 2007 and historical averages (1949-2006) for the Sacramento River at Freeport

	Oct.	*Nov.*	*Dec.*	*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May*	*Jun.*	*Jul.*	*Aug.*	*Sep.*
Historical Monthly Mean Flow (cfs)	12,300	16,100	26,500	35,200	41,000	37,900	29,200	24,500	18,200	15,400	14,700	14,900
Water Year 2006 Monthly Mean Flow (cfs)	14,074	13,387	35,458	66,152	48,921	67,340	77,647	52,145	27,210	18,587	18,865	18,010
Percent of Historical	114%	83%	134%	188%	119%	178%	266%	213%	150%	121%	128%	121%
Water Year 2007 Monthly Mean Flow (cfs)	11,719	12,152	17,048	13,897	22,811	18,293	13,634	9,338	12,302	18,981	17,659	14,764
Percent of Historical	95%	75%	64%	39%	56%	48%	47%	38%	68%	123%	120%	99%

With a dry WY 2007, there were minimal inflows to and outflows from the dams and storage was significantly less than in the previous year, as shown in Figure 2. In summer months (mid-June to August) of WY 2007, dams increased outflow releases to augment flows on the American and Sacramento Rivers. This lowered dam storage and increased flows (measured at Freeport) above historical means. These unusual flow releases can be attributed to the large demand for water. The export pumps were shut down for nearly two weeks in early June so when pumping resumed, increased flows were necessary to “help support Delta outflow requirements and Central Valley Project water supplies south of the Delta” (USBR 2007).

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San Joaquin River Flows, Water Years 2006 and 2007

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For the San Joaquin River Basin, the wet water year (WY) of 2006 produced higher than average runoff, while the dry WY of 2007 produced lower than average runoff. The San Joaquin River (SJR) Basin encompasses 15,214 square miles, 9.6% of the State (Schoellhamer, this issue, figure 1). Flows in the SJR during WY 2006 were consistently higher than historical averages, except during a period from October through December and late February when flows were below the historical average at Vernalis (USGS 11303500) the most downstream gage on the SJR (Figure 1). Peak river flows during WY 2006 were observed in April, with discharge nearly four times the average at Vernalis (Table 1) though never greater than historical highs. During WY 2007, flows were consistently lower than the historical average with the exception of October and November. Peak river flows during WY 2007 were observed in early May, with discharges approximately half of the historical average.

Major watersheds in the SJR Basin showed similar discharge trends due to the respectively wet and dry water years of 2006 and 2007. Flow in Chowchilla and Eastside bypass were higher than average for WY 2006 during late spring, and low for WY 2007, with flow surpassing the Mariposa Bypass limit of 8,500 cfs during WY 2006. Merced, Tuolumne, and Stanislaus Rivers had similar trends with increased and decreased flow during WY 2006 and WY 2007, respectively. High precipitation and snow pack during WY 2006 corresponded with increased storage in dam and reservoirs, leading to increased dam releases. Storage during the dry WY 2007 was significantly less than WY 2006, leading to decreased outflows. Total daily storage for the largest reservoirs in the SJR basin, including Lake McClure, Don Pedro Reservoir, New Melones Reservoir, New Hogan Reservoir, and Friant Dam (Schoellhamer, this issue, figure 1), are displayed in Figure 2 for WY 2006 and 2007. High precipitation increased flow in the SJR during WY 2006 that satisfied the Vernalis Adaptive Management Plan (VAMP) required flow of 7,000 cfs for salmon smolt migration (San Joaquin River Group Authority). However, WY 2007 required additional reservoir releases due to flow values less than the VAMP standards (Bruce Herbold, U.S. Environmental Protection Agency, oral communication). The wet WY 2006 and dry WY 2007 that were seen across all of California were reflected in SJR flow trends.

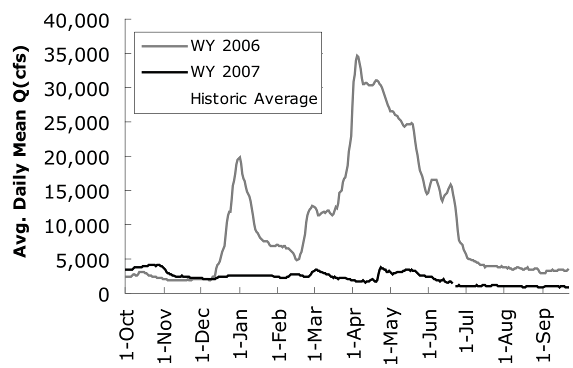

Figure 1 Flow in SJR at Vernalis (USGS 11303500)

Table 1 Average monthly flow data for water years 2006, 2007, and historical averages (1923-2006) for the SJR at Vernalis (USGS 11303500)

	Oct	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*
Historical Average Flow (cfs)	2,290	2,290	3,530	5,170	7,100	7,470	7,330	7,780	6,500	2,640	1,480	1,790
WY 2006 Monthly Avg. Flow (cfs)	2,619	2,038	3,521	13,170	6,458	11,700	27,940	26,050	15,690	5,547	3,697	3,316
Percent of Historical	114%	89%	100%	255%	91%	157%	381%	335%	241%	210%	250%	185%
WY 2007 Monthly Avg. Flow (cfs)	3,851	2,538	2,354	2,587	2,534	2,555	2,313	3,015	1,676	1,093	1,007	1,013
Percent of Historical	168%	111%	67%	50%	36%	34%	32%	39%	26%	41%	68%	57%

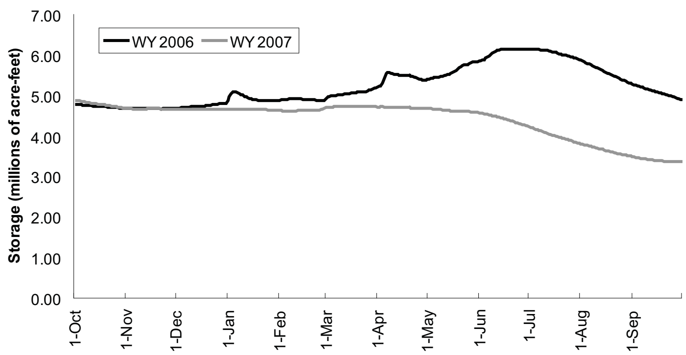

Figure 2 Total daily storage in SJR basin reservoirs including Lake McClure, Don Pedro Reservoir, New Melones Reservoir, New Hogan Reservoir, and Friant Dam (CDEC)

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Flow in the San Francisco Bay Tributaries, Water Years 2006 and 2007

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This article considers the flows into the San Francisco Bay from the nearby rivers and creeks excluding the Sacramento and San Joaquin River (Figure 3, Schoellhamer, this issue). Flow data are collected from 13 US Geological Survey (USGS) stations in the San Francisco Bay Area (Table 1). The watershed size ranges from 7.26 square miles for Matadero Creek to 633 square miles for Alameda Creek. The 13 stations combine to have a total drainage area of 2,260 square miles. The San Francisco Bay tributaries contribute about 10% of the total fresh water inflow to the bay (SFEP 2005). Historical data from 1929 to 2006 are used to calculate historical mean daily flow to compare to water year 2006 and 2007.Due to the higher precipitation in water year (WY) 2006 than in WY 2007 (Carr, this issue), San Francisco Bay tributaries all had higher runoff in WY 2006 than WY 2007. In WY 2006, the measured tributary flow into the Bay excluding flows from the Sacramento and San Joaquin rivers was 1760 cfs. In WY 2007, the tributary in flow was 279 cfs.

Figure 1 shows the sum of all station's mean daily flow for WY 2006, WY 2007 and the historical average. In WY 2006 and 2007, the total flow volume from the 13 stations is 1.27 million acre-feet (MAF) and 0.20 MAF, respectively. The average annual flow volume over the period of record is about 0.6 MAF. In WY2006, Napa River at Napa (USGS ID: 11458000) had the highest flow (501 cfs). Lowest flow was measured at Matadero Creek (USGS ID: 11166000), 6.03 cfs. The highest mean daily flow in WY 2006 was 24,100 cfs in Napa River at Napa Station (USGS ID:11458000) on December 31. In WY 2007, flow rates were significantly lower at all stations. Alameda Creek near Niles station and Matadero Creek recorded annual average flow of 58 cfs and 0.9 cfs, respectively. This is about 80% decrease from WY 2006 in mean annual flow. The highest mean daily flow in WY 2007 was 1,610 cfs at Alameda Creek Flood Control Channel station on February 27. Precipitation is the main reason for the difference of inflow into the Bay. WY 2007 only saw moderate storm events in December and February, whereas WY 2006 had storm events from December 2007 to April 2008.

Table 1 San Francisco Bay tributaries stations summary

Bay Tributaries	*Station ID*	*Period of Record(Years)*	*Drainage Area (Sq Miles)*	*Annual Mean Discharge (cfs)*		
				WY2006	*WY2007*	*Historic*
Alameda Cr Flood Control Ch	11180700	1958-2006	639	233	25	101
Alameda Creek near Niles	11179000	1969-2006	633	242	58	141
Coyote Creek	11172175	1998-2006	319	90	28	49
Guadalupe Creek	11169025	2001-2006	160	142	40	87
Marsh Creek	11337600	1993-2006	38	30	3	13
Matadero Creek	11166000	1952-2006	7	6	0.9	3
Napa River at Napa	11458000	1959-2006	218	501	47	217
Napa River at St Helena	11456000	1929-2006	79	197	28	96
Novato Creek at Novato	11459500	1947-2006	18	35	3	13
San Francisquito Creek	11164500	1931-2006	37	54	5	22
San Lorenzo Creek	11181040	1967-2006	45	44	11	23
Saratoga Creek	11169500	1933-2006	9	17	2	9
Sonoma Creek at Agua Caliente	11458500	1954-2006	58	170	25	73

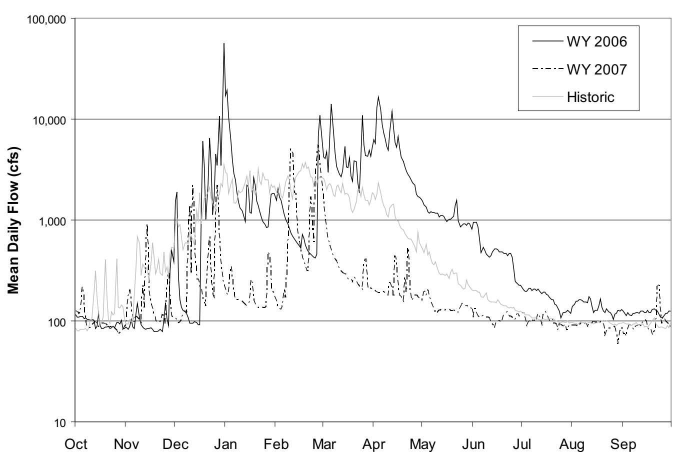

Figure 1 San Francisco Bay tributaries mean daily flow (cfs) WY 2006, WY 2007, and average from historical record

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Diversions from the Delta, Water Years 2006 and 2007

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Delta diversion flows were generally higher in Water Year (WY) 2006 as compared to 2007, reflecting the respective change from a wet to dry year. Exports in both years were generally above average. Annual and daily mean flows for WY 2006 and 2007 were compared with historical (WY 1995-2007) flows at key Delta diversions, including the Contra Costa Canal (CCC), the State Water Project (SWP) and Central Valley Project (CVP) pumping plants, and the North Bay Aqueduct (NBAQ), as well as flows related to channel depletions (CD) (Figure 2, Schoellhamer, this issue). Data were obtained primarily from the website of Dayflow, an Interagency Ecological Program (IEP) tool to calculate various flows within the Delta (IEP 2007). Dayflow data were not available for WY 2007; instead, flow data for 2007 were computed using documented Dayflow formulae, with input data from the California Data Exchange Center (CDEC 2007), Central Valley Operations Office (CVO 2007), and Dayflow documentation (IEP 2007).

Total exports (CCC+SWP+CVP+NBAQ) during water years 2006 and 2007 were higher than the mean historical total exports of 7,804 cfs (5.65 MAF per annum) by about 12% (8,722 cfs) and 2% (7,972 cfs), respectively (Figure 1). The significantly higher exports in 2006 can be attributed primarily to greater SWP exports, while the slightly higher exports in 2007 were caused by greater CVP exports. The greatest change in total diversions was in channel depletions, which were 58% higher than average in 2007. However, CD values, which are partially dependent on precipitation, are estimated using poorly developed gross channel depletion estimates and precipitation data from only one station. The mean relative contributions to total diversions are depicted in Figure 2. SWP and CVP constitute about 85% of total diversions (97% of exports). Exports were lower in 2007 than in 2006 not because precipitaion was lower in 2007 but because pumping was curtailed during June 2007 in an effort to protect delta smelt.

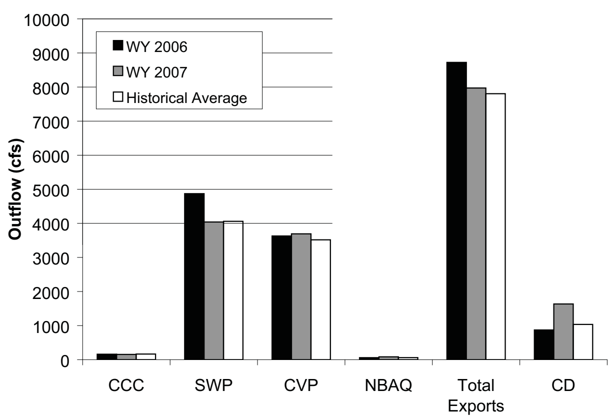

Figure 1 Mean annual Delta diversions for WY 2006 and 2007 compared with historical means (WY 1995-2007) for CCC, SWP, CVP, NBAQ, total exports (CCC+SWP+CVP+NBAQ), and channel depletions (CD)

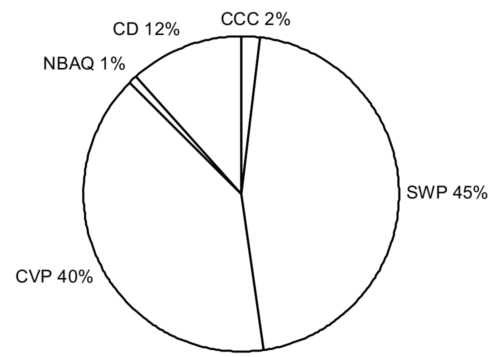

Figure 2 Percent distribution of average total exports among the major diversions in the Delta (WY 1995-2007)

There was considerable intra-annual variation of total exports during 2006 and 2007(Figure 3). Historically export flows fluctuate around approximately 8,000 cfs until about mid-March, when exports drop to just above 2,000 cfs from mid-April to mid-May. Subsequently, exports increase to just over 10,000 cfs during July and August, after which flows drop back to about 8,000 cfs again by mid-October. Water exports were above average for both WY 2006 and 2007 during the high export periods of the year (July through December) (Figure 3). This finding is consistent with a general trend of increased total annual exports during the past decade, as indicated by the historical data (not shown). During April -May when pumping rates are normally reduced in any year, exports from the SWP were curtailed much longer than usual. The SWP pumps were shut down completely during June 1-9, 2007, due to concerns of pumping impacts on Delta smelt (DWR 2007). Pumping rates remained below 100 cfs through June 16.

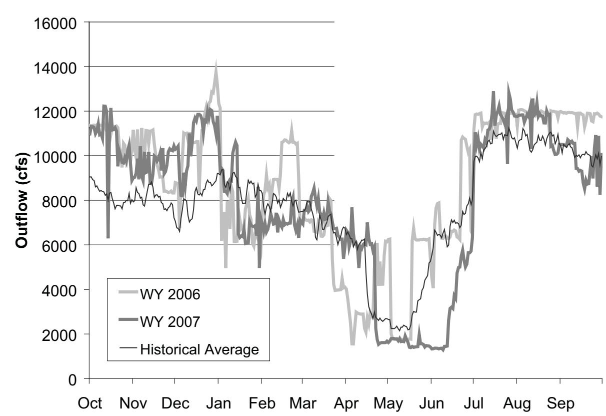

Figure 3 Mean daily Delta total exports for WY 2006 & 2007 compared with historical mean (WY 1995-2007)

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Delta Water Flows during Water Years 2006 and 2007

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This article discusses Delta outflow to San Francisco Bay and flow within the Delta for water years (WY) 2006 and 2007. Delta outflow data was collected from Dayflow, the Interagency Ecological Program's (IEP) Delta water flow data vault. WY 2006 and 2007 Delta outflows are compared to outflows since WY1995. Water flows into the Sacramento/San-Joaquin Delta are largely governed by the Sacramento and San Joaquin Rivers, with smaller rivers such as the Cosumnes and Mokelumne having a less, yet important, direct contribution to the Delta. Flows in the majority of these rivers are controlled by dam releases upstream. Precipitation and runoff from melting snowpack throughout the northern California region also largely impact Delta flows.

Overall WY 2006 and 2007 were very different hydrologically, with WY 2006 being wetter than WY 2007. As Figure 1 shows, WY 2006 Delta outflow exceeded the historical average throughout the majority of the year. The yearly average outflow from the Delta of 60,508 cfs in WY 2006 exceeded that of any yearly average on record since 1995. The peak of the WY 2006 data during late December and early January (Figure 1) corresponds to a period of heavy precipitation and water inflows into the Delta (Carr, Ross, Zelin, all this issue). Conversely, WY 2007 was much drier with outflows consistently lower than the mean for the entire water year. The average outflow for WY 2007 was 9,095 cfs, which represents the driest average year on record since 1995. The small peak in the WY 2007 data occurring in late February was likely a result of near normal monthly precipitation (Carr, this issue).

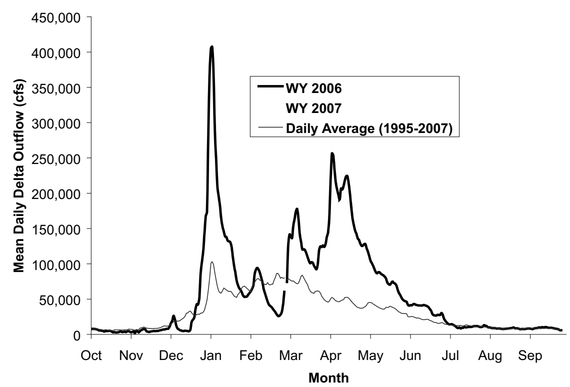

Figure 1 Delta outflows for water years 2006 and 2007, including historic average (1995-2007). Note the above average flows for Winter 2006 and the below average flows for the entirety of WY 2007 (IEP 2007).

Tidally-averaged water flows at several US Geological Survey (USGS) flow gages throughout the Delta area were also collected for WY 2006 and 2007 (USGS 2007). These selected sites all show increased seaward flow during WY 2006, and decreased flow during WY 2007 compared to historic averages. Data obtained from two selected USGS gages (Old River at Bacon Island and Middle River) are presented in Figures 2 and 3. These two sites (Figure 2, Schoellhamer, this issue) were selected as they contained a comprehensive dataset for both water years and the flow data followed similar trends to other flow gauges throughout the Delta (when data was available). Both gages have collected daily, tidally-averaged flow data since 1987. Figures 2 and 3 show the tidally-averaged flows in Old and Middle Rivers, respectively, during WY 2006 and WY 2007 along with their respective average flows. The trends in Figures 2 and 3 are similar to those in Figure 1, with an above average flow during WY 2006 and a below average flow during WY 2007. Although WY 2006 had the highest yearly average Delta outflow (since 1995), flows in Old and Middle Rivers for the fall/summer months of WY 2006 were below normal. Two possible causes of the low flows during these months were the below normal precipitation (Carr, Figure 1, this issue) and an increase in water exports from the Delta. Both stations are close to the State and Federal pumping facilities. Water exports were approximately 1000-4000 cfs above average exports during WY 2006 for the months in question (Figure 3, Rheinheimer, this issue). Flows from the Sacramento and San Joaquin Rivers were normal or above normal for the majority of WY 2006 (Ross, Zelin, this issue). Therefore it is unlikely that decreased Delta inflows caused the observed trends .

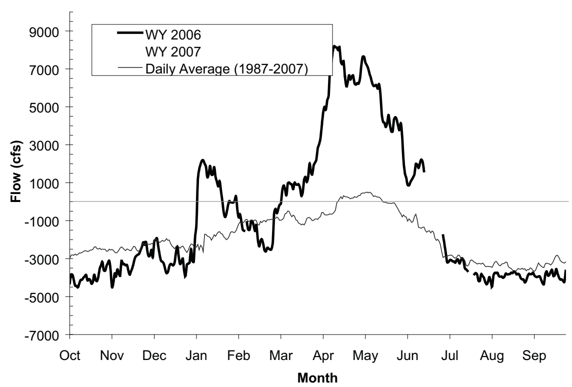

Figure 2 Tidally-averaged flow in Old River at Bacon Island for WY 2006, WY 2007, and the historical average. Positive values are seaward(north). The period of record for this gauge began in 1987 (USGS 2007).

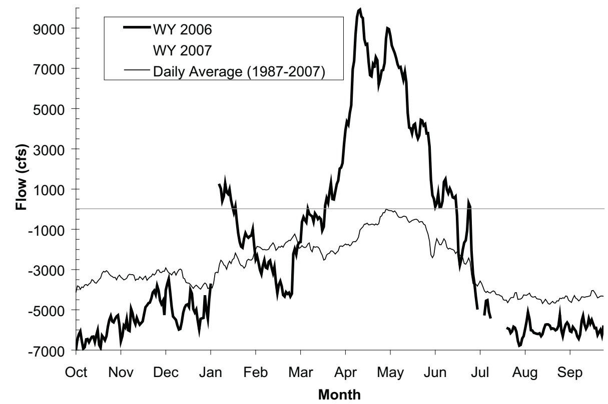

Figure 3 Tidally-averaged flow in Middle River for WY 2006, WY 2007, and the historical average. Positive values are seaward(north). The period of record for this gauge began in 1987 (USGS 2007).

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Coastal Upwelling and Sea Surface Temperature, Water Years 2006 and 2007

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Seasonal wind patterns off the coast of California cause offshore surface water movement. The transported water is replaced by colder subsurface water that carries organic carbon,nitrogen and other nutrients upwards from the ocean bottom, a process called upwelling. Upwelling systems thus affect the composition and productivity of phytoplankton, zooplankton and fish communities. Upwelling varies intra-annually with seasonal shifts in wind speed and direction and inter-annually with ocean-scale climate phenomena such as the Pacific Decadal Oscillation. (Beer 1997). The Coastal Upwelling Index measures the intensity of offshore surface transport due to alongshore wind stress (Cloern et al. 2005).

Hourly sea surface temperatures from NOAA buoy 46026 in the Pacific Ocean, located 18 nautical miles off-shore from San Francisco Bay, were retrieved and analyzed for water years (WY) 2006 and 2007 and compared with historical data (NOAA NDBC 2007). Historic monthly mean sea surface temperatures were calculated from 1982 to 2001. An upwelling index was retrieved for 39°N 125°W on the United States west coast from the Environmental Research Division of NOAA (NOAA ERD 2007).

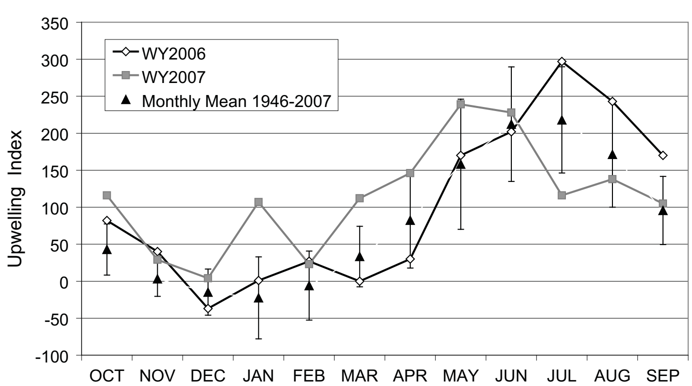

Figure 1 Mean monthly upwelling index for WY2006, WY2007, and the historical period of record (1946-2007). One standard deviation above and below the historic monthly means is shown (NOAA ERD 2007).

Upwelling in WY2006 and WY2007 was generally stronger than historical mean monthly upwelling. Five months in 2006 and four months in 2007 had an index greater than one standard deviation above the historic mean (Figure 1). Mean monthly sea surface temperatures for WY 2006 were generally warmer than historic mean monthly temperatures, and WY 2007 temperatures were generally cooler than historic mean monthly temperatures (Figure 2).

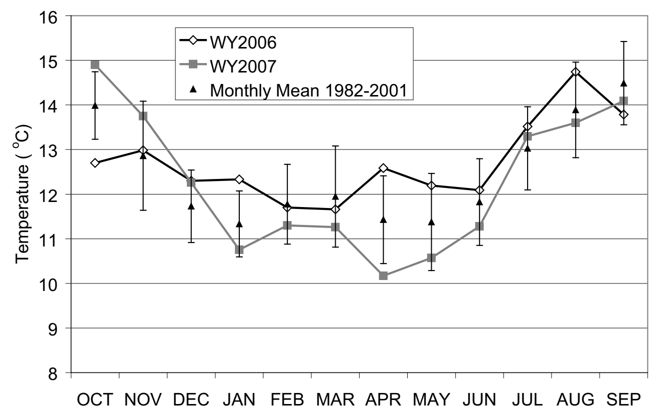

Figure 2 Monthly mean temperature at NOAA Buoy 46026 for WY2006, WY2007 and the historical period of record (1982-2001). One standard deviation above and below the historic monthly means is shown (NOAA NDBC 2007).

Upwelling and sea surface temperature variations were complex and unpredictable. Upwelling in October and January of WY 2007 was significantly stronger than historical mean monthly upwelling (greater than two standard deviations above the historical mean) (Figure 1). March and April 2006 were characterized by weak upwelling in contrast to the strong upwelling that occurred in these months during WY 2007 (Figure 1). The greatest difference in mean monthly sea surface temperatures occurred between April 2006 and 2007 with a difference of 2.4 °C (NOAA NDBC 2007). Hourly sea surface temperatures began surfacing during the last 10 days of June 2006, dropped from nearly 16 °C to 10 °C during the first part of July, and then continued to climb again (NOAA NDBC 2007). This cooling of temperatures in the early part of July 2006 indicates strong upwelling that is reflected in an upwelling index greater than one standard deviation above the historic mean (Figure 1). WY 2006 ended with relatively high upwelling indices, whereas upwelling was weak by the end of WY 2007 (Figure 1).

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San Francisco Bay Meteorology: Sea Level Pressure, Wind Speed, and Wind Direction for Water Years 2006 and 2007

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In water years 2006 and 2007, atmospheric pressure at sea level, wind speed, and wind direction, followed historical patterns in the San Francisco Bay area. Analysis of meteorological trends is necessary to evaluate an estuary system as a whole. For example, sediment dynamics in areas of environmental or engineering concern can be strongly influenced by wind waves (Bricker et al. 2005), thus it is imperative that meteorological trends within the targeted area be well understood. These three characteristics were analyzed using data for three sites: offshore at Environmental Buoy 46026 (Station 992640), near Travis Air Force Base (Station 745160), and in the South Bay near Moffett Federal Airfield (Station 745090) (Figures 2 and 3, Schoellhamer, this issue).

Sea level pressure averaged approximately 1017 mb (NOAA 2007) at these three sites over water years 2006 and 2007 with a standard deviation of +/-0.8 mb (Table 1). The wind blew predominantly from the northwest, especially during April to October (Figure 1). Out of the three meteorological parameters, wind speed varied the most from station to station. Annual averages of 11-12 mph were recorded both off shore at Environmental Buoy 46026 and near Travis Air Force Base, while an annual average of approximately 5 mph was found at Moffett Airfield (Table 1). Figure 1 shows a representative time series of wind speed at Environmental Buoy 46026 during water year 2006. The annual average at this location is 12.6 mph with a standard deviation of +/-7.0 mph

Table 1 Mean annual wind speed and sea level pressure for Stations 992640 Environmental Buoy 46026, 745090 at Moffett Field, and 745160 at Travis Air Force Base. (NOAA 2007)

	Wind Speed (mph)		
STA	*Environmental Buoy*	*Moffett Airfield*	*Travis AFB*
WY 2007	12.7	5.3	12.7
WY 2006	12.6	5.8	11.2
WY 2005	12.1	5.5	11.3
WY 2004	13.2	5.6	13.4
	Sea Level Pressure (mb)		
STA	*Environmental Buoy*	*Moffett Airfield*	*Travis AFB*
WY 2007	1017.4	1017.9	1016.4
WY 2006	1016.1	1017.0	1015.7
WY 2005	1015.5	1016.4	1015.4
WY 2004	1016.3	1014.3	1016.0

Beginning in 2003 and 2004, sea level pressure throughout the Bay peaked between 1020 mb up to 1033 mb from November to March. Wind direction, however, was less consistent and without dominant trends in water years 2003 and 2004, whereas in 2006 and 2007 the wind blew predominantly from the northwest (300° – 360°) in the South Bay and offshore, and from the southwest (210° – 250°) at Travis Air Force Base. Wind direction at Travis Air Force Base exhibited the greatest historical consistency, whereas the South Bay location had the greatest variability. The average annual wind speed throughout the Bay is relatively consistent temporally, but highly variable spatially. At the offshore location, the greatest magnitudes of wind speed (40 – 45 mph) generally occur during February and March, with the exception of WY

2005, which peaked at 40 mph in mid January. At Travis Air Force Base, historical peak wind speed values occur from June to August. Wind speed at Moffett Field also peaks during this late-summer period but is usually not as great as the other locations. However, WY 2007 at this location presents an exception: maximum speeds consistently reached over 20 mph between June and August. Data from 2004, 2005, and 2006 do not share this characteristic (NOAA 2007). In general, however, San Francisco Bay Area meteorology during water years 2006 and 2007 demonstrated similar characteristics both to each other and to historical data.

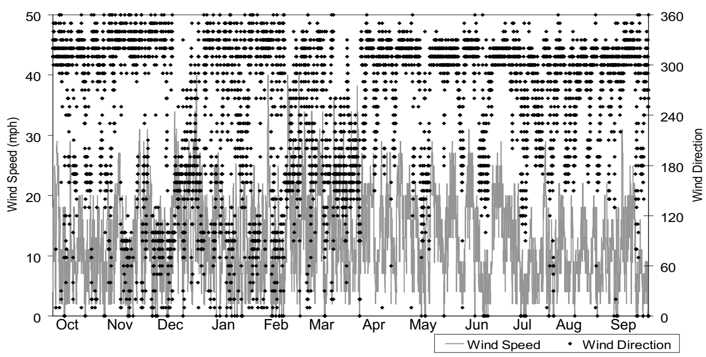

Figure 1 Wind speed and wind direction for WY 2006, Station 992640 Environmental Buoy 46026. Wind direction denoted 0 from north, 90 from east, etc. (NOAA 2007)

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Water Level in San Francisco Bay, Water Years 2006 and 2007

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Hourly water level data were analyzed for water years (WY) 2006 and 2007 at six stations. The data were retrieved from the National Oceanographic and Atmospheric Administration Physical Oceanographic Real-Time System (NOAA PORTS 2007), and the California Data Exchange Center (DWR 2007). Alameda, Golden Gate, Port Chicago and Redwood City stations provided complete records for WYs 2006 and 2007, whereas the Mallard Island and Richmond stations had significant missing. The datum for these data is mean-lower-low – water (MLLW).

Tidally-averaged water level was calculated with a low-pass Butterworth filter with a cutoff frequency of 1/40 hours (Warner et al. 2002). Water level at most stations was higher during WY 2006 than during WY 2007 (Table 1). This trend is in agreement with water flows, precipitation and salinity observations: increased water flows and precipitation during WY 2006 contribute to increased water level and decrease water salinity in San Francisco Bay (Loboschefsky, Carr, Hestir, all this issue). Of the stations with complete data sets, Port Chicago, being the closest to the freshwater source, exhibited the largest mean water level difference between WYs 2006 and 2007 (0.13 m), while other stations had a smaller and equal difference (0.09 m).

Table 1 Mean water level for NOAA PORTS and CDEC stations for WYs 2006 and 2007. (*) Incomplete data for WYs 2006 and 2007; (**) Incomplete data for WY 2007.

	Mean Water Level (m)		*Difference (WY 2006-WY 2007), (m)*
Station Name	*WY 2006*	*WY 2007*	
Alameda	1.09	1.00	0.09
Golden Gate	1.00	0.91	0.09
Mallard Island	0.45	1.13	(-0.68)*
Port Chicago	0.88	0.75	0.13
Redwood City	1.40	1.31	0.09
Richmond	1.09	0.95	(0.14)**

The Golden Gate Station plot in Figure 1 represents a typical graph of the water level as a function of time for the two water years. Water level in WY 2006 is more variable than WY 2007, presumably due to greater and more variable precipitation and freshwater inflows during WY 2006. Water level during WY 2007 generally decreases during the first half of the water year to a minimum in spring and then increases during the second half.

Shaded areas on Figure 1 indicate times when water level peaked at all stations during WY 2006. The distinct peaks occurred in December-January and February-June periods. Both peaks can be attributed to the freshwater inflow caused by the above average precipitation and run-off from melting snowpack during these periods (Loboschefsky, Carr, Ross, Zelin, this issue). Salinity was substantially lower for these periods as well (Hestir, this issue). This correlation also supports the hypothesis that freshwater contributed to elevated water levels in WY 2006.

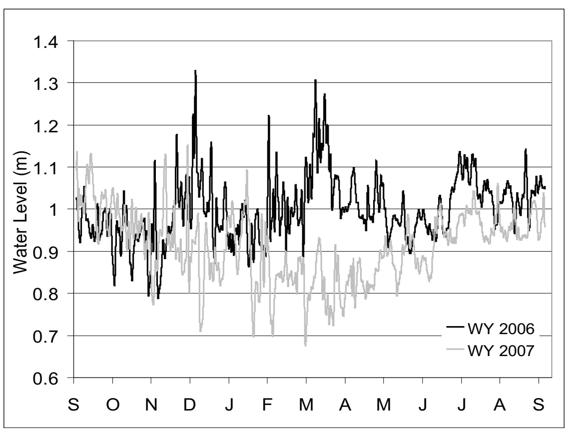

Figure 1 Tidally averaged water level at Golden Gate station for water years 2006 and 2007 (NOAA PORTS 2007)

The amplitudes of the peaks varied among the stations and with the proximity to fresh water sources in the Bay. For example, in WY 2006, the winter peak at Port Chicago reached 1.5 m, 0.62 m greater than the mean water level of 0.88 m, whereas Golden Gate and Alameda peaks were 1.33 and 1.41 m, both only 0.33 m greater than their mean values of 1.0 and 1.08 m, respectively. Redwood City water level followed a pattern similar to Figure 1. However, the peaks were at a substantially smaller amplitude because Redwood City is isolated from the major flood path from the Delta to the Golden Gate. The Richmond station did not provide much data throughout WY 2006, however, it had a distinct peak during spring.

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Salinity in the Bay and Delta, Water Years 2006 and 2007

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Salinity in the San Francisco Estuary was very different between water years (WY) 2006 and 2007, controlled primarily by differences in precipitation (Carr, this issue) and inflow into the Delta from the Sacramento and San Joaquin Rivers (Loboschefsky, this issue). Salinity in the Estuary is measured at continuous monitoring stations located in the San Francisco Bay at Tiburon (SFBEAMS 2007), in the Suisun Bay at Martinez and Port Chicago, in the Delta at Mallard Island, Collinsville, and Antioch, on the San Joaquin River at Jersey Point, and in the Sacramento River at Rio Vista and Cache Slough (CDEC 2007)

(Schoellhamer, this issue, Figures 2 and 3). Continuous hourly salinity data were downloaded from the SFBEAMS website in the practical salinity scale, and the CDEC website in units of electrical conductivity (micro- or milli-Siemens/cm) which was then converted into units of salinity in practical salinity units (psu; Schoellhamer and Buchanan 2007).

Longitudinal transects (145 km from Rio Vista to Calaveras Point (Station 36) in the South Bay) of the estuary are made by the US Geological Survey (2007), which uses a submersible instrument to gather water quality data, including conductivity, temperature, suspended solids, chlorophyll, and dissolved oxygen during monthly cruises with the *RV Polaris*. Surface and bottom salinity data were downloaded and a stratification metric was developed from the difference of surface and bottom salinities. This metric was plotted for each station as a function of distance from station 36 in the South Bay (Schoellhamer, this issue, Figure 3), the starting location of each cruise. These plots are reproduced for each month of the water year. Data were not collected in June 2006, May, 2007, and June 2007.

Hourly salinity data indicate that salinities overall were lower in WY2006 than WY2007. Most notably, Martinez, Port Chicago, Mallard Island, Antioch, Collinsville all had very low (< 1 psu) salinities from approximately January through July 2006. Figure 1 shows the hourly salinity data collected by the upper Port Chicago sensor. During this same low salinity period, salinity increased at the Cache Slough sensor from approximately 0.5 to 0.8 psu (January-April 2006), nearly half of the range of salinities measured by that sensor (not shown). The Yolo Bypass was used significantly in WY2006 and the Sacramento weir was opened from December 31, 2005 to January 9, 2006 (Ross, this issue). Schemel et al. (2004) described low specific conductance in the Yolo Bypass during periods of inundation, followed by rapid, persistent increases after Sacramento River inflow stopped. This post-inflow increase in the Yolo Bypass is consistent with the observed increase in 2006 in Cache Slough, which is downstream from the Yolo Bypass. Sensors downstream from Cache Slough did not record the increase in 2006. This increase at Cache Slough did not occur in 2007, as the Bypass did not have significant flow that year. In 2007 salinities in Antioch, Collinsville, and Martinez were lower from January through July than during the remainder of the water year, but remained much higher than for the same period in WY2006 (~1-5 psu).

Salinities measured by the *Polaris* cruises did not differ greatly (0-2 psu) between 2006 and 2007 during the months of October, November, and December. However, surface salinities measured in January, February, and March 2007 were significantly higher than the same monthly measurements from 2006; salinity was as much as 20 psu greater in January 2007 compared to January 2006. The greatest salinity differences between the two years were measured in the South and Central Bays. A qualitative comparison of salinity data from WY2006 and WY2007 with historic averages shows that while October-December salinities from both years did not vary much from historical averages, January-April salinities were lower than historic averages in 2006 and higher than historic averages in 2007. Additionally, vertical stratification in the Bay was much stronger in WY2006 than WY2007 (Figure 2), most likely due to high freshwater outflow in WY 2006 (Loboschefsky, this issue). Vertical stratification was greatest in the Central and North Bays. The difference between surface and bottom salinities was greatest in both years between January and May (data not collected in June), but 2006 differences were almost double those in 2007. This finding indicates that the Estuary was much more mixed in 2007 than 2006; South Bay was the most vertically mixed subembayment in both years.

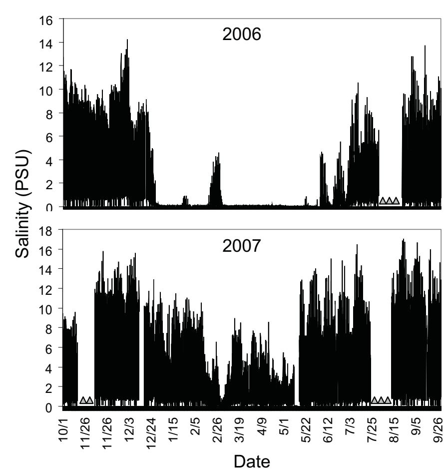

Figure 1 Hourly salinity data plotted against time for water years 2006 (above) and 2007 (below) collected by the upper Port Chicago continuous monitoring station. Triangles represent missing data.

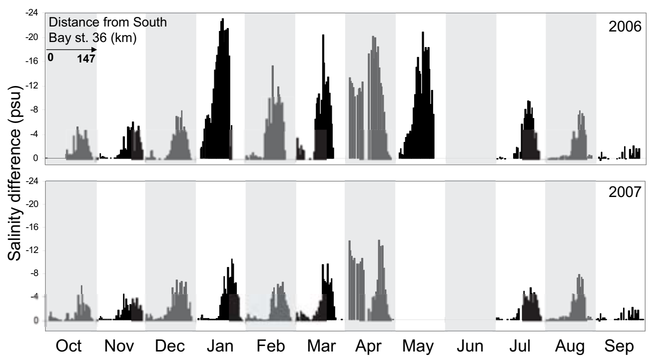

Figure 2 The salinity difference (surface-bottom) for each Polaris cruise station plotted as a function of distance from station 36 in the South Bay, for each month of the water year. Data was not collected in June 2006, May 2007, and June 2007.

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Suspended Sediment in San Francisco Bay and Delta, Water Years 2006 and 2007

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Throughout the San Francisco Bay and Delta, suspended sediment concentration (SSC) for Water Year 2006 followed historical trends with minor variations due to above average precipitation in January (Carr, this issue). SSC for Water Year 2007 dipped well below historical trends in March due to below average precipitation that month (Carr, this issue).

Suspended sediment concentration is measured monthly by a submersible instrument package at 37 fixed stations on the 147 km *RV Polaris* cruise (USGS 2007) from the South Bay starting at Calaveras Point (station 36) to Rio Vista in the Delta (Figures 2 and 3, Schoellhamer, this issue). Calculated SSC data for Water Years (WY) 2006 and 2007 and historical data were downloaded from the USGS Water Quality of San Francisco Bay website. Downloaded data, from the 37 stations were condensed into six geographic areas, the South Bay, Central Bay, San Pablo Bay, Carquinez Strait, Suisun Bay, and the Delta, (Figure 2, Schoellhamer, this issue) and plotted monthly for each water year with the historical data (Figure 1A-1F).

Starting in the South Bay, WY2006 began with relatively low surface and bottom SSC, consistent with historical data. SSC was higher than historical values at the end of WY2006 (Figure 1A). The South Bay, especially near station 36 (Figure 2, Schoellhamer, this issue), is shallow and thus highly susceptible to sediment resuspension by wind-driven waves (Schoellhamer et al., 2007). The northwesterly winds required to create such waves in the South Bay typically occur in the spring, however elevated bottom SSC in October WY2007 may be due to northwesterly winds through the entire summer of WY2006 (Weathers, this issue). SSC peaked in the South Bay to more than double historical values in February and April of WY2007. This elevated SSC was likely due to peak precipitation occurring in February (Carr, this issue), which caused the highest peak flow (Pan, this issue) and the first major pulse of sediment to enter the bay (Schoellhamer et al., 2007). This pulse is seen throughout the Bay in February WY2007 (Figure 1A-1F). The abnormally high SSC in April of WY2007 may have resulted from the annual spring increase in northwesterly wind (Schoellhamer et al., 2007).

The Central Bay (Figure 1B) showed a peak in SSC in January WY2006, which was likely due to above average rainfall and freshwater inflow for that month (Carr, this issue, Loboschefsky, this issue, Pan, this issue). Data was only available for the South and Central Bay for January WY2006. Aside from high SSC in January WY2006, and low SSC in March WY2007, SSC in the Central Bay generally followed historical trends throughout the year for both WY2006 and WY2007.

For WY 2006, SSC in San Pablo Bay (Figure 1C) followed historical trends except for dipping in April and May, possibly due to increased stream flows from spring snow melt (Carr, this issue, Loboschefsky, this issue, Ross, this issue, Zelin, this issue). San Pablo Bay SSC for Water Year 2007 followed the same trend as seen in the Central Bay.

Carquinez Strait for WY2006 experienced an above-average peak in bottom SSC in March, followed by below-average values in surface and bottom SSC throughout the remainder of the year (Figure 1D). The above-average bottom SSC may be attributed to a large longitudinal salinity gradient due to above-average freshwater inflows during March of 2006, causing gravitational circulation and consequent sediment convergence (Schoellhamer and Burau, 1998). For WY2007, Carquinez Strait experienced similar trends in SSC observed throughout the Bay.

For Suisun Bay (Figure 1E), SSC was very different in WY2006 and WY2007. Both generally followed the yearly historical trend, however, where WY2006 followed historical data trends with little vertical gradient in SSC, WY2007 had a significant vertical gradient in SSC, with surface SSC well below historical throughout WY2007 starting in January (Figure 1E).

Finally, SSC in the Delta for WY 2006 followed historical trends, with the exception of slightly lower SSC in February. This reduction was possibly due to the flushing out of all readily available sediment during the above average flows in January (McKee et al., 2006). For WY2007, January, February and March surface SSC were well below historical average, almost zero in March, possibly due to below average precipitation and flow (Carr, this issue, Loboschefsky, this issue).

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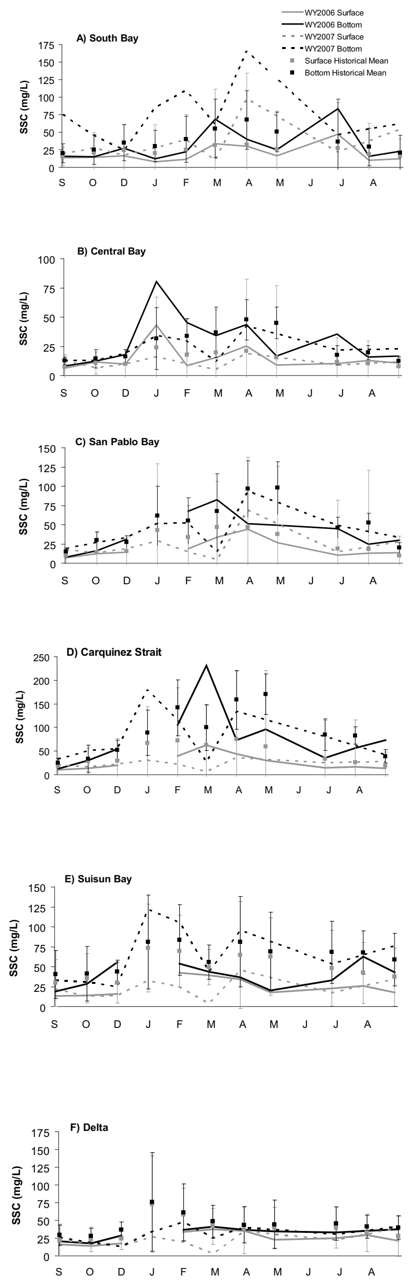

Figure 1 Surface (gray) and bottom (black) suspended sediment concentrations (SSC) in mg/L compiled for the South Bay (A), the Central Bay (B), San Pablo Bay (C), Carquinez Strait (D), Suisun Bay (E), and the Delta (F) plotted for WY2006 (solid line), WY2007 (dashed line), and historical (box with one standard deviation bar).

Water Temperature in San Francisco Bay and Delta, Water Years 2006 and 2007

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Water temperature in the San Francisco Estuary (SFE) is influenced by atmospheric heating, tidal excursion, solar radiation, air temperature, wind stress, and river and stream inflow (Lucas et al. 2006). Water temperatures data for SFE were retrieved from a USGS database, which provides vertical temperature profiles from a Conductivity-Temperature-Depth (CTD) instrument (USGS 2007). Because bottom and surface temperature generally followed similar trends, analysis for Water Years (WY) 2006 and 2007 was made only for surface temperature. To visualize the interdaily temporal and spatial distribution of the Bay temperatures, I plotted temperature as a function of distance from station 36. In this analysis, January is chosen as a representative month for December to March (which exhibited similar overall monthly spatial variability), whereas July exemplifies the period from April through November (Figure 1 and 2).

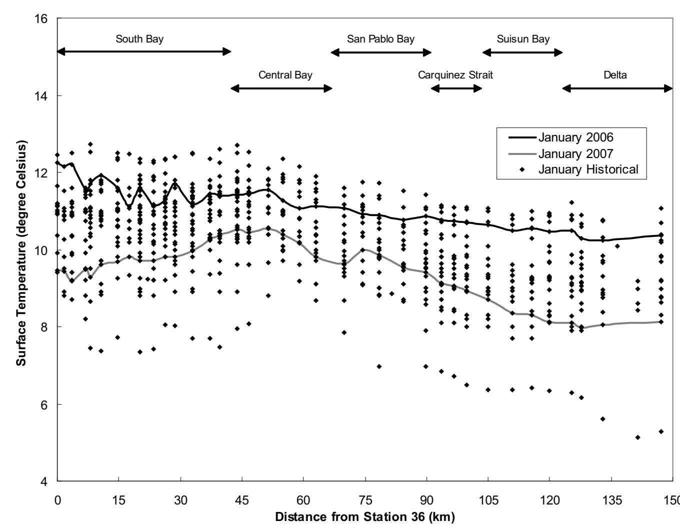

Figure 1 January 2006, January 2007, and historical January temperatures in the San Francisco Estuary.

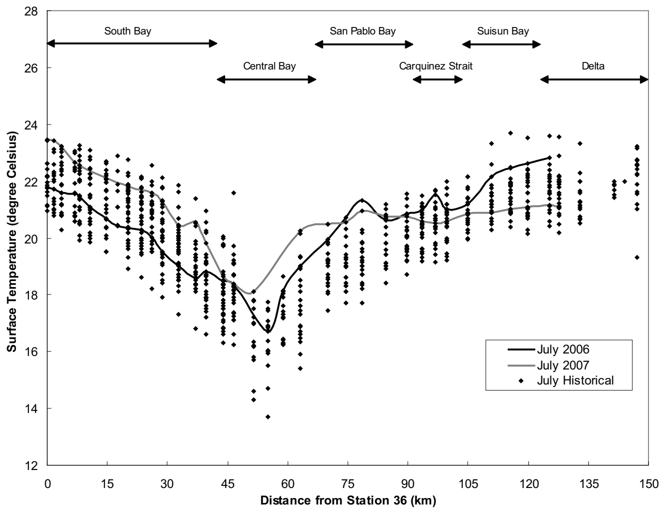

Figure 2 July 2006, July 2007, and historical July temperatures in the San Francisco Estuary.

Water temperature in the SFE exhibits temporal and spatial variability. Maximum and minimum temperatures in WY 2006 occurred in the Sacramento River, with 23°C in July and 10°C in March, respectively (Table 1). In WY 2007, temperature peaked at 23°C in July in the South Bay, while temperatures in the Sacramento River again hit an annual low of 8°C in January. The greatest variation of temperatures took place in the South Bay in WY 2007 with range of 14°C, followed closely by a range of 13°C in the Sacramento River during the same water year. Water temperatures in July 2006 were less than July 2007 from the South Bay to San Pablo Bay, after which they surpassed July 2007 steadily all the way to the Delta (Figure 2). However, Bay temperatures in January 2006 were consistently warmer than in January 2007 (Figure 1). July temperatures climbed to a historical high in San Pablo Bay during WY 2006. July 2007 also experienced record high temperatures in Central Bay as well as near station 36 in South Bay (Figure 2). Contrary to July, January temperatures in WY 2006 and 2007 followed the historical trend throughout the SFE (Figure 1).

The Pacific Ocean can influence water temperatures in the SFE (Connell, this issue). In July, minimum temperatures are found in Central Bay (Figure 2). Due to its vicinity to the Pacific Ocean, Central Bay is more susceptible to mixing with comparatively cooler oceanic water in July (Figure 2, Connell, this issue). The effect of mixing is especially obvious during the summer season when Bay temperatures were significantly higher than oceanic water. This effect was not illustrated by Bay temperatures in January (Figure 1) because the Bay and Ocean were about the same temperature.

Table 1 Surface temperature maximums, minimums, and ranges in the San Francisco Estuary for WY 2006 and 2007

WY 2006 USGS Stations	*Maximum Temp (°C)*	*Month*	*Minimum Temp (°C)*	*Month*	*Range (°C)*
South Bay	22	Aug	11	Jan	11
Central Bay	20	Aug	11	Jan	9
San Pablo Bay	21	July	11	Jan	11
Carquinez Strait	22	July	10	Mar	11
Suisun Bay	22	July	10	Mar	12
Sacramento River	23	July	10	Mar	13
WY 2007 USGS Stations	*Maximum Temp (°C)*	*Month*	*Minimum Temp (°C)*	*Month*	*Range (°C)*
South Bay	24	July	9	Jan	14
Central Bay	20	Sep	10	Jan	10
San Pablo Bay	21	July	10	Jan	11
Carquinez Strait	21	July	9	Jan	12
Suisun Bay	21	July	8	Jan	13
Sacramento River	21	July	8	Jan	13

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Chlorophyll in San Francisco Bay, Water Years 2006 and 2007

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Chlorophyll, a measure of phytoplankton biomass, showed temporal variability during water years (WY) 2006 and 2007 in the San Francisco Bay, where concentrations of chlorophyll can vary due to freshwater inflows, tides, solar radiation, and wind. Specifically, the spring-neap tidal cycle can have a large impact on chlorophyll concentrations in the San Francisco Bay (Cloern, 1996). During spring tides, there is vertical mixing in the water column, and phytoplankton is exposed to benthic grazers. During neap tides, there is less vertical mixing, which causes stratification to build, and the phytoplankton remains in the photic zone (Alpine et al., 1985). Chlorophyll in San Francisco Bay is measured during monthly cruises of the *RV Polaris* from South San Francisco Bay station 36 to Rio Vista (Figures 2 and 3, Schoellhamer, this issue). To analyze the temporal variability in chlorophyll concentrations for WY 2006 and 2007, surface chlorophyll concentrations were obtained from the USGS Water Quality of San Francisco Bay Database (USGS 2007). Surface chlorophyll concentrations were averaged for each subembayment and plotted for each month of the water year for the South and North Bay (Figure 1 and Figure 2). North Bay includes Carquinez Strait and Suisun Bay. Surface chlorophyll concentrations were analyzed instead of bottom chlorophyll concentrations because they are in the photic zone and had similar variability.

The South Bay regularly exhibits a spring bloom from February through May. February of WY 2006 featured the highest chlorophyll concentration ever recorded in February in South Bay (32.80 mg/m^3, Figure 1). During WY 2006, concentrations in the South Bay were relatively high when compared to historical averages. For WY 2007, the highest recorded chlorophyll concentration in the South Bay, 25.49 mg/m^3 (Figure 2), occurred in April. This value was relatively high when compared to historical averages. High concentrations of chlorophyll in the South Bay can be due to higher than average precipitation and freshwater inflow in WY 2006 (Carr, Zelin, Ross, and Pan, all this issue).

For the North Bay, a range of chlorophyll concentrations from 1.11 mg/m^3 – 6.3 mg/m^3 were recorded for WY 2006 and 2007 (Figure 2). The relatively low values in North Bay relative to historical values were likely due to the presence of a species of Asian clam known as *Corbula amurensis*, which have been changing the ecology of the San Francisco Bay since the 1980s. (Carlton et al., 1990).

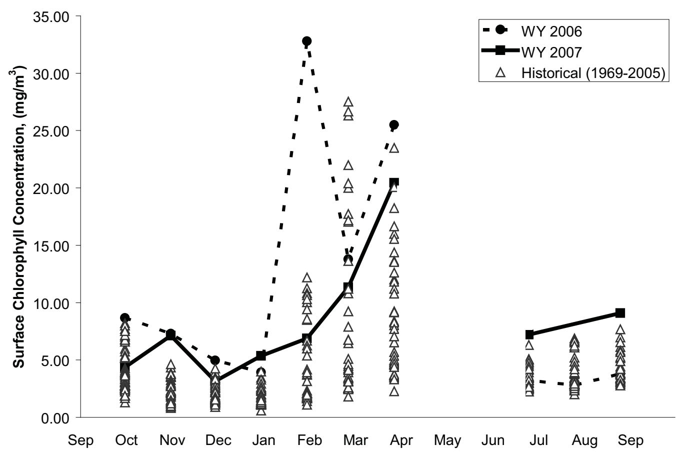

Figure 1 Surface chlorophyll concentration in South Bay plotted for each month of the water year. Data not collected in June 2006, May 2007, June 2007, and August 2007.

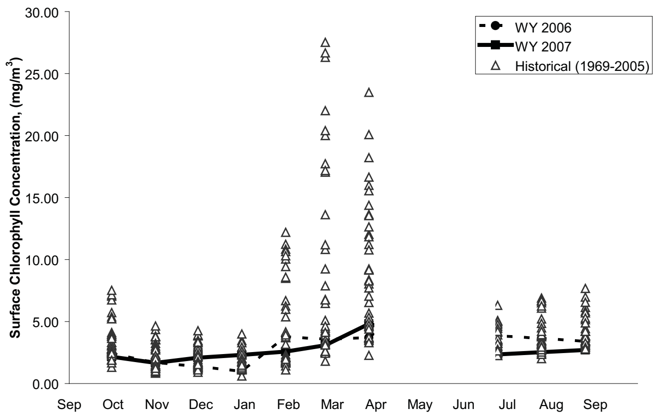

Figure 2 Surface chlorophyll concentration in North Bay plotted for each month of the water year. Data not collected in June 2006, May 2007, June 2007, and August 2007.

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