The Goleta Slough Watershed

A review of data collected from October 2005 through September 2006 by Santa Barbara Channelkeeper's Goleta Stream Team

by Al Leydecker

Introduction

The streams that drain the Goleta Slough watershed transport pollutants such as bacteria and excess nutrients down to the slough and ocean, and the purpose of Santa Barbara Channelkeeper's Stream Team program is to provide comprehensive monitoring of this ecologically important catchment. The Goleta Stream Team began in the summer of 2002 as a partnership program of Santa Barbara Channelkeeper and the Isla Vista Chapter of the Surfrider Foundation. The program has three goals: to collect baseline information about the health of the watershed; to help identify sources of pollution; and to educate and train a force of watershed stewards in the local community.

Stream Team conducts monthly on-site testing at designated locations on streams tributary to the Goleta Slough and in the slough itself. Near the beginning of each month, teams of volunteers measure physical and chemical parameters using portable, hand-held instruments. Data collected include on-site measurements of dissolved oxygen, turbidity, conductivity, *p*H, temperature and flow. Water samples are collected at each site and later processed in Channelkeeper's laboratory for three Public Health bacterial indicators using approved standard methodology (Colilert-18 and Enterolert-24, manufactured by Idexx Laboratories; US-EPA, 2003). Additional samples are analyzed for nutrients through the cooperation of the Santa Barbara Channel – Long Term Ecological Research Project (SBC-LTER) at the University of California, Santa Barbara. The nutrient parameters measured are ammonium, nitrite plus nitrate, orthophosphate, total dissolved nitrogen and total dissolved phosphorus. Characteristics such as vegetation and observed aquatic life are also recorded at each site. Occasionally, tests for other ions and contaminants are conducted. As part of every sampling event, instruments and meters are checked and calibrated against factory standards before taking them out into the field. Additional quality control checks are periodically performed in the field and as part of every bacteriological and chemical analysis.

In December 2006, a comprehensive report and analysis of the data collected during the first five years of the program was prepared and circulated to interested stakeholders, environmental organizations and government agencies. This report is available in PDF format on the Stream Team website at http://www.stream-team.org/Goleta/main.html, as are numerous other special reports on conditions in local watersheds. The data collected by Stream Team are also available here.

The purpose of this report is to supplement the original document, *Goleta Stream Team: 2002-2005*, and bring it up to date with a summary and analysis of an additional year of data. Since this document is meant to supplement rather than replace the original report, it does not contain the introductory sections describing the environmental setting, hydrologic background and detailed sampling site descriptions. The reader is referred to the original document for that information.

We include the historic maps (Figure 1) from that report as a reminder that the area of the slough has been substantially reduced over the years, from an estimated 1,150 to 430 acres, and the expansion of the Santa Barbara Airport currently underway will further reduce the natural habitat.

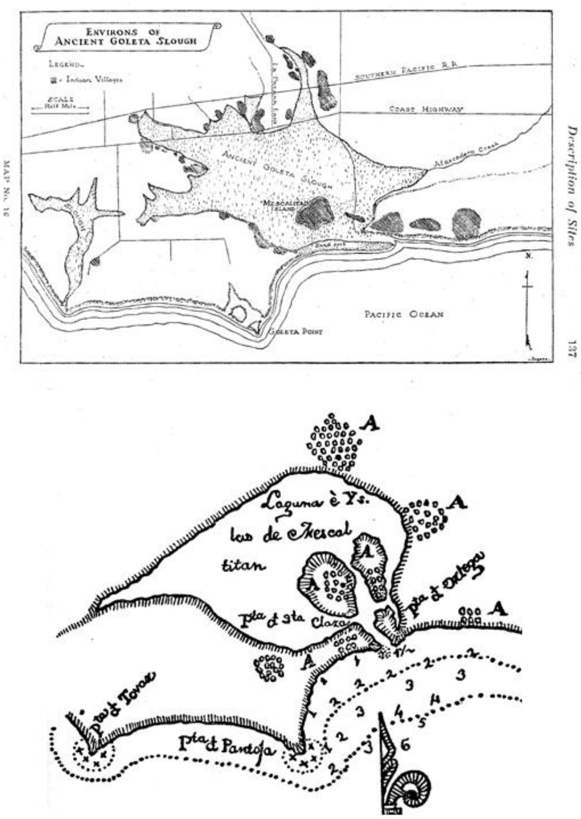


Figure 1. *Lower panel:* The villages of Mescaltitan, the earliest known map of the Goleta Slough by Pantoja y Arriaga, 1792. *Upper panel:* An artist's depiction of the historic slough boundaries on a more recent road map (all historical maps are from Nelson).

Table 1 shows the drainage area of each of the creeks that contribute to the 47 square mile slough watershed, and the percentage of land in major land-use classifications for each; the watersheds are shown in Figure 3. Atascadero Creek is the most urban, Los Carneros the least. Tecolotito has the most intensive agricultural use (citrus and avocado orchards), but all the creeks have a least some. Agriculture and urban uses typically contribute significant amounts of pollutants to both creeks and the slough. The vast majority of flow in these streams comes from flash discharges during major storms. While perennial water often flows at upper mountain elevations, it rarely reaches the foothills during the dry season, and most of the slough's tributaries usually run dry in early spring. The major exceptions are Tecolotito and Atascadero creeks, where agricultural runoff in the first case, and urban seepage and landscape watering ("urban nuisance" water) in the second, provide low flows throughout the year. Not all the tributary creeks are equally important to the functioning of the slough. Atascadero (Maria Ygnacio is part of the Atascadero system), San Jose and San Pedro enter the slough on its extreme eastern edge, within a few hundred meters of the mouth, and have little influence on slough conditions during most of the year. In contrast, Tecolotito and Los Carneros, although smaller streams, enter on the northwest corner and it is their waters, along with tidal inflows, that determine water quality for much of the wetland.

Table 1. *Watersheds tributary to the Goleta Slough. Land characteristics and uses are shown as a percent of total watershed area, "impervious" indicates the area of impervious surfaces (streets, sidewalks, roofs, parking lots, etc.) in the watershed – areas where almost all of the rainfall runs off onto surrounding lands and into the creek.*

	area	impervious	residential	commercial	chaparral	forest	agriculture
	sq. miles	%	%	%	%	%	%
Atascadero	7.5	20.4	43.3	5.8	18.6	6.4	23.2
Maria Ygnacio	12.0	4.4	8.2	0.9	52.6	26.0	10.8
San Jose	8.9	7.7	12.2	2.4	36.5	25.2	21.4
San Pedro	7.7	12.4	19.2	5.7	30.5	8.6	33.8
Tecolotito	5.8	11.0	12.9	6.2	34.0	14.2	30.4
Los Carneros	5.6	5.1	4.0	2.6	34.3	11.8	45.1

Sampling Locations

In selecting our Stream Team sampling sites, our goal was to sample at least two locations on each tributary, one just above the tidal limit, as close to the slough as possible, and the other as far up the drainage as practical, preferably above the urban boundary. Problems with access to private property and low initial volunteer numbers prevented us from fulfilling this goal. However, over time, volunteer participation has improved and additional sites have been added, a second Glen Annie (Tecolotito) Creek location in January 2003, an upper San Jose Creek site in January 2004, and two sites near the slough outlet in October 2004. Additional sites will be added in the near future. Sampling is typically accomplished by three teams: one on the Atascadero system, another on San Jose Creek and the slough, and a third monitoring Tecolotito, Los Carneros and San Pedro. A map of the watershed and sampling locations (original and added locations are shown in different colors) is shown in Figure 2.

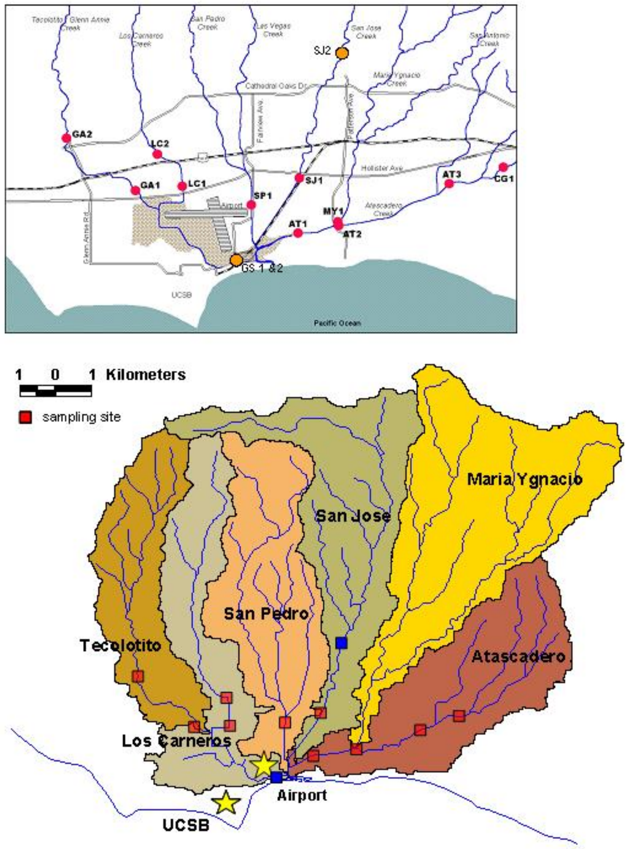


Figure 2: *Upper panel:* Map of Channelkeeper's Goleta Stream Team sampling sites. *Lower panel:* Sampling sites shown on a map of the Goleta Slough watershed. Locations added in 2005 are shown in blue.

AT1, Atascadero Creek at Ward Drive, is sampled on the upstream side of the small concrete and rock dam (weir) that lies on the far side of the bike path. The weir forms a boundary between fresh and tidal-influenced brackish waters and marks the entry of Atascadero system waters into the slough.

AT2, Atascadero Creek at Patterson Avenue, marks the junction of the two major branches of Atascadero Creek: Atascadero and Maria Ygnacio. Both are sampled at this location. Atascadero is unusual because, unlike most South Coast streams, it does not extend to the mountain crest but has its origins just above Cathedral Oaks Road. Sampling here monitors waters from suburban Santa Barbara.

MY1, Maria Ygnacio Creek at Patterson Avenue, is adjacent to AT2, on the north side of the bridge pier. The Maria Ygnacio branch of the Atascadero consists of Maria Ygnacio and San Antonio creeks. These drainages go all the way to the crest of the mountains and contribute most of the flow to the Atascadero system during storms. MY1 represents a “high quality” urban stream. It carries mountain water through suburban housing and parks and has a more natural channel than the other tributaries and a reasonable buffer area that helps protects the creek.

AT3, Atascadero Creek at Puente Drive, is sampled downstream of the bridge. The creek is contained within a steep-sided, concrete channel. The largest creek in the Santa Barbara area, Atascadero also has the longest continuous stream of water during the dry months, and we sample this stream at four locations. AT3 is the third location moving upstream.

CG1, Cieneguitas Creek at Nogal Drive, is sampled just above, or underneath, the bridge. This is the fourth sampling point on the Atascadero system. Above Puente Drive there are two major tributaries: Atascadero (which is usually dry) and Cieneguitas. Cieneguitas Creek is sampled for urban runoff from the upper State Street area.

Perhaps the best way to view the Atascadero sampling scheme is that at CG1, urban runoff from the relatively small area between upper State Street and Foothill Road is sampled. The change in water quality, when runoff from the more commercial uses around Modoc and Hollister are added, is monitored next (AT3). Then additional impacts, when agricultural and golf course runoff are included, are measured at AT2, and compared with what is expected to be cleaner flow from a less impacted creek (MY1). And finally, we look at what happens when plant nurseries and more agriculture are added to the mix and when the creek is converted into a long skinny lake during the dry season (AT1).

SJ1, San Jose Creek at Hollister Avenue, is monitored just downstream of a bridge crossing San Jose at the end of the Sizzler's Restaurant parking lot. After the rainy season this creek is often dry.

SP1, San Pedro Creek near Hollister Avenue, is sampled off of Fairview Road, approximately ¼ mile south of Hollister. This location is downstream of the Twin Lakes Golf Course (located on the uphill side of Hollister) and is typically dry during the summer. Both San Pedro and San Jose creeks flow through the heart of Goleta's commercial and industrial districts. Together they have almost as much flow as the Atascadero system and represent 35 percent of the Goleta Slough watershed.

LC1, Los Carneros Creek at Hollister Avenue, is sampled on the upstream side of the bridge. At this location, Los Carneros Creek is a cement channel containing little or no vegetation with businesses and parking lots lining both sides of the creek. Sampling here is difficult because there is no easy access. Often dry, sampling at this location was discontinued in 2006.

LC2, Los Carneros Creek at Calle Real, is sampled on the upstream side of the culvert. During the dry season flow is low, but there is usually enough water to sample. Since the Los Carneros watershed is relatively undeveloped, sampling here, above the Highway 101 intersection, gives us some idea of what runoff into the slough must have been like prior to urban development further downstream. Los Carneros and Tecolotito creeks are the most important freshwater sources for the slough; the other tributaries enter too close to the slough mouth to impact water in the slough itself. Compared with Tecolotito, Los Carneros is less developed and has fewer commercial or residential areas within its watershed.

GA1, Glen Annie/Tecolotito Creek at Hollister Avenue, is located at the rear of the commercial building on the northeast corner of Hollister and Los Carneros Road. The creek runs along the back edge of the parking area and it is sampled at about the mid-point. Here Tecolotito is relatively deep, wide and slow-flowing and flows year-round. Two sites are sampled on Glen Annie; this is the lowermost (downstream) site. Tecolotito Creek is the largest agricultural stream in Goleta, and sampling it at two locations allows us to separate the pollution signal originating from avocado and citrus ranches (and a golf course) in the foothill area from that coming from Highway 101 and commercial uses between the two sampling sites. Tecolotito and Los Carneros creeks supply most of the slough's freshwater. Of the two, Tecolotito is the major source of excess nutrient contamination.

GA2, Glen Annie Creek at Cathedral Oaks Road, is sampled between the culvert at Cathedral and the golf course access road bridge. This is the uppermost (upstream) Glen Annie site where the bulk of the agricultural and golf course runoff that strongly impacts Goleta Slough is monitored. The creek between the two Glen Annie locations flows with water throughout the summer because of these sources.

SJ2, San Jose Creek at North Patterson Avenue, is sampled just upstream of the bridge. This location, added to the program in January 2004, is right on the urban boundary and usually has year-round flow, mostly from upstream agricultural runoff. However, San Jose Creek is less impacted by agriculture than either Glen Annie or Los Carneros creeks. This is the furthest upstream point currently sampled in the program.

GS1 and GS2, Goleta Slough at the bicycle bridge, are two recently added sampling sites adjacent to Goleta Beach, near the mouth of the slough but upstream of where San Pedro, San Jose and Atascadero creeks join. The slough here is wide and tidally influenced and we sample along the bridge with a bucket at two locations, with GS1 nearer the ocean and GS2 closer to the airport. GS2 was recently eliminated since the data showed no significant differences between the two sampling points. GS1, the remaining sampling site, was relocated to the center of the bridge.

Hydrology

In the discussions and presentation of data that follow, the use of the terms “year” and “annual” will almost always refer to the “water-year.” Unlike a calendar year, the water-year begins on October 1 and ends the following September 30, i.e., water-year 2006, with which this report is concerned, began on October 1, 2005 and ended on September 30, 2006. Hydrologists and agencies concerned with water in California use a water-year concept because it better fits the seasonal progression of annual precipitation - rainy to dry, snowfall to snowmelt.

Rainfall Variability

The dominant hydrologic characteristic of the Santa Barbara area, and indeed of all streams in coastal southern California, is extreme inter-annual variation in rainfall and watershed runoff. Since 1868, the average winter rainfall in downtown Santa Barbara has been 18 inches (SBC-PWD).[1] However, “average” conveys no sense of the extreme variability. Very few years actually have “average” rainfall; most years are drier than average and a relatively few really wet years heavily influence the record (these are usually, but not always, associated with strong El Niño events; Null, 2004; Monteverdi and Null, 1997). If we define a “wet” year as having rainfall at least 150 percent above the average (greater than 27 inches in Santa Barbara), there have been sixteen “wet” years since 1868, approximately one every eight and a half years. The 1990s were unusual in that we had three wet years (1993, 1995 and 1998) within a relatively short span of time.

However, El Niños are just one of the climate cycles influencing local weather. The region is also impacted by the Pacific Decadal Oscillation (PDO), a roughly 50-year pattern of alternately cold and warm waters that abruptly shift location in the Pacific Ocean (Mantua et al., 1997; Minobe, 1997; Mantua, 2000). The “cold” PDO phase moves the jet stream (and a majority of

[1] Climate data for the Santa Barbara/Goleta area are also available from a number of internet sources: DRI-WRCC, CDEC, CCDA, CSB-PW, NWS-LA and JISAO.

winter rain) northwards, while the “warm” phase pushes it, and rainfall, southwards, giving the South Coast and southern California wetter winters.

Annual flows in the Goleta creeks, dependent on rainfall, mimic the Santa Barbara rainfall record, and both show the influence of these climate cycles. One way of displaying long-term patterns is a plot of *cumulative departures from the mean*. Taking Atascadero Creek as an example, its average annual flow is equivalent to 4.7 inches of rainfall (measured at Patterson Avenue; USGS-NWIS).[2] The upper panel of Figure 3 plots the cumulative rainfall and flow excess or deficiency, or in other words, a continuous accounting of how much each year’s rainfall or flow affected the long-term departure away from maintaining the 18-inch average rainfall or 4.7 inch per year average flow (falling points indicate below average annual values, rising points above average).

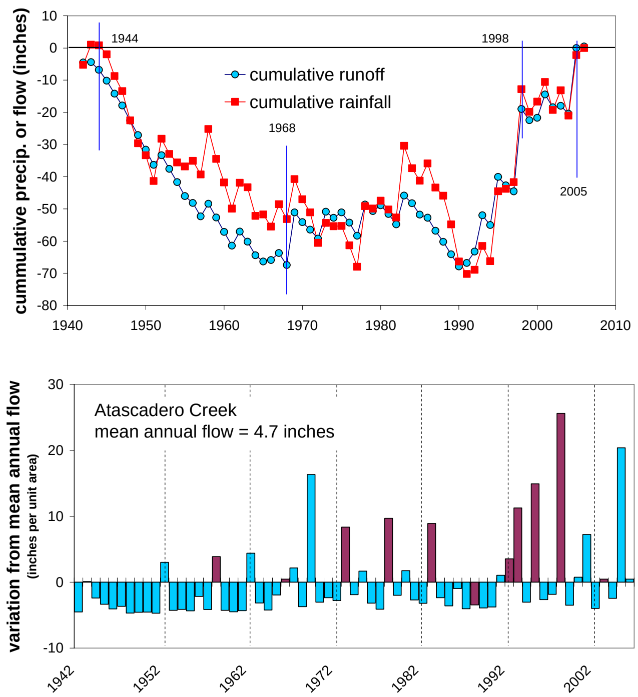


Figure 3. Upper panel: The cumulative flow excess or deficiency – how much each water-year’s flow at Atascadero (measured in inches of runoff at Patterson) varied from the 4.7 inch overall average – is shown with the Santa Barbara cumulative rainfall plot (average rainfall of 18 inches from 1942-2005). The flow pattern shows the same rising and falling trends as the rainfall record. Declining trends in flow are even more pronounced than those for rainfall (i.e., the 60s and 70s). Lower panel: Mean annual flow on Atascadero Creek (at Patterson Avenue) is 4.7 inches per unit drainage area (equivalent to 6.6 cfs). The distribution is skewed – “above the mean” years tend to be extremely wet. Years shown as dark bars were El Niño episodes. The chart shows a significantly greater number of wet years since 1991.

The plot shows a pattern of alternately rising and falling trends, where flow and rainfall were either generally above or generally below average, lasting decades. Increasing trends are generally caused by an increased frequency of wet years. The general pattern between 1944 and 1968 was for below average flows (a decreasing trend), but from 1968 to 1998 the trend reversed (except during the great California drought of 1987-1992). Since 1992, flows have generally been above average (lower panel, Figure 3).

[2] If we assume that the average rainfall in the Goleta watershed is roughly similar to that of Santa Barbara, then approximately 25 percent ends up flowing down local streams. Most of the rest is evaporated or transpired by plants and trees, and a smaller part recharges the groundwater table or is stored as soil moisture.

Cycles of Change

The extreme rainfall variability experienced in the Santa Barbara area engenders cycles of sediment deposition and removal, algal growth, and the advance and retreat of riparian and aquatic vegetation along the region's streams. In turn, these changes dramatically alter the appearance and biological functioning of creeks and adjacent areas and regulate inter-annual variations in commonly measured water quality parameters and the uptake of nutrients.

Major winter storms, such as occur during severe El Niño years, begin a transformational cycle by completely scouring natural channels of vegetation and fine sediment; this occurs roughly once every eight and a half years. The scoured streambed, with broadened flows, warmer water temperatures, the absence of shade and a nutrient-rich environment (caused by higher nutrient contributions from enhanced groundwater inputs following a wet winter along with abundant nitrogen and phosphorus from urban and agricultural runoff) becomes dominated by filamentous algae (principally *Cladophora*, *Rhizoclonium*, *Enteromorpha* and *Spirogyra* spp.). Under these conditions, even relatively undeveloped creeks or pristine backcountry streams provide a hospitable environment for explosive algal growth.

Even where nitrate concentrations are low, high phosphorus content from eroding mountain bedrock allows expanded growth of algal species able to utilize symbiotic relationships with bacteria to fix atmospheric nitrogen. As long as the storms of succeeding winters continue to be severe enough to keep the channel clean and sediment moving to the ocean, algae dominate and thrive.

However, sooner or later a low runoff year occurs – mostly sooner, since most years have less than half the average runoff (median annual flow in Atascadero is less than half the average). In the absence of severe winter floods, sediment accumulates in the streambed and seedlings, having gained a toe-hold the previous summer, become more deeply rooted. Plants begin to out-compete algae by over-shadowing the water surface and narrowing the channel through entrapment of fine sediment (Leydecker and Altstatt, 2002, Leydecker et al., 2003). The rapid re-growth of riparian vegetation (*Salix* spp. and *Arundo donax*) provide increased shade to a narrowed waterway and algal growth continues to be prevalent only in open waters. Over the years these processes increasingly stabilize the creek and elevate the threshold flow of any future scouring storm.

This narrative describes what happens in "natural" streams, those with rocky or sandy bottoms and banks, and minimally functioning riparian or buffer areas. A majority of the Goleta Stream Team sampling locations fit this description (i.e., GA1, GA2, CG1 and SJ2). However others, the engineered and "hardened" urban creeks (i.e., SP1, LC1, SJ1 and AT3), undergo accelerated and limited versions of the described cycle every year, as even small storms generate enough flow to scour concrete channels. Where there is no riparian buffer or overhanging vegetation, and where only limited sediments accumulate for the rooting of plants on concrete streambeds, *every* year is dominated by algal growth.

Since the start of the program, Goleta Stream Team has sampled a wide variety of conditions dictated by annual variations in rainfall. The previous big rainfall event, the last major flood that reset the transformational cycle seen during most of the sampling period, occurred during the severe El Niño winter of 1998. Throughout the years of sampling, from 2002 through 2004, Channelkeeper observed and documented these changes (cf. SBCK(a)). Figure 4 shows the variations in both monthly and annual rainfall that have occurred during the study period. Prior to 2005, one year was slightly above normal (2003) and two below normal (2002 and 2004), one of which (2002) could be characterized as a severe drought year.

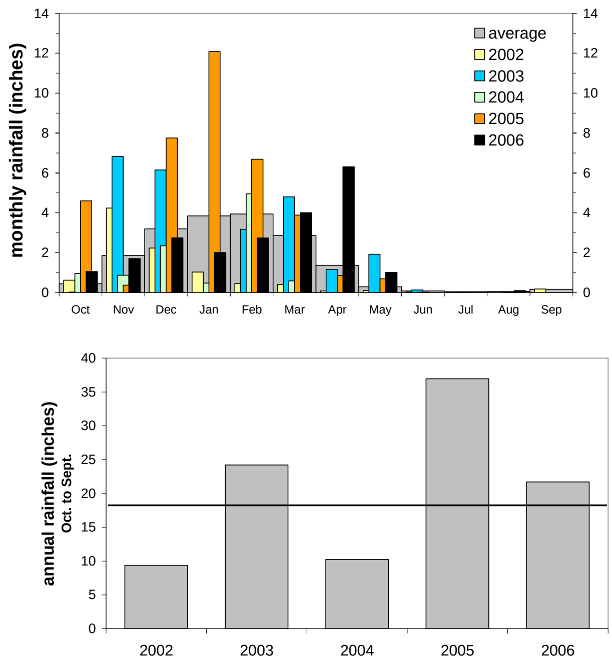


Figure 4. Monthly (upper panel) and yearly (lower panel) rainfall for 2006 and the earlier years of the Goleta Stream Team survey. The data are for downtown Santa Barbara. The heavy line in the lower panel represents the average annual Santa Barbara rainfall of 18.15 inches. While rainfall in 2006 was not as remarkable as in 2005, it was an above average year (21.7 inches). What was unusual was the extremely wet spring; April rainfall was 6.31 inches, the second wettest in recorded history (since 1868) and far above the median of 0.72 inches.

An Extraordinary Year

The 2005 water-year, characterized by very weak El Niño conditions in the Pacific, began with expectations of little more than another below-normal rainfall winter. However, in the three weeks following Christmas, the South Coast was hit with a series of major winter storms delivering impressive amounts of rainfall in two distinct pulses, the first from December 26, 2004 through January 4, 2005 and, after a few days of sunshine, the second from January 7-11, 2005. In downtown Santa Barbara, 9.5 inches were recorded during the first phase and the same amount in the second. The totals at San Marcos Pass were 18.2 and 24.6 inches, respectively. By the end of January, total Santa Barbara rainfall was more than six inches above the annual average.

As shown in the lower panel of Figure 3, not all wet years are severe El Niño years. At times, some extremely wet winters are caused by a much shorter weather cycle of 30-60 days called the "Madden-Julian Oscillation." Simplifying the description greatly, atmospheric high pressure off of the Pacific Northwest moves west, allowing a low pressure system to develop offshore, which in turn sweeps heavy moisture from Indonesia into southern California. This type of weather system is often called a “pineapple express” as the moisture plume passes over the Hawaiian Islands en route. This system delivered extraordinary amounts of rainfall in the winter of 2005. The rains continued through March and April, depositing a total of 37 inches in downtown Santa Barbara, more than twice the annual average.

Another good year

2006 was, again contrary to expectations, another good water-year. Total rainfall in downtown Santa Barbara was 21.7 inches (SBC-PWD). This was below the rainfall of 2001 and 2003 (Figure 4), but still 3.7 inches above average (6 inches above the annual median). But what made the year exceptional was the extravagantly excessive rainfall of April. In downtown Santa Barbara, 6.31 inches were recorded. The historical median for April rain is 0.72 inches (one half the recorded years had April rains below, the other half above, this amount). April 2006 proved to the second wettest April in Santa Barbara (since 1868) with more than eight times the normally expected amount of rain. The rains continued into May, with 1.2 inches compared to a long-term median (since 1927) of 0.03 inches. The bar graph in the upper panel of Figure 4 shows the wet nature of the spring of 2006 when compared with previous survey years, and highlights that most of the rainfall occurred rather late in the season (more than half the total rainfall fell after February).

One affect on the Goleta creeks of two good water-years in a row, one with exceptionally heavy rainfall and the other with an unusually wet spring, was enhanced groundwater inflows. Wet years, while noted for large amounts of runoff, also replenish groundwater reservoirs, elevating water tables and increasing dry-season seepage into rivers and creeks. This can be most directly seen in the unusually high flows that follow a wet winter, but there is also a carry-over of higher flows into subsequent years. Figure 5 compares annual rainfall and runoff for each year from 1998 through 2006 for three Goleta Stream Team sampling sites with gauging stations (USGS-NWIS) in the upper panel, and only April through September flows in the lower. Dry-season flows show little of the rough proportionality between runoff and rainfall visible in the annual totals, and 2006 was characterized by markedly high summer flows.

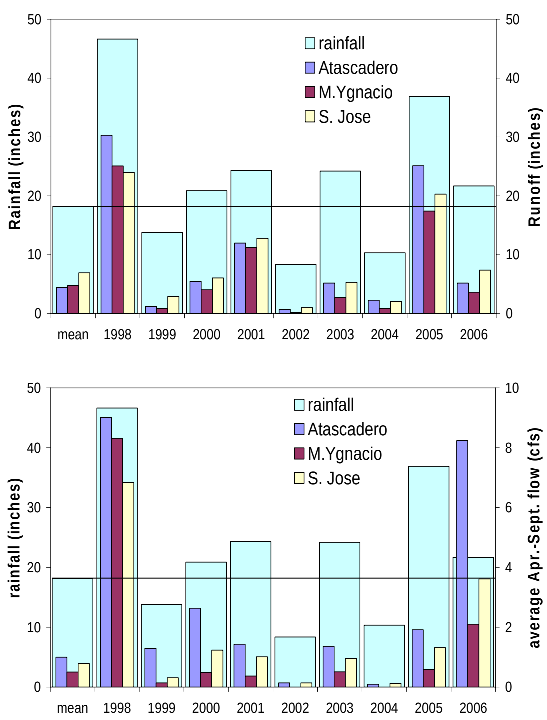


Figure 5. Annual water year rainfall (Santa Barbara/Goleta) is plotted for the severe El Niño year of 1998 and every year since. Annual runoff (in inches) for the three USGS gauging stations in the Goleta Slough watershed is shown on the right-hand axis in the upper panel, and the average April to September flow (in cubic feet per second, cfs) in the lower. The horizontal line represents the mean annual rainfall of 18 inches. Dry-season flows in 2006 were higher than in any year since 1998. (Flow data from http://nwis.waterdata.usgs.gov/ca/nwis/monthly/).

Appreciable rainfall was directly responsible for some of the increased April and May runoff, but flows in the months that followed were also higher than might have been expected (Figure 6).

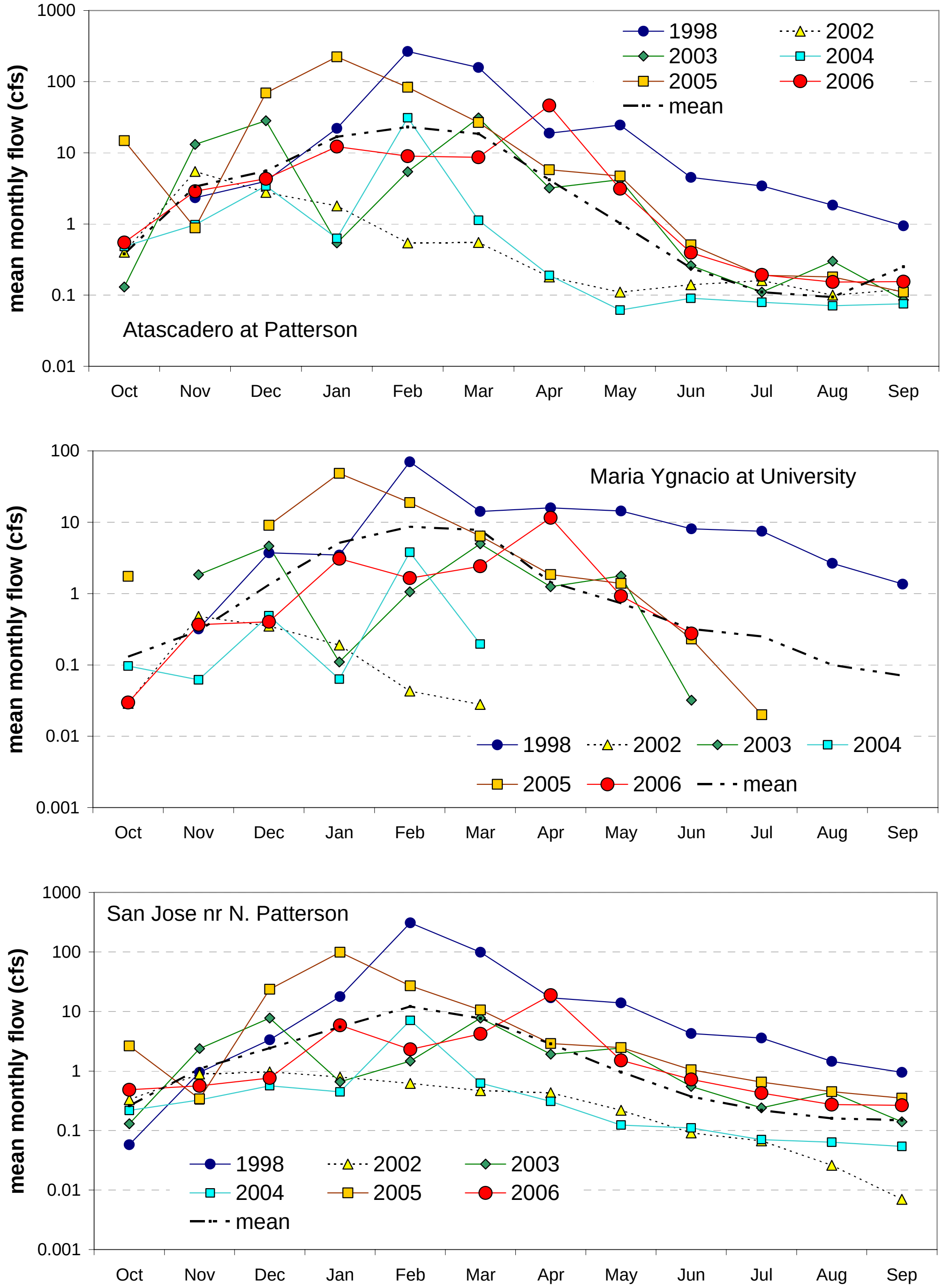


Figure 6. Monthly flows during 2006 contrasted with the big El Niño year of 1998 and earlier Goleta Stream Team survey years. Mean monthly flows from the historical gauging station record (since 1942 for San Jose and Atascadero, since 1971 for Maria Ygnacio) are also shown. Thanks to a wet spring, 2006 dry-season flows were nearly as high as in 2005 in spite of considerably less total rainfall.

Measurements of the depth to the water-table as recorded from wells provide some additional insight into groundwater variations and how they might influence seepage into local creeks. Data from two types of wells (USGS-NWIS), shallow wells that reflect annual variations in rainfall and the seasonal response that follows, and deeper wells that record long-term trends, are shown in Figure 7. Only limited amounts of data for 2006 was available at the time of this writing, but it clearly shows that shallow water-table levels remained high while deeper levels continued a long-term increase begun around 1991. These increases, aided by unusually heavy late spring rains, made 2006 a year with exceptional high dry-season flows.

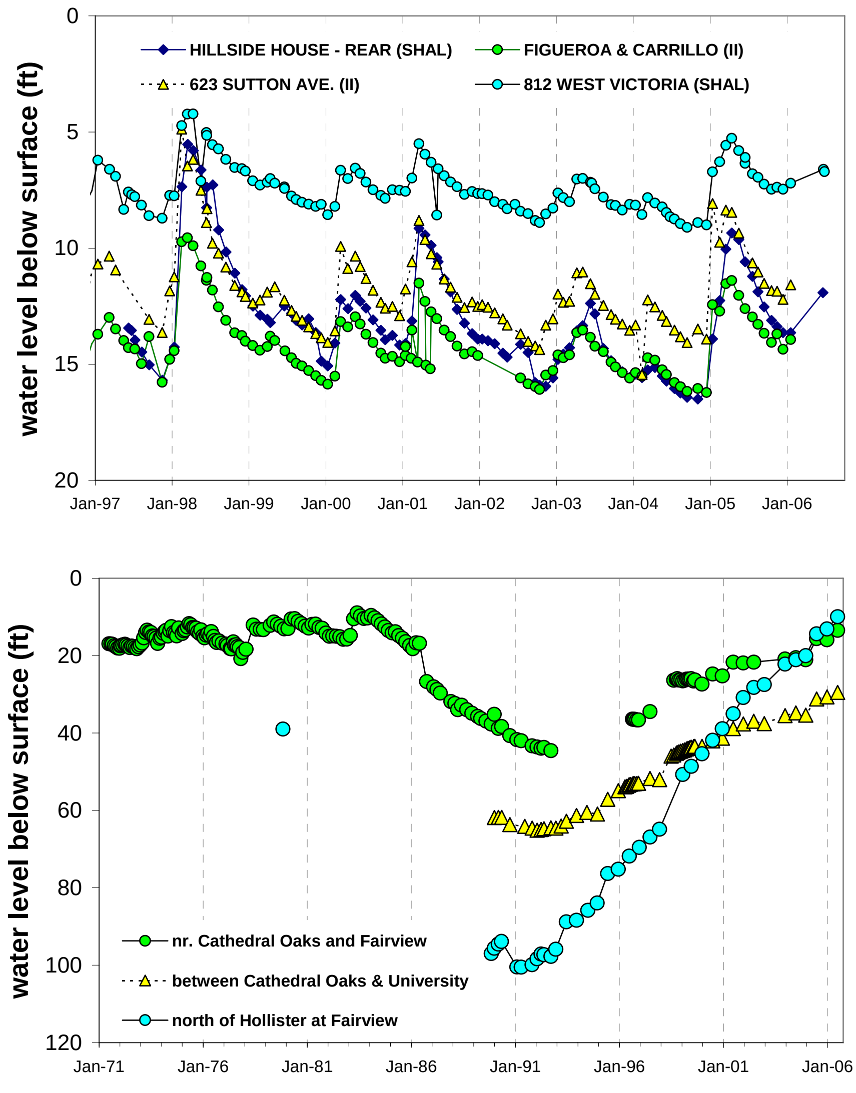


Figure 7. Water levels in shallow Santa Barbara City wells (upper panel) and in deeper wells located in the upper Goleta area (lower panel) (USGS-NWIS). By early summer 2006, shallow water table levels, while not as high as in spring 2005, had reached levels last seen in 2001. Deeper wells, in contrast, do not reflect year to year variations in rainfall, but exhibit the overall trend of increased rainfall since 1991 (cf. Figure 3). These too show an increase in 2006 over previous groundwater levels.

Conductivity[3]

Water is one of the most efficient solvents in the natural world with the ability to dissolve a great many solids. Most of these solids when put into solution carry an electrical charge. For example, chloride, nitrate and sulfate carry negative charges, while sodium, magnesium and calcium have positive charges. These dissolved substances increase water's *conductivity* – its ability to conduct electricity. Therefore, measuring the conductivity of water indirectly indicates the amount of total dissolved solids (TDS) in solution. It is not a perfect measure because some substances, particularly organic compounds like alcohol or sugar, are very poor conductors. Each stream tends to have a relatively consistent range of conductivity that, once established, can be used as a baseline for future comparisons. Conductivity tends to decrease in winter when heavy rainfall and runoff increase the amount of fresh, lower conductivity water flowing in streams. With increased flow, mineral concentrations become more dilute. Conversely, in late summer and fall, especially during periods of drought, high evaporation rates enable dissolved solids to become more concentrated, raising conductivity.

Conductivity is affected by temperature; as temperature rises, conductivity increases. For this reason, conductivity is usually reported at a standard temperature: standard conductivity is conductivity at 25 degrees Celsius (25°C). The basic unit of measure is the *siemen*: conductivity is measured in micro-siemens per centimeter (µS/cm) or milli-siemens per centimeter (mS/cm). Distilled water has a conductivity around 0.5 to 3 µS/cm. The conductivity of rivers in the United States generally ranges from 50-1,500 µS/cm. Drinking water is usually required to meet a standard of 1,000 mg/L total dissolved solids and a maximum conductivity of 1,600 µS/cm (cf. CSB-PW, 2004).

Conductivity in Goleta streams is usually above the 1,600 µS/cm limit for a number of reasons. For one, these waters have naturally high mineral content due to easily eroded marine sediments in the coastal mountains of their upper watersheds. Second, runoff from agricultural and suburban irrigation carries high mineral content into streams. Third, summer evaporation in very low and shallow flows concentrates dissolved solids in the water. Finally, these same flows in paved channels often pick up measurable amounts of calcium, carbonate and sulfate from concrete.

When presenting 2006 data for conductivity and all other parameters, we use two formats. One shows the 2006 monthly variation against a background of average monthly values (determined by averaging monthly results from 2003 through 2005), and the other shows the average 2006 value along with the long-term average from 2003 through 2005. In other words, monthly and average 2006 values are contrasted with previous results. This enables us to tell at a glance where significant departures from the expected have occurred. Since only two years of data are available for the Goleta Slough sampling location (GS1), and since we've seen significant flows in Maria Ygnacio (MY1) in only the last two years, variations during 2006 will be directly compared with those of 2005 at these sites. Monthly variations in conductivity for each sampling location are shown in Figure 8 and the annual averages in Figure 9.

[3] US-EPA (1997), Deas and Orlob (1999) and Heal the Bay (2003) were used in the preparation of the sections on water quality parameters.

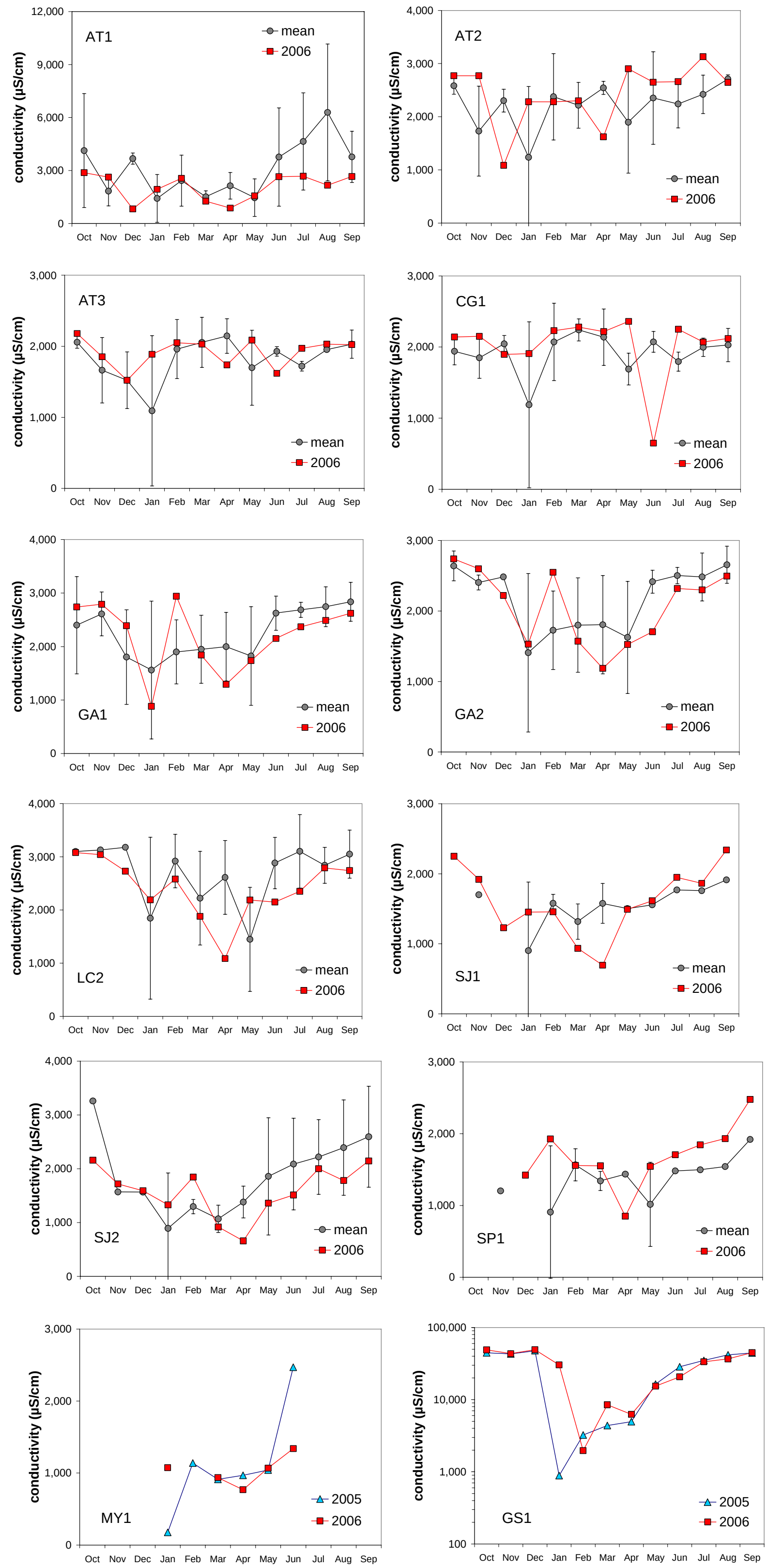


Figure 8. Monthly conductivity for the Goleta Stream Team sampling locations during the 2006 water-year is shown with along with average monthly conductivity from 2002-2005. Error bars indicate the standard deviation in monthly conductivity. Conductivity at MY1 and GS1 in 2005 and 2006 are shown in the bottom panels.

Figure 8 indicates that 2006 conductivities were below average in some locations and above average in others. All sites show lower than usual April values due to appreciable rainfall. Measurements taken during or soon after storms show very low conductivities due to large amounts of fresh runoff. Rain in the Santa Barbara area generally has a conductivity between 10-40 µS/cm.

Error bars in Figure 8 indicate the monthly standard deviation. The inference is that we could expect conductivity to fall within the error bars every two out of three years. In other words, a 2006 value within the error bars can be considered relatively normal. For statisticians, reasonable values are those which fit between *two* standard deviations – twice the limits shown by the error bars – and Figure 8 shows very few results that fit this description.[4]

However, statistical tests with Goleta Stream Team data provide only a rough measure of differences at this point in time. One problem is that too few years of data have been collected for the purposes of comparison, and some of those years were quite different (i.e., drought conditions in 2002 vs. an extremely wet year in 2005). Another problem is that measurements affected by rainfall, while relatively rare (statistically speaking, samplers will encounter rain approximately once every other year) dramatically increase the standard deviation. Months in Figure 8 that show a large difference between error bars, i.e., indicating a wide variation in monthly values, include storm values in the data record. Monthly averages derived from limited data show no error bars in the figure and some months are totally absent; these data identify sites that are usually dry during those months (i.e., SP01 and SJ01 in the fall). Maria Ygnacio, which in some years has no sampled flow at all, is not even shown for these reasons.

These problems aside, the general tendency seems to be lower conductivity during the dry season on agricultural streams with year-round water, such as San Jose, Los Carneros and Glen Annie. Increased seepage into these streams from shallow, lower conductivity groundwater after the late spring rains is a possible reason. Conductivity, everything else being equal, generally increases with the age of water – the longer water is in contact with soil or geologic strata, the higher its conductivity. Groundwater has higher conductivity than water in the soil, and older groundwater has higher conductivity than younger.

In contrast, three of the four Atascadero sampling sites (AT2, AT3 and CG1) show increases in dry-season conductivity, although in June there was an abrupt departure from this pattern. It is difficult to identify a possible reason. These summer flows are derived from urban nuisance waters of indeterminate origin and may simply be subject to large variations. Still, some locations have had a record of consistent conductivity over the years (i.e., very small standard deviations for some months at AT3 and CG1), and the 2006 values are a suprising departure. Interestingly, dry-season conductivity at AT1 was lower than usual, begging the question as to why.

Between AT2 and AT3, Atascadero Creek takes on the form of a long, skinny lake, and its water quality parameters exhibit lake-like characteristics. When flow is very low, water is retained in this section for long periods of time and increases its conductivity via excessive evaporation – note the increase towards extremely high previous values from May to August shown on the graph. Greater flows in 2006 decreased residence time, which led to reduced evaporation and lower conductivity.

[4] Measurements that fall outside of two standard deviations are considered relatively rare, normally occurring only five percent of the time. Applying this to monthly conductivity, this occurs only once every twenty years and a value this far outside the norm would be considered significantly different.

At the Goleta Slough site (GS1), conductivity in 2006 was generally similar to that in 2005. Note the use of a log scale in Figure 8, which was necessary to demonstrate the wide variation in values that occurs over a year. The lowest value was 886 µS/cm measured during the storms of January 2005 when the slough contained only fresh runoff; the highest was 49 mS/cm, close to the 53 mS/cm figure typically used for the Pacific Ocean. Conductivity is a good indicator of exactly what kind of water resides in the slough at any point in time, but that is addressed in a later section discussing data from the slough.

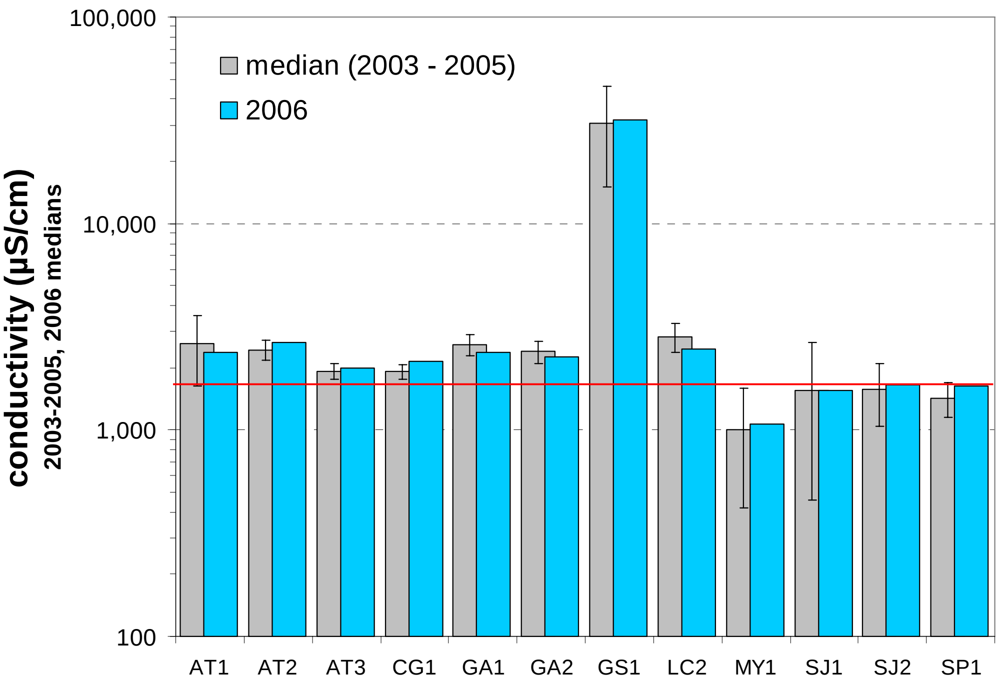


Figure 9. Median conductivity during the 2006 water-year is contrasted with median conductivity for the previous three years (2003-2005). The error bars indicate the twice the standard error of the median, i.e., the 2006 median would be expected to lie within these error bars, whereas anything beyond these limits could indicate a significant change. No locations exhibit this kind of change. The horizontal line represents a generally accepted upper conductivity limit of 1,600 µS/cm for drinking water. GS1 measures salt/brackish water near the mouth of the slough.

Conductivity results are summarized in Figure 9, where median 2006 conductivity is contrasted with the median of all previous data.[5] A large difference between the average and the median (as was noted for annual flows at Patterson Avenue) indicates an unbalanced distribution of data.

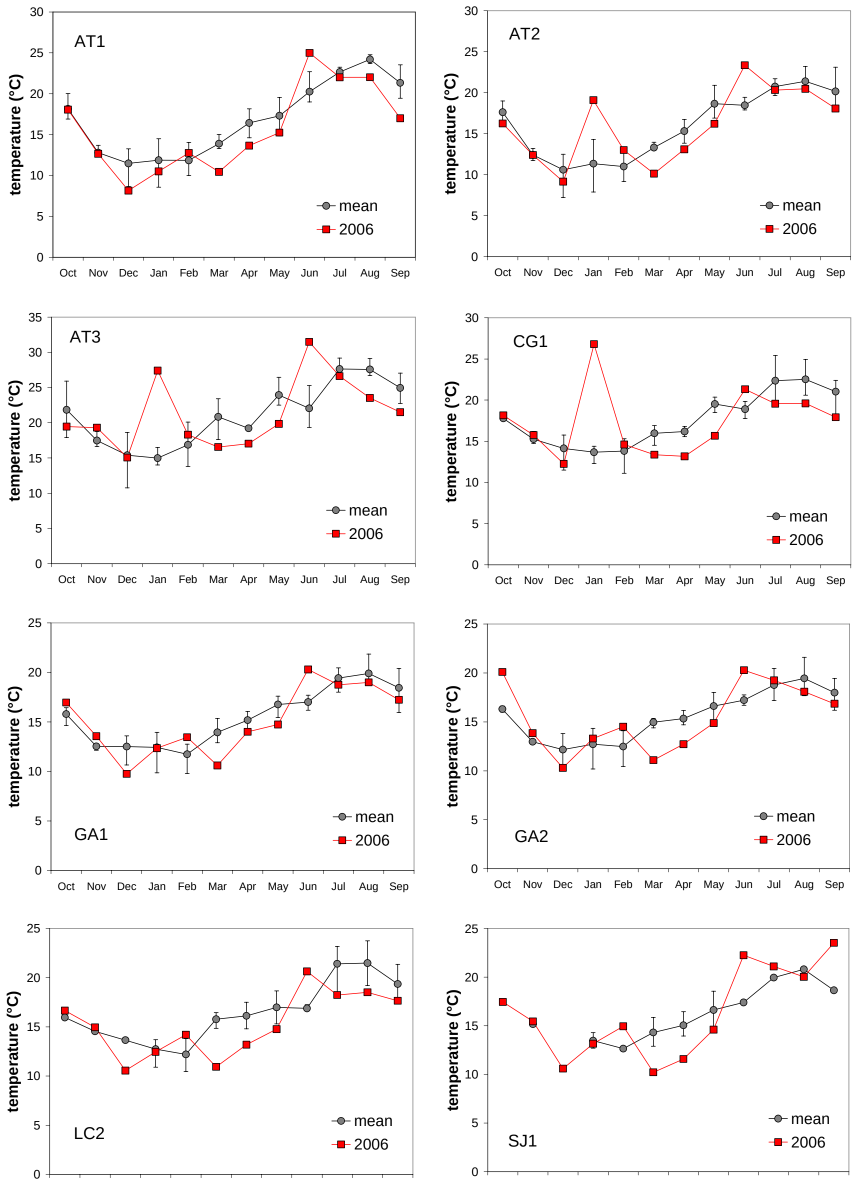
The error bars in Figure 9 show twice the standard error of the median. The standard error indicates how much variation might be expected from repeated measurements on the same stream; the smaller the error, the greater the confidence that the mean or median accurately characterizes the stream. With the exception of CG1, none of the sites show a 2006 value that falls outside of the error bars, i.e., none of the differences noted in 2006 were significant except

[5] The *median* is the middle value in a series of measurements: half the monthly measurements are above the median, half below. When very high or very low values (such as conductivity during a storm) occasionally occur in a data series, the median is a better measure of the typical or normal value than the average or *mean*.

for that location. Almost all of the Goleta Stream Team sampling sites have median conductivities above the 1,600 µS/cm drinking water limit. Sites than do not, such as MY1, are almost always dry between storms and their measurements reflect the lower conductivity values of stormflow. GS1, measured near the mouth of the slough, records the highly brackish[6] environment of this location.

Temperature

The expected annual pattern for water temperature is straightforward - rising from winter lows to summer highs and then decreasing in early fall. In other words, water temperature follows changes in air temperature.



[6] Containing a mixture of seawater and freshwater.

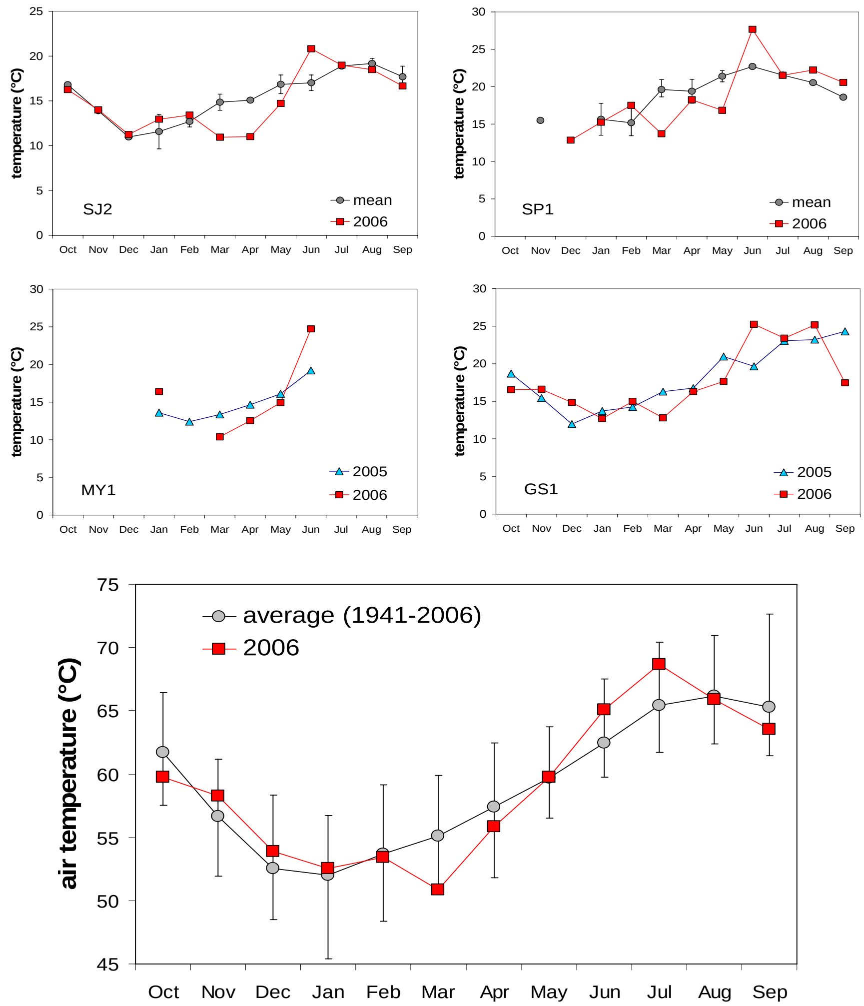


Figure 10. Monthly water temperatures for the Goleta Stream Team sampling locations during the 2006 water year are shown with average monthly temperatures from 2003-2005. Error bars indicate the maximum and minimum temperatures recorded in past years. Water temperatures at MY1 and GS1 for 2005 and 2006 are shown in the middle panels. 2006 average monthly air temperatures are contrasted with long-term values on the bottom. Error bars indicate maximum and minimum average monthly air temperature.

In Goleta, that pattern is observed at all sites (Figure 10), albeit there were some significant 2006 departures from average monthly water temperatures measured in past years. The error bars in Figure 10 indicate the maximum and minimum monthly temperatures recorded in the past.

One obvious difference between 2006 and the long-term average was that of lower water temperatures in March, April and May. Abundant rain and increased flows account for the difference. The last chart in Figure 10, showing average air temperatures in 2006 and comparing them with the long-term monthly means, indicates that temperatures in March and April 2006 were lower than normal. In contrast, air temperatures in June were higher than normal, possibly accounting for the higher June water temperatures exhibited at all sites. However, comparing monthly averages of air temperature with water temperature measured on a single day is not definitive. The weather in early June was unusually warm, with the two days preceding the June 5th sampling exhibiting temperatures in the high 80s. That all sites show similar trends during these months indicates that the probable cause must be general in nature, like weather, and not particular to a single stream or small group of streams.

It is more difficult to explain is what might account for above average temperatures seen at the upper three Atascadero locations in January 2006. These values are nothing short of extraordinary, measuring near 30°C, almost 15°C above the mean of previous years. The water temperature at CG1 was the highest ever recorded by Goleta Stream Team at that site. The validity of the data is not in question. Water temperature is the most accurate measurement made during sampling since it is measured nine separate times using three different meters at each location. It is obvious that somewhere upstream of CG1 hot water was released into the creek (30°C is 87°F, and the original source had to be considerably warmer). Unfortunately the source remains unknown, although the volume released had to be considerable since abnormally high temperatures were seen at three different sites over a period of an hour and a half.

Plant cover, increased flows and cooler weather produce lower water temperatures while the opposite circumstances produce higher. Sites with adequate riparian cover (GA1, GA2, SJ2) have cooler water temperatures than those without (AT1), but the highest temperatures are seen in open concrete channels (AT3, SP1 and SJ1). Sites that go dry often show aberrant results during the low trickling or puddle type flows seen at the beginning and end of wet episodes.

Annual averages (with error bars denoting maximum and minimum water temperatures for both 2006 and the overall average) are shown in the bottom panel of Figure 12. Aside from increased maximum temperature measurements at some locations, there were no overall changes from past years. The graph includes three horizontal lines to help put these results in perspective. These mark important threshold temperatures for trout and steelhead: above 24°C leads to death; below 16°C indicates good dry-season conditions; and below 11°C in winter is excellent for spawning and incubation (Brungs and Jones, 1977; Armor, 1991; McEwan and Jackson, 1996; Sauter et al., 2001). As temperatures rise, fish find it increasingly difficult to extract oxygen from water, while at the same time the maximum amount of oxygen able to be held in solution decreases.

While the temperature requirements for steelhead are rather stringent, warm-water fish have greater tolerance for higher temperatures. Channelkeeper data show that temperatures often increase above 24°C in late summer and rarely drop below 11°C in winter. Reasonable departures from these criteria are probably not a vital concern. Southern steelhead evolved in what are essentially warm-water rivers and streams and undoubtedly have greater tolerance for higher temperatures than their more northern cousins; moreover, fish are not passive participants but are free to seek out more favorable conditions (Matthews and Berg, 1997; Stoecker, 2002).

Dissolved Oxygen

Aquatic organisms are dependent on the presence of oxygen; not enough dissolved oxygen and they weaken or die. Water temperature, altitude, turbulence, season and time of day all affect the amount of oxygen in water; water holds less oxygen at warmer temperatures and higher altitudes, and photosynthesis by plants and algae can cause significant variations.

Dissolved oxygen (DO) is usually measured in milligrams per liter (mg/L) or percent saturation. Milligrams per liter is the weight of oxygen in a liter of water.[7]

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[7] It is often simpler to think of mg/L as “parts per million” (ppm); since a liter of water weighs a million milligrams, 1 mg/L is the same as one part of dissolved oxygen in a million parts of water.

Cold-water fish (trout and steelhead) require oxygen levels above 6 mg/L and DO above 8 mg/L may be required for spawning (Davis, 1975; US-EPA, 1986; Bjorn and Reiser, 1991; Deas and Orlob, 1999). Warm-water fish can tolerate concentrations as low as 4 mg/L. Below 4 mg/L, fish are in danger, and below 2 mg/L, usually defined as the beginning of hypoxia, all other aquatic organisms become stressed. Anoxic conditions, i.e., the total disappearance of oxygen, is not only fatal to oxygen-dependent biota but also leads to fundamental microbial and geochemical changes in stream and sediments.

Dissolved oxygen concentrations during 2006 at the Goleta Stream Team sampling sites are shown in Figure 11. Also shown are average monthly concentrations from 2002-2005. Error bars on these values represent the maximum and minimum values of past measurements. Compared with previous results, DO in 2006 presents a mixed picture. In some months we saw new maximum concentrations while in others we saw new minimums. Unlike conductivity and water temperature, there appears to be little consistency in the year to year pattern for DO. Only at some sites do we see a general trend towards higher winter concentrations (December-March), caused by colder temperatures and increased aeration (i.e., riffles and cascades), followed by lower values in summer and fall (i.e., CG1, AT2 and GA1). Elsewhere, biology and other factors overwhelm the physics of oxygen solubility.

With the exception of lower Atascadero (AT1), monthly concentrations were always above 4 mg/L, and except for low values at a number of sites in October, almost always above 6 mg/L. A majority of the monthly 2006 measurements were above 9 mg/L. Unfortunately, this is not good news. DO concentrations can often be too high and, as such, indicate problems.

Stream sampling typically takes place in daylight. During much of the year, algae and underwater aquatic vegetation use sunlight for photosynthesis, removing carbon dioxide from the water column and replacing it with oxygen. This process is reversed at night when oxygen is

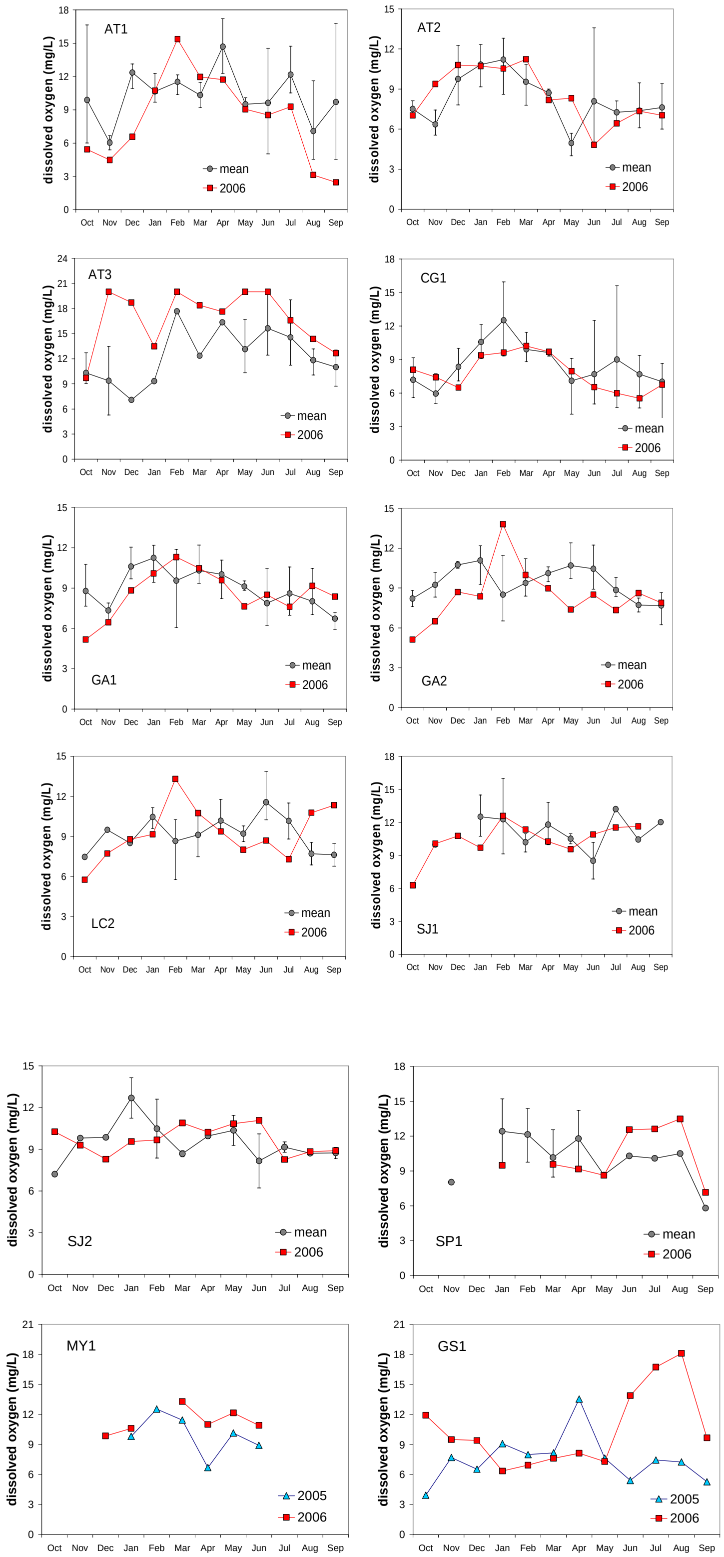

Figure 11. Monthly dissolved oxygen concentrations for the Goleta Stream Team sampling locations during the 2006 water-year are shown along with average monthly concentrations from 2002-2005. Error bars indicate the maximum and minimum values recorded in past years. Dissolved oxygen at MY1 and GS1 in 2005 and 2006 are shown in the bottom panels.

removed and carbon dioxide added (Carlsen, 1994; NM-SWQB, 2000). Thus very high daytime oxygen concentrations can indicate an overabundance of algae. Under these conditions, oxygen reaches a minimum just before sunrise, and concentrations during this critical period determine the actual threat to fish and other aquatic species, a threat that is ordinarily not evaluated (Windel et al., 1987; Deas and Orlob, 1999; PIRSA, 1999).

Summertime water temperatures in Goleta usually peak somewhere between 20-25°C (Figure 10). Water at these temperatures, in equilibrium with a sea-level atmosphere, can contain maximum concentrations of 9 and 8.25 mg/L of dissolved oxygen, respectively (i.e., when completely saturated). Winter stream temperatures are generally around 10-15°C, allowing DO concentrations of 10-11 mg/L at complete saturation. Therefore, summer concentrations above 10 mg/L, or winter concentrations greater than 12 mg/L, are an indicator of too much oxygen during daylight testing (and therefore the possibility of too little during the early morning hours that follow), and many of the Goleta Stream Team sampling sites exhibit this problem during at least part of the year.[8]

Goleta Stream Team also measures *percent saturation*, the amount of DO compared with what water, at the measured temperature and altitude, can hold at equilibrium; in other words, the oxygen excess or deficiency compared with a theoretical maximum. Theoretical, because streams can often be super-saturated with oxygen (i.e., contain greater than 100 percent). The key word is *equilibrium*, meaning the attainment of some steady state, a balance between the amount of oxygen entering and the amount leaving. A stream slowly warming as morning air temperatures rise can become super-saturated, as can a turbulent reach actively entraining oxygen. But the only process capable of achieving high amounts of super-saturation is photosynthesis. A dissolved oxygen content in excess of 120 percent saturation is a good indicator of algal problems (it can go as high as 400 percent). Figure 12 shows 2006 percent DO saturation results for the sampling sites and demonstrates the large extent of algal problems during the past year. At only three locations - AT2, CG1 and GA1 - was this indicator of excessive algal growth absent.

[8] Note the late winter/early spring oxygen peaks at AT1 and SP1, the summer and early fall peaks at SJ1 and SJ2, and the almost year-round presence of abnormally high oxygen levels at AT3.

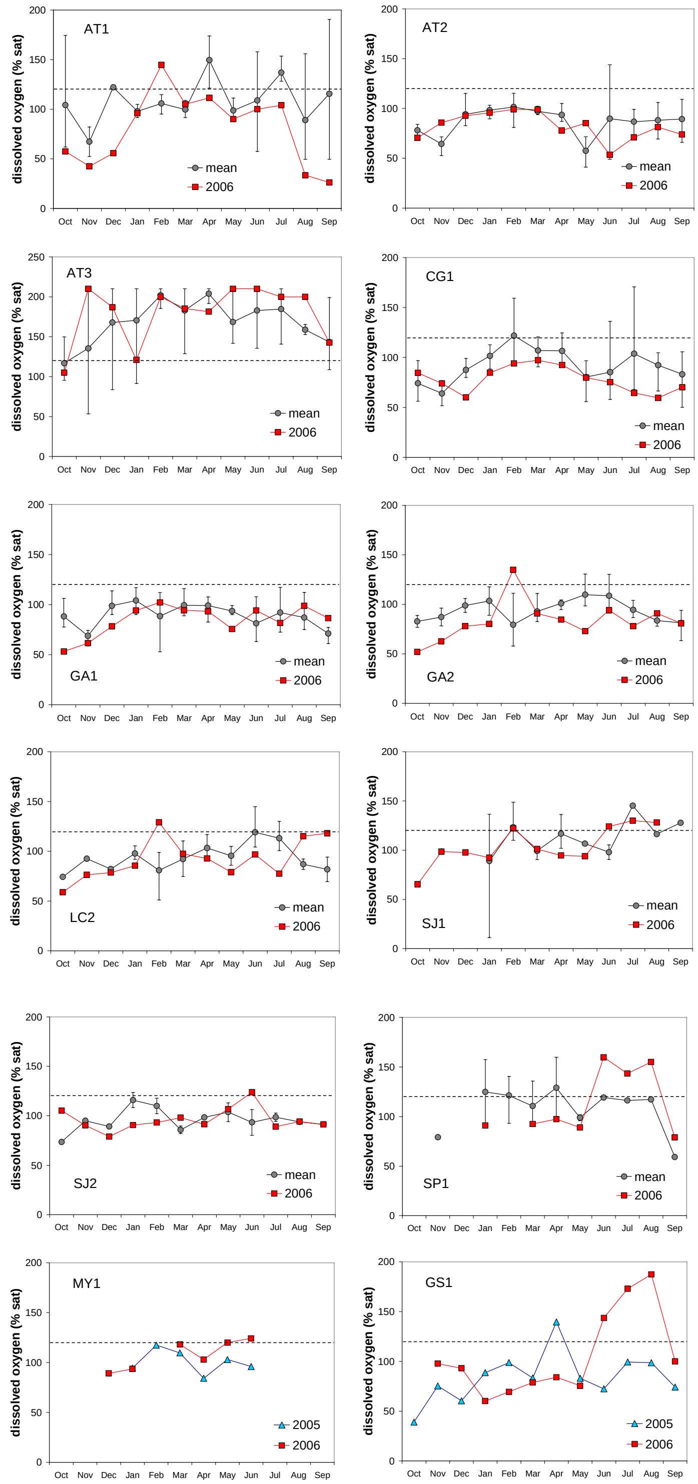

Figure 12. Monthly dissolved oxygen concentrations in percent saturation for the Goleta Stream Team sampling locations during the 2006 water-year are shown with the average percent saturation from 2002-2005. Error bars indicate the monthly maximums and minimums from past years. Percent saturation for MY1 and GS1 in 2005 and 2006 are shown in the bottom panels. Dashed lines indicate 120 percent saturation; values above 120 percent are a probable indicator of excessive algal growth.

Winter storms in 2005 improved conditions for excessive dry-season algal growth in Goleta by opening the creeks to sunlight, removing competing vegetation, sweeping insect predators out to sea, flushing sediment and restoring rocky streambeds (the ideal substrate for most problem-causing algal species in this area), and, through increased groundwater infiltration, insuring expanded habitat and plentiful nutrients. These conditions continued during 2006. In fact, algal growth during 2006 may have exceeded that in 2005. The absence of typical mid-winter rains caused an unusual February bloom. Other blooms occurred during the warmer weather of June through August. Conversely, the rains of March, April and May generally retarded algal growth, mainly by periodic flushing via stormflow.

The situation at AT1 is particularly puzzling. DO was noticeably low from August through December 2005 (circa 4.5 mg/L, compared with previous measurements averaging above 10 mg/L) and again in August (3.1 mg/L) and September 2006 (2.5 mg/L). We referred earlier to the rock and concrete weir at AT1, and the long skinny lake, backing water up almost to the Patterson Bridge that it creates. During the dry season, very low flows simply trickle over the weir and water becomes ponded behind the weir for extended periods of time (the estimated retention time is 7-10 days). It is not difficult to visualize why DO levels in the reach above AT1 might be low: limited oxygen entrainment in a relatively deep, quiet segment along with increased uptake by aquatic organisms and decay in accumulating bottom sediments during these long retention times.

The riddle is not why oxygen levels were low at the end of the dry season, but why they were *lower* in 2006 than they were in 2005 when 2006 flows were higher and retention times shorter (as measured at the Patterson gauge).[9] It is possible that sediments accumulating since the floods of 2005 have increased decay rates, but earlier years, when sediment levels were even greater (i.e., 2002 or 2004), show no similar oxygen depression. The other side of the oxygen equation, the presence or absence of algae, may also have played a role: for some reason the usual fall algal decline in 2006 may have been more pronounced. At present, we can only conclude that some combination of increasing rates of decay and decreasing algal biomass have caused potentially dangerous lower levels of dissolved oxygen at AT1.[10]

Mean annual DO concentrations for the Goleta Stream Team sampling sites in 2006, along with mean concentrations from previous years, are shown in the upper panel of Figure 13. The error bars indicate maximum and minimum concentrations for each set of data. As with temperature, three important benchmarks are indicated by horizontal lines: above 8 mg/L represents near ideal conditions; below 6 mg/L trout and steelhead to feel stress (but experience no lasting harm in the short term); and below 4 mg/L lies severe damage and death. As before, these markers pertain particularly to steelhead and trout; for warm-water fish each limit could be lowered by 1 mg/L, decreasing them to 7, 5 and 3 mg/L, respectively.

[9] Increased groundwater seepage may have further increased the difference. The subjective impression of the sampling team was that 2006 flows were noticeably higher than in previous years.

[10] Lower algal biomass would have decreased measured DO during sampling events but would also have meant less night-time oxygen depression, i.e., perversely indicating poorer conditions while improving the overall situation. DO remained low in October 2006 (2.68 mg/L) and then abruptly increased in November and December (6.37 and 6.98 mg/L, respectively. A small amount of rain on 26-27 October (about 0.3 inches) may have been responsible for the change.

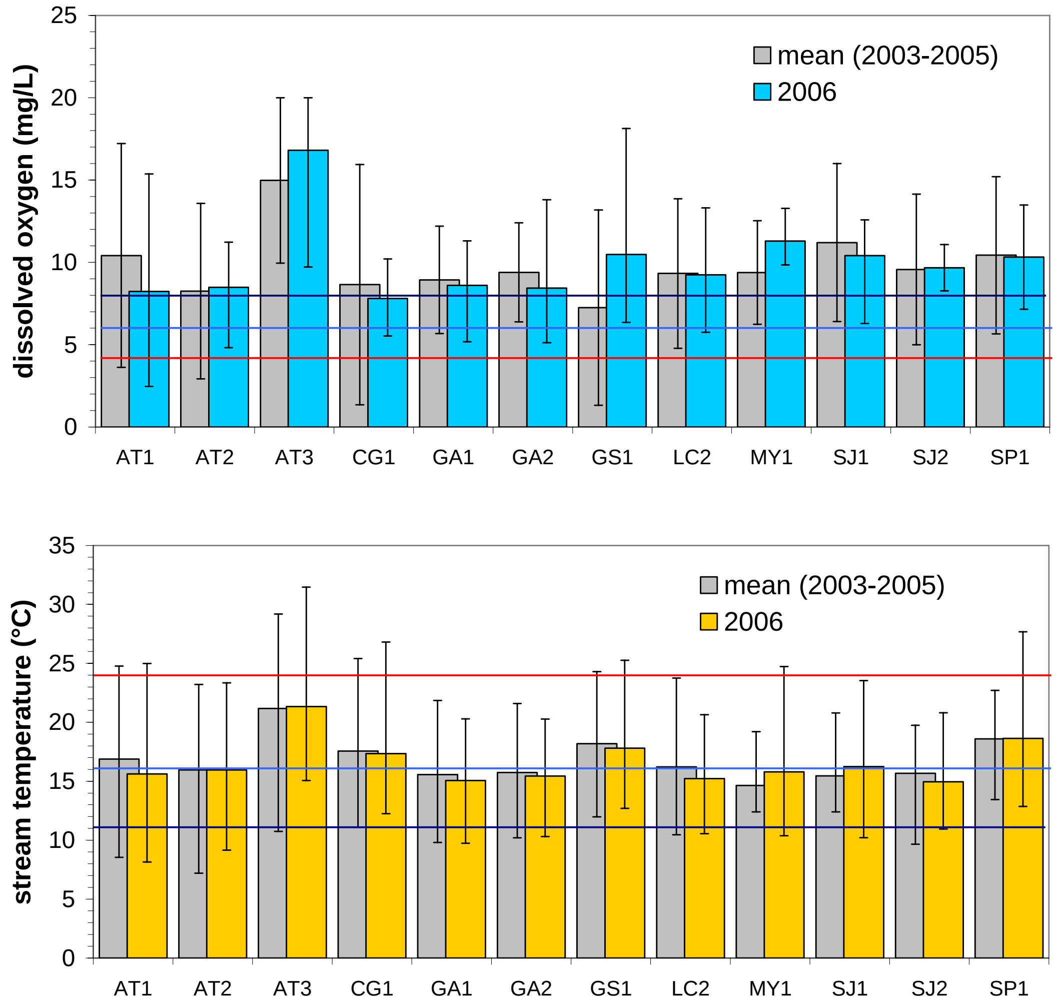

Figure 13. *Upper panel:* Average dissolved oxygen concentrations for the Goleta Stream Team sampling locations during the 2006 water-year are contrasted with mean dissolved oxygen from 2003-2005. Error bars indicate the maximum and minimum concentrations for each average. The three horizontal lines mark important DO milestones: above 8 mg/L represents near ideal conditions; at 6 mg/L hypoxia begins and fish begin to feel stress (but no lasting harm in the short term); and below 4 mg/L lies severe damage and death. *Lower panel:* Average 2006 water temperatures are contrasted with mean temperature from 2003-2005. Error bars again indicate maximum and minimum temperatures. The lines represent temperature milestones: above 24°C leads to death; below 16°C indicates good dry season conditions; and below 11°C is excellent for spawning and incubation. Extreme values become critical at locations with measurements below (for DO) or above (for temperature) the uppermost line.

Figure 14 contrasts average percent saturation in 2006 with the average from previous water-years. The error bars again indicate maximum and minimum monthly percent saturation for each set of data. In both Figures 13 and 14, AT3 stands out as having particularly severe algae problems. Surprisingly, the other location with extraordinary algal productivity in 2006 was the slough itself, which experienced an appreciable bloom in June, July and August.

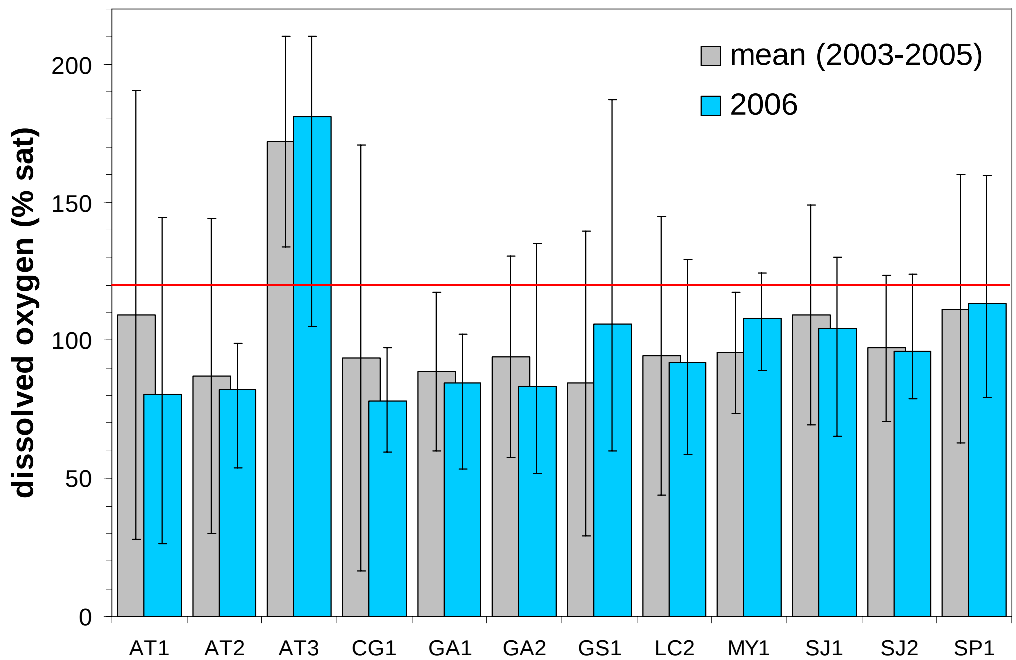

Figure 14. Average dissolved oxygen concentrations (in percent saturation) during the 2006 water year are contrasted with average values from 2003-2005. Concentrations above 120 percent saturation (horizontal line) usually indicate problems with algal growth – over-saturation during daylight followed by depleted concentrations at night. The error bars indicate the maximum and minimum percent saturation at each site.

*p*H

*p*H is a relative measure of alkalinity and acidity, an expression of the number of free hydrogen atoms present in water. It is measured on a scale of 1 to 14, with 7 indicating neutral – neither acid nor base. Lower numbers show increasing acidity, whereas higher numbers indicate more alkaline waters. *p*H numbers represent a logarithmic scale, so small differences can be significant: a *p*H of 4 is a hundred times more acidic than a *p*H of 6. All plants and aquatic species live within specific ranges of *p*H, and altering *p*H beyond these ranges causes injury or death. Pollutants can push *p*H toward the extremes, and low *p*H in particular is highly dangerous because it allows toxic elements and compounds to *mobilize*, or go into solution, and be taken in by aquatic plants and animals. A change of more than two points on the *p*H scale can kill many species of fish. The EPA and Central Coast Regional Water Quality Control Board (CRWQCB-CC) regard a *p*H change of more than 0.5 as harmful (CRWQCB-CC, 1994).

There are numerous available standards for *p*H. Fish live within a range of 5-9, but the best fishing waters lie between 6.5-8.2. The CRWQCB-CC uses a standard of 7.0-8.5 for surface water and 6.5-8.3 for potable water and swimming (CRWQCB-CC, 1994). The Los Angeles Regional Water Quality Control Board uses 6.5-8.5 (CRWQCB-LA, 1994), and the US EPA recommends 6.5-8.0 as being optimal for aquatic animals. We use 8.5 as an upper reference limit since the Goleta Slough watershed is within the jurisdiction of the CRWQCB-CC.

Photosynthesis, discussed earlier in the section on dissolved oxygen, removes carbon dioxide from the water at the same time that it releases oxygen. Removing carbon dioxide is the same as removing acidity, thus photosynthesis increases *p*H as it increases the amount of dissolved oxygen (PIRSA, 1999; NM-SWQB, 2000).

Normally, absent this process, we should see little change in *p*H. The dissolved minerals that give Goleta waters high conductivity contain large amounts of carbonates which "buffer" the river against large variations (waters in the region typically contain around 120 mg/L of acid neutralizing capacity expressed as carbonate), but changes in the concentration of dissolved carbon dioxide are a major exception.

Figure 15 shows monthly 2006 *p*H measurements along with the average monthly results from previous sampling. The error bars represent maximum and minimum values for 2003-2005. As might be expected, algal productivity at AT3 kept *p*H above the 8.5 limit for much of the year. Elsewhere, values were in the allowable 7.0-8.5 range with two exceptions: SP1, where algal growth was responsible for high readings in December and February, and SJ2, with very low values in January and February. Figure 17 summarizes the 2006 results, comparing the annual mean with the overall mean from previous years. The general trend was a slight decrease in 2006, with lower maximum values at all locations except those that exhibited excessive algal growth (AT1 and SJ1 showed higher average *p*H, while values remained relatively consistent at SP1 and GS1).

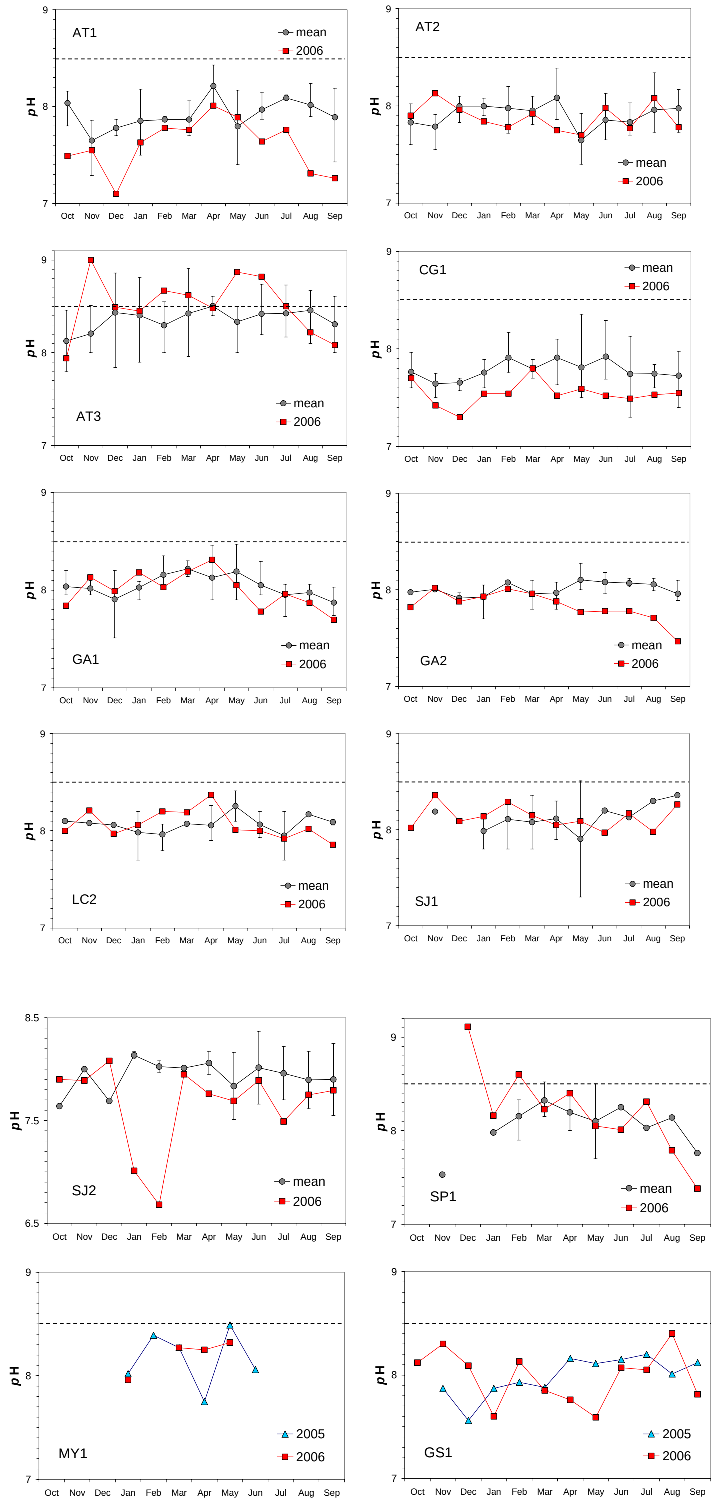

Figure 15. Monthly *p*H values for the Goleta Stream Team sampling locations during the 2006 water-year are shown along with the average *p*H from 2003-2005 (*p*H of the average H ion concentration). Error bars indicate the maximum and minimum values from 2003-2005. The bottom panels show *p*H at MY1 and GS1 during 2005 and 2006.

Some of the *p*H variations, for example the low values at SJ2 (Figure 15), defy easy explanation. When significant amounts of algae are present, dissolved oxygen concentrations and *p*H should rise and fall together. Percent DO saturation is plotted in Figure 16, along with *p*H data from Figure 15, for a subset of Goleta locations. Many sites, such as AT3 and GS1, do show the expected correspondence, and the general trend is visible at almost all other locations at least part of the time, but at others *p*H appears to vary without rhyme or reason, such as at GA2 and AT2. *p*H is difficult to measure accurately, and this may simply be an example of that. It is also possible that much of the dry-season flow seen in these creeks comes from a shifting mixture of varying sources.

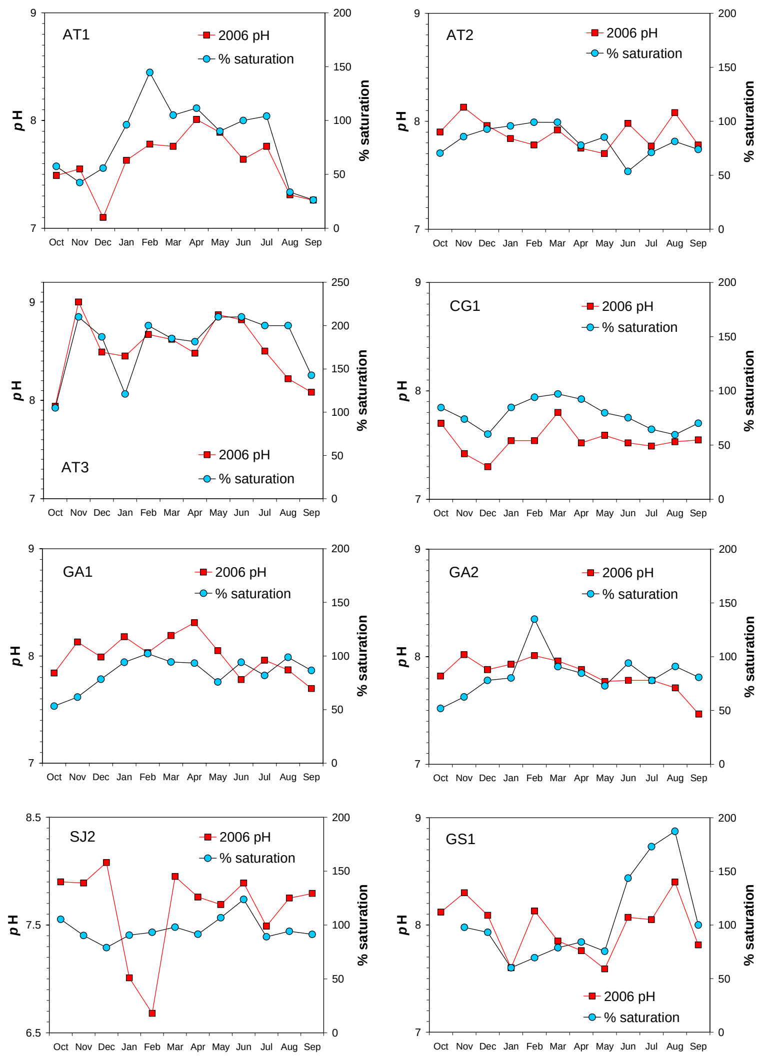

Figure 16. Monthly 2006 percent DO saturation values for selected Goleta Stream Team sampling locations are plotted along with *p*H data from Figure 15. Since Goleta waters are highly buffered, there should be a reasonable correspondence between *p*H and percent saturation – both increase with daylight photosynthesis. This pattern is generally confirmed by the results, although at times, particularly when percent saturation is low, the relationship breaks down.

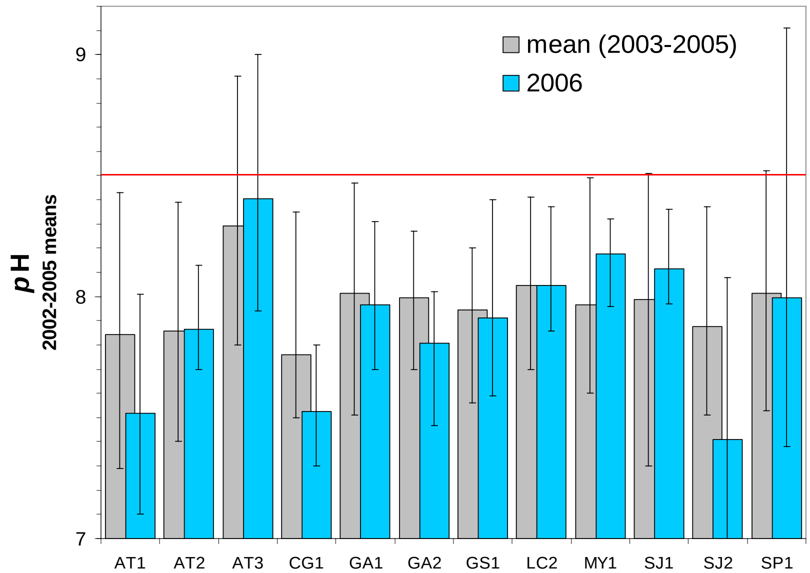

Figure 17. Average *p*H during the 2006 water-year is contrasted with average values from 2003-2005. The error bars indicate the highest and lowest values measured for each time period at the sampling locations. The horizontal line represents the Central Coast Regional Water Quality Control Board's upper *p*H limit (8.5 for warm or cold water habitat from the Basin Plan). A *p*H above 8.3 is typically associated with excessive algal growth. Average *p*H is the equivalent to the mean hydrogen ion concentration and not the average of monthly *p*H values.

Turbidity

Turbidity is a measure of water clarity and the amount of sediment suspended in the water column. There are numerous methods for measuring turbidity and it is variously reported in a number of different units. Channelkeeper measures clarity with a turbidity meter (or nephelometer) that reports results in Nephelometric Turbidity Units (NTU). A nephelometer passes a beam of light through a water sample and records how much of the beam is scattered at right angles. The more sediment in the sample, the more light is scattered and the higher the turbidity reading.

Particles suspended in the water column have both long- and short-term effects on steelhead and other fish (Sigler et al., 1984; Newcombe and MacDonald, 1991; ODEQ, 2001a, 2001b). Over the long term, sediment settles on the bottom and fills the interstices between streambed gravels, decreasing the amount of desirable habitat for spawning and for the insects that fish feed upon. Over the short term, turbidity reduces the ability of fish and invertebrates to find food. Water quality begins to be degraded by suspended sediment somewhere between turbidities of 3-5 NTU, while turbidities above the range of 7-10 NTU appear to diminish the numbers and variety of benthic invertebrates (Quinn et al., 1992; Munn et al., 1989). At turbidities above 25 NTU, impacts on steelhead and trout begin to be noticeable. These limits apply to the dry season and periods between storms. During storms they become meaningless in Goleta watersheds as local suspended sediment concentrations reach tens of thousands of milligrams per liter, producing turbidity readings in the hundreds of thousands. Fortunately, in Goleta and Santa Barbara, turbidities rapidly drop soon after the end of rainfall and return to near-background levels within 3-7 days of a storm.

Figure 18 shows 2006 median turbidity for each of the sampling locations along with median turbidity for the earlier record (2003-2005). Two of the horizontal lines on the figure represent typical Public Health drinking water limits: a maximum turbidity of less than 5 NTU and no more that 5 percent of monthly samples greater than 0.5 NTU. The third represents an ecological standard.

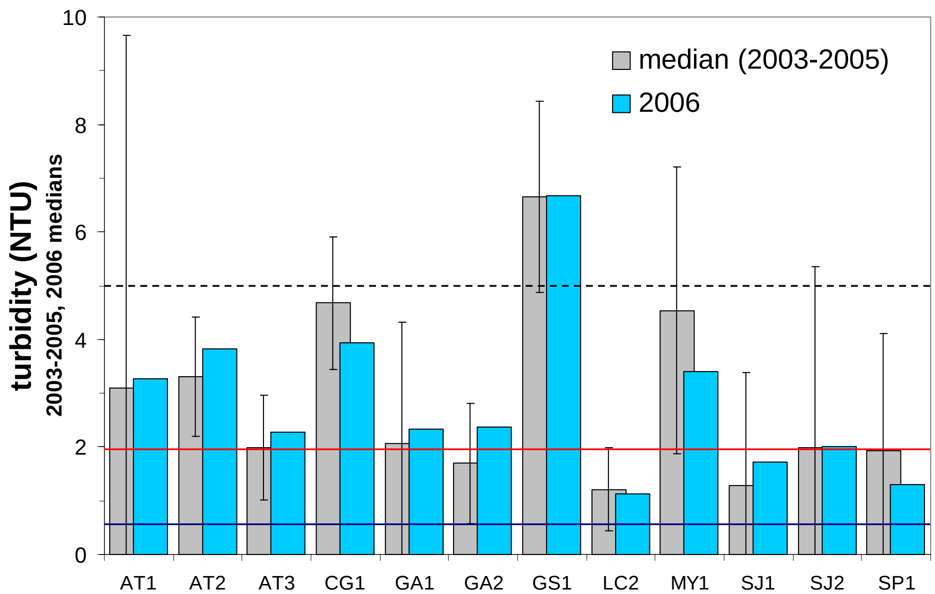

Figure 18. Median turbidity during the 2006 water-year is contrasted with the median for water-years 2003-2005. Error bars indicate twice the standard error of the median (non-storm values). Two of the horizontal lines mark typical Public Health drinking water quality benchmarks: a maximum turbidity of 5 NTU and no more than five percent of monthly samples with greater than 0.5 NTU. The middle line indicates the EPA's proposed ecological limit for maximum (non-storm) turbidity in streams of this region: 1.9 NTU.

Since increased turbidity may be related to over-productivity or excess nutrient enrichment – a more biologically productive water often contains increased amounts of suspended organic matter – the EPA has suggested turbidity standards for various eco-regions in the United States. The goal for Ecoregion III, the xeric (dry) west, in which the most of the Goleta sampling points are located, is less than 1.84 NTU (US-EPA, 2000b). Ecoregion III has been further divided into sub-regions, and the sub-region in which the Goleta streams lie (sub-region six) has a slightly higher 1.90 NTU limit.[11]

Turbidity measurements in 2006 were roughly compatible with those of earlier years, well within two standard errors of the 2003-2005 medians (Figure 18). Most locations had higher turbidity, though some were lower. Generally, when flows are relatively high, turbidity increases (higher

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[11] Some parts of these watersheds may be classified as in Ecoregion II, sub-region 8: Western Forested Mountains, Southern California Mountains (US-EPA, 2000a). These more stringent standards are probably inappropriate for streams whose waters mainly originate on the California coastal plain. Subregion 8 data is sparse and rudimentary, based only on a single stream, and we have chosen to use only the Ecoregion III (6) nutrient criteria standards.

stream velocities tend to keep more particles in suspension), and greater amounts of algae tend to increase the amount of suspended organic matter. Sites with higher 2006 turbidity tended to combine both these factors. 2005 results were also higher than in previous years for similar reasons. The only exceptionally high result, GS1, is probably an artifact of tidal surges near the slough mouth. Using the EPA criterion (and applying it only to non-storm data), the Atascadero and Glen Annie systems appear to have persistent problems with excessive turbidity, but even at these sites it is below biologically significant limits (7-10 NTU).

Nutrients

Phosphorus and nitrogen are essential nutrients for all living organisms (nitrogen for protein synthesis and phosphorus for energy transformation in cells), but in excess amounts they cause severe problems (Sterner, 2002, Smith et al, 1999, Carpenter et al., 1989). The primary cause is *eutrophication*, defined as over-enrichment or over-fertilization of a lake or stream, which sets off a chain of undesirable events including accelerated plant growth, algal blooms, low dissolved oxygen and, if carried to extremes, the death of oxygen-dependent aquatic life.

Phosphorus in streams and rivers can come naturally from soil, rocks and decaying plants, or unnaturally in runoff from pastures, fertilized lawns and cropland. Failing septic systems and wastewater treatment plants are also sources, as are disturbed land areas and drained wetlands. Phosphorus, both as phosphate and in organic molecules, moves in solution or attached to particles suspended in flow.

Nitrogen is available as dissolved inorganic molecules (nitrate, nitrite and ammonium) and as dissolved or suspended organic matter (complex compounds associated with living, or once living, tissue). Nitrate, the most common form of nitrogen found in the Goleta watersheds, can be toxic to warm-blooded animals, particularly babies, at high concentrations (greater than 10 mg/L) and there may also be a link between high nitrate levels and cancer (cf. non-Hodgkin's lymphoma, Ward et al., 1996). Sources of nitrate include effluent from wastewater treatment plants, runoff from fertilized lawns and cropland, failing septic systems, animal manure and industrial discharges. Nitrates move quickly into streams and rivers since they readily dissolve and are not adsorbed on soil particles.

Nitrate

Nitrate is the most important form of dissolved nitrogen in the streams of the Santa Barbara/Goleta area. Roughly 70 percent of the total dissolved nitrogen in river and stream samples is nitrate (ammonium contributes about one percent and organic compounds make up the rest). Monthly nitrate concentrations in 2006 for the Goleta Stream Team sampling sites are shown in Figure 19. Results are expressed in mg/L as nitrogen, i.e., milligrams of nitrogen per liter.[12]

The 2006 data display patterns similar to those seen in the past (i.e., when compared with 2003-2005 monthly averages on the same figure), although individual data points may vary considerably. Two basic patterns are represented: locations that show an increase in nitrate during the rainy season and those that show a decrease.

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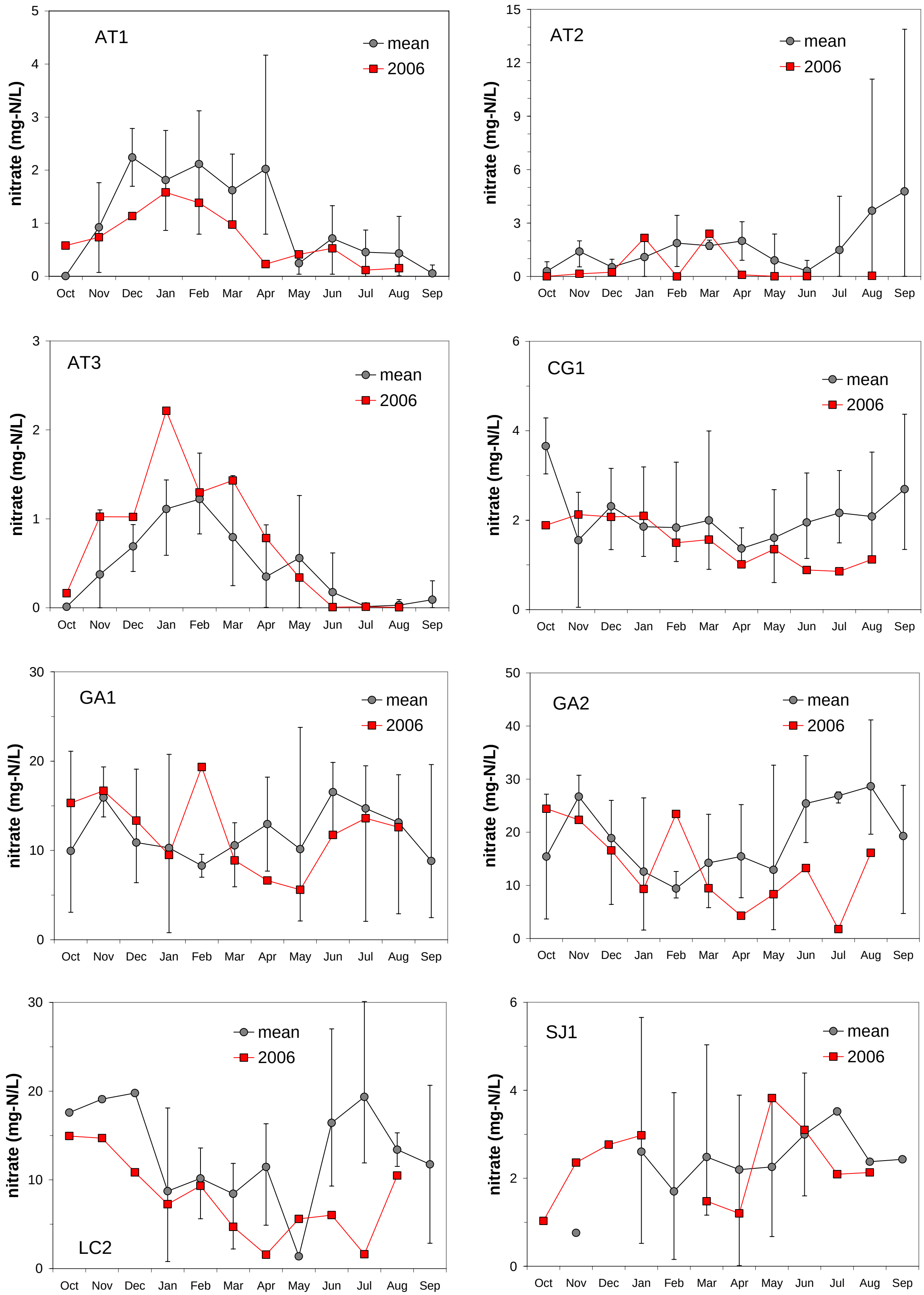
[12] There are other ways of expressing chemical concentration but this is the most common. It is easier to think of mg/L as "parts per million," i.e., 10 mg-N/L as 10 parts of nitrogen in a million parts of water.

The first pattern is produced by increased amounts of high-nitrate soil and groundwater entering the stream as the rainy season progresses, followed by a decrease as plants, algae and bacteria remove nutrients throughout the subsequent growing season. Low flows enhance this effect. Biological uptake reduces the amount of available nitrate as water flows downstream, and since *amount* is the product of concentration multiplied by flow, the decrease in concentration is much greater when flows are low. This pattern is typically seen at urban locations; AT3 provides a good example.

The second pattern occurs when very high baseflow nitrate concentrations from agricultural runoff are diluted by winter stormflows and groundwater inflows. Then, as natural flows decrease during the growing season and irrigation wastewater becomes increasingly important, concentrations rise. Flow in these streams is usually higher than in urban drainages and the total amount of nitrate is almost always excessive (i.e., GA1, GA2, LC2 and SJ2). An “agricultural” pattern can sometimes be seen in urban areas, since golf courses and parks are fertilized and irrigated as much as if not more than farm fields and orchards (Schueler, 2000).


AT1
AT2
AT3
CG1
GA1
GA2
LC2
SJ1
mean
2006
nitrate (mg-N/L)
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep

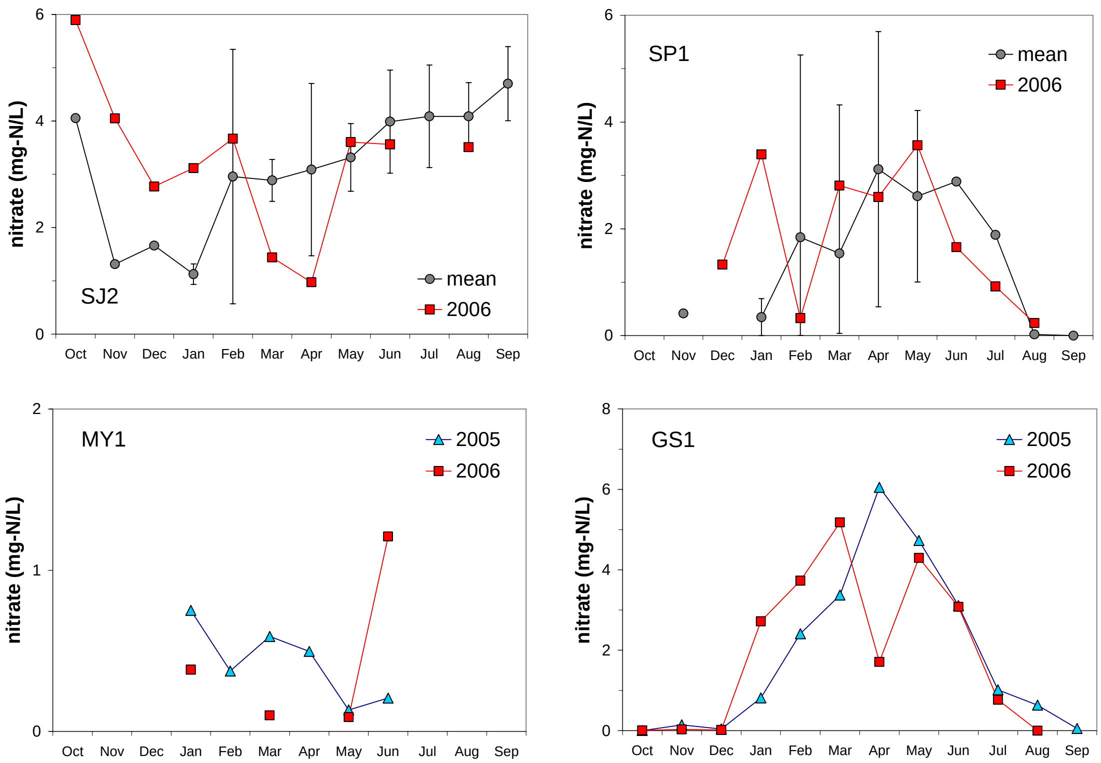


Figure 19. Monthly nitrate concentrations for the Goleta Stream Team sampling locations during the 2006 water-year are shown with average monthly nitrate from 2003-2005. Error bars indicate the maximum and minimum monthly concentrations during past years. Nitrate concentrations at MY1 and GS1 during 2004 and 2005 are shown in the bottom panels.

Annual results, expressed as average water-year concentrations for 2003-2005 and 2006, are compared in Figure 20. Error bars on the 2003-2006 averages indicate twice the standard error of the mean, and significant changes may have occurred at those locations where 2006 results fall outside these limits (i.e., AT2 and AT3). However, differences in the years that make up the 2003-2005 average have to be considered before drawing this conclusion: in terms of rainfall and runoff, 2003 was normal, 2004 dry, and 2005 extremely wet. Average nitrate concentrations for each year are plotted for locations and years with year-round (or nearly year-round) flow in Figure 21. Error bars again show twice the standard error of each mean.[13]

[13] In the upper panel data are plotted on a log scale, which allows widely ranging values to be shown in greater detail on the same graph but visually minimizes differences between numbers. The lower panel, a normal view more easily grasped, is included to illustrate the advantages and pitfalls of a log scale.

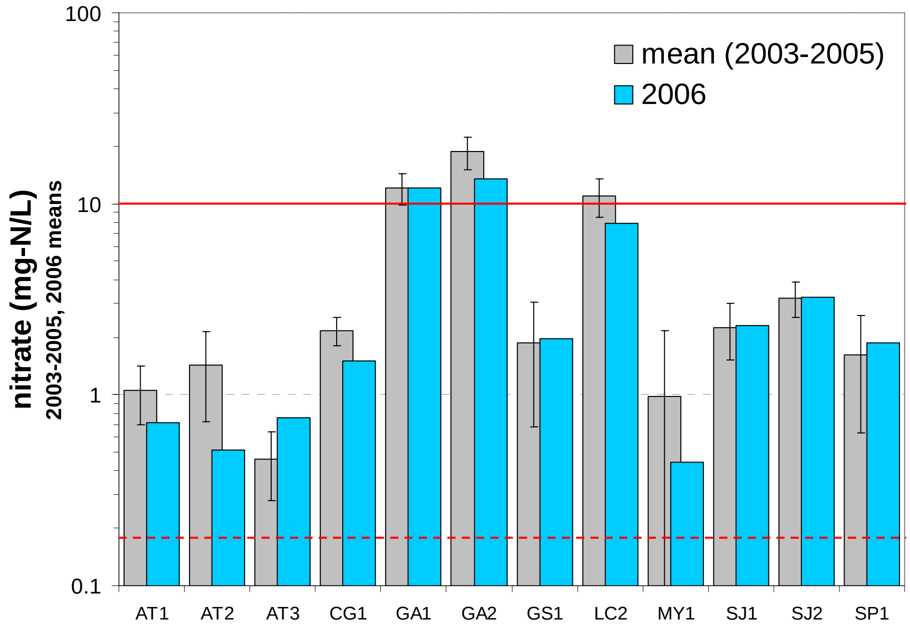


Figure 20. Average nitrate concentrations for the Goleta Stream Team sampling sites during the 2006 water-year are contrasted with average concentrations over the previous three years (2003-2005). The error bars indicate twice the standard error of the mean, i.e., the 2006 average would be expected to lie within these error bars, while anything beyond these limits could indicate a significant change. Note that most 2006 locations are generally within or below the error bars. The solid horizontal line marks the 10 mg/L Public Health limit for nitrate; the dashed line is the EPA's proposed limit for maximum nitrate in this region of 0.16 mg/L. Sampling locations downstream of agricultural land usually exceed the ecological limit (GA, SJ, GS and LC) and often exceed the Public Health limit if agricultural use is extensive.

While not strictly accurate, as a general rule of thumb averages whose error bars do not overlap can be considered statistically different. Figure 21 demonstrates that this is rarely the case (exceptions are CG1, GA2 and LC2 during the drought year of 2004). Indeed, the data leave a rough impression that the drier the year, the higher the average nitrate concentration (2004 was higher

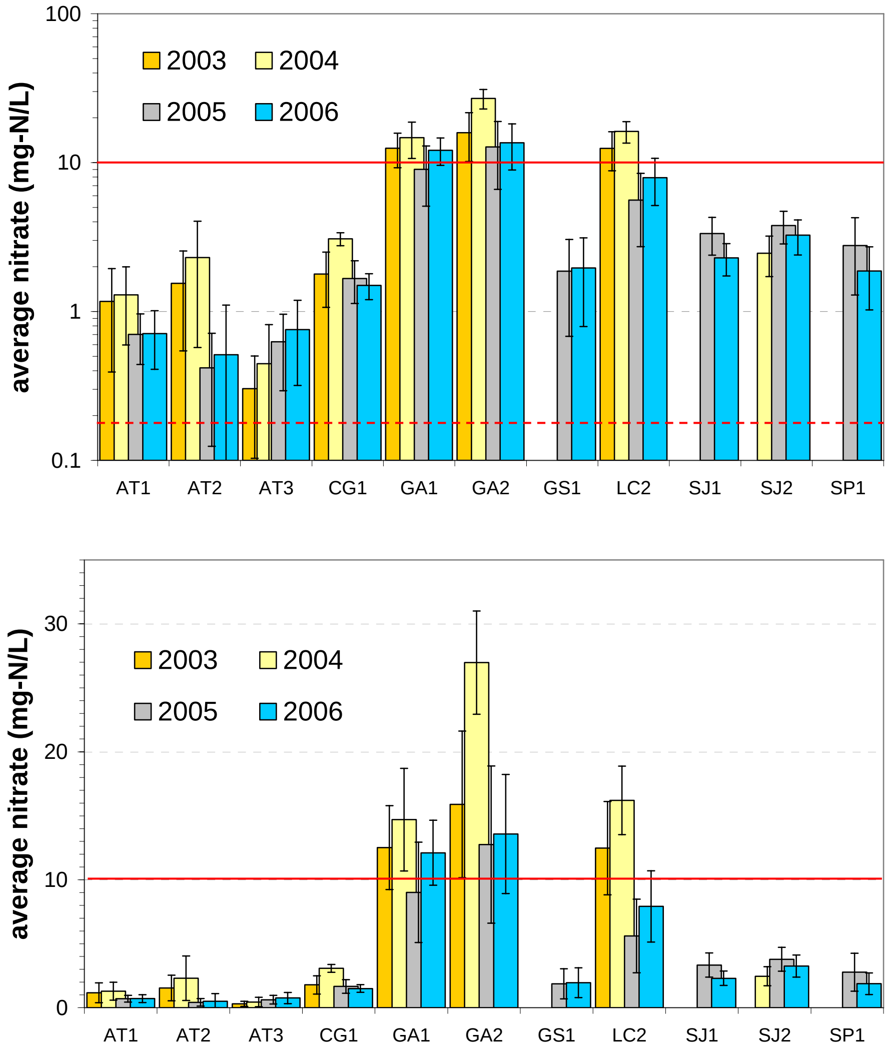


Figure 21. Average annual nitrate concentrations from 2003-2006 at Goleta Stream Team sampling sites (only locations and years with ± year-round flow are shown). Data are plotted as both log and normal values. The error bars indicate twice the standard error of the mean. The solid horizontal line marks the 10 mg/L Public Health limit for nitrate; the dashed line is the EPA's proposed limit for maximum nitrate in this region of 0.16 mg/L.

than 2003, and both of these years were higher than 2005 and 2006). However, this begs a number of questions as to why nitrate in 2006 was sometimes lower than in 2005 and why, if the urban pattern is different from the agricultural, do we see similar year to year variations (i.e., AT1 and AT2 show the same variation as the agricultural sites GA1, GA2 and LC2). At this point we can only say that these differences are not statistically significant and probably result from variations in environmental conditions and dry-season water sources as well as too few samples.

Figures 20 and 21 show, as horizontal lines, two indicators of excessive nitrate. The uppermost is the almost universal Public Health limit of 10 mg-N/L (CRWQCB-LA, 2001). However, 10 mg/L is far too much nitrate in terms of eutrophication and river health. The EPA has suggested standards for various eco-regions in the United States and the goal for Ecoregion III, in which Goleta is located, is less than 0.38 mg/L of total nitrogen (US-EPA, 2000b). Notice that this is less than 4 percent of the Public Health nitrate limit. Ecoregion III has been further divided by the EPA into sub-regions, and for our sub-region (sub-region 6) a slightly higher 0.52 mg/L limit has been proposed. Sub-region 6 also has a suggested nitrate limit of 0.16 mg/L (for nitrate alone, not total nitrogen). This is the lower limit shown on the figures.

Agriculturally dominated sites such as GA1, GA2 and LC1 almost always exceed the Public Health limit, and all sites greatly exceed the ecological limit. At present, no state environmental nutrient standards have been established for California, but recent water quality assessments have used criteria of <0.5 mg/L, 0.5-1.0 mg/L, and >1.0 mg/L total nitrogen as indicators of high, medium and poor quality waters, respectively (CSWRCB, 2006a). These criteria are less conservative than the EPA's ecoregion standards, but all Goleta sites consistently exceed 1 mg-N/L total nitrogen except Maria Ygnacio, and all but MY1 and AT1 exceed 1 mg/L with nitrate alone.

Phosphate

As with nitrate, there is no definitive answer for how much phosphorus is too much. There are no Public Health limits for phosphate but there are ecological standards. For example, the EPA has recommended levels of maximum phosphorus concentration for streams in Ecoregion III - an overall recommendation of 0.022 mg-P/L, increased to 0.030 for sub-region 6 (US-EPA, 2000b). California does not as yet have an environmental or ecological standard, but criteria of <0.01 mg/L, 0.01-0.1 mg/L, and >0.1 mg/L total phosphorus are beginning to be used as indicators of high, medium and poor quality waters, respectively (CSWRCB, 2006).

If "poor" quality water is equated with values above the EPA ecoregion standard, these criteria are less conservative and we use 0.030 mg-P/L as a benchmark (0.03 mg/L or 30 µg/L as phosphorus). All streams in the Santa Barbara/Goleta area have high phosphate concentrations because of the high phosphorus content in the marine deposits that make up a large part of the geologic strata of these watersheds (Dillon, 1975; Grobler and Silberbauer, 1985; Schlesinger,1997).[14]

[14] This is somewhat reflected in the increased sub-region 6 EPA limit.

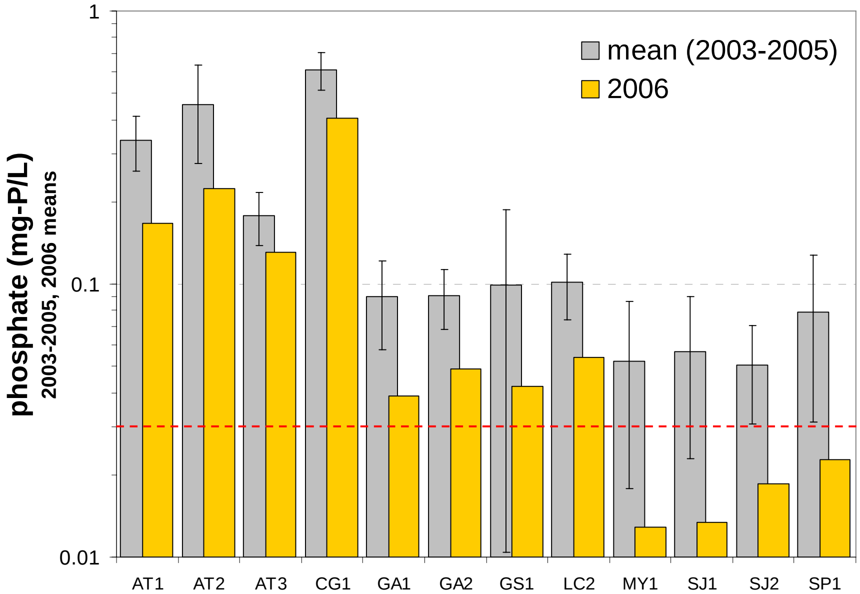
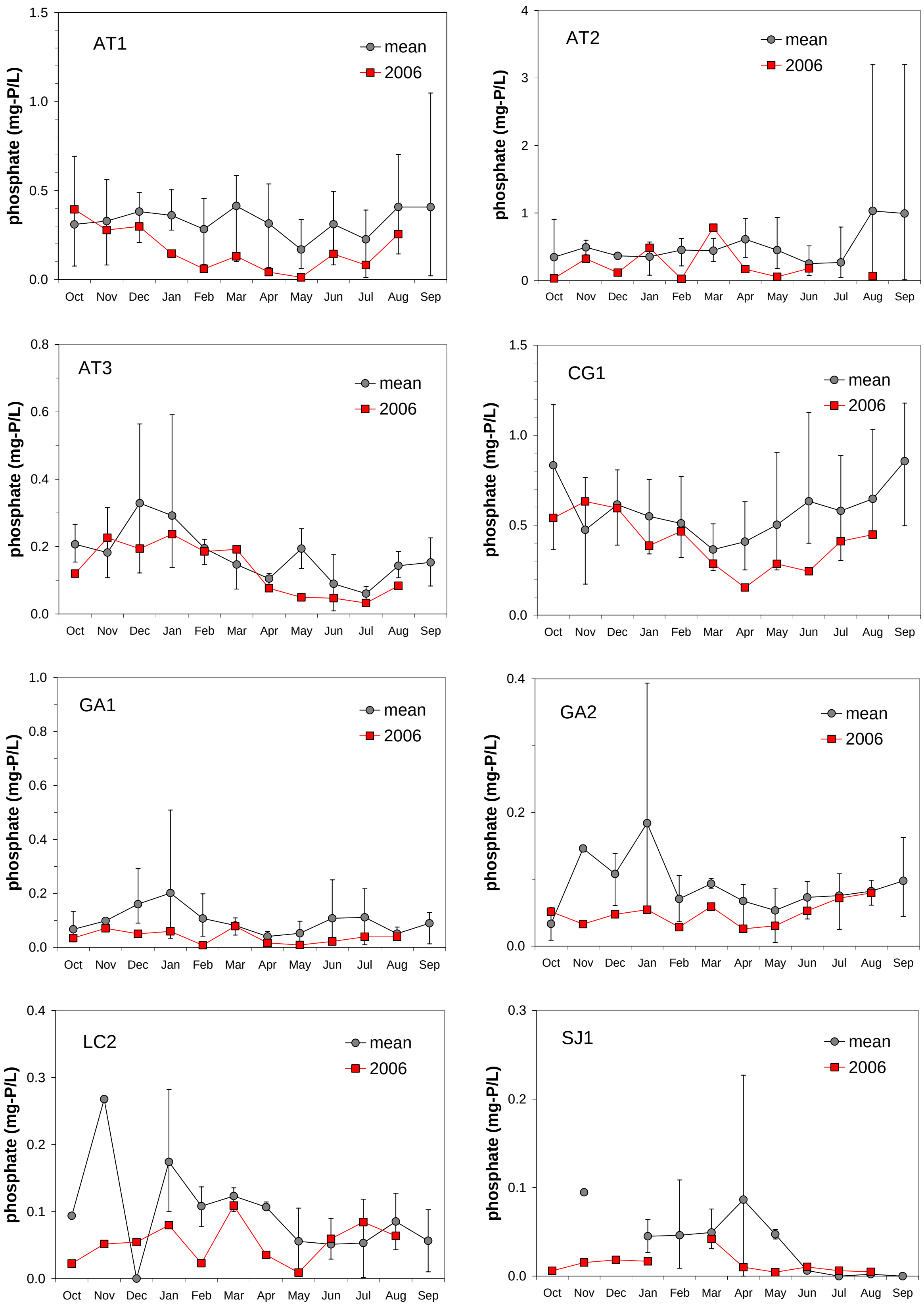


Figure 22. Average phosphate concentrations for the Goleta Stream Team sampling sites during the 2006 water-year are contrasted with average concentrations over the pervious three years (2003-2005). The error bars indicate twice the standard error of the mean, i.e., the 2006 average would be expected to lie within these error bars, whereas anything beyond these limits could indicate a significant change. Note that almost all 2006 results fall below the error bars, indicating unusually low phosphate. The lowermost dashed line marks the EPA's proposed limit for maximum phosphorus in this region of 0.030 mg/L.

Figure 22 summarizes 2006 phosphate results, showing annual mean phosphate concentrations at each location and contrasting them with the 2003-2005 average. The results are quite surprising: *all* locations had lower average phosphate concentrations in 2006, and the difference is significant since, with the exception of GS1 where 2005 is the only reference year, the results are two or more standard errors below the 2003-2005 mean. The monthly data in Figure 23 verify this conclusion at almost every location. There are two possible explanations: less phosphate entered the slough and its tributaries in 2006, and/or larger amounts were removed by biological uptake and productivity.


AT1
mean
2006
phosphate (mg-P/L)
0.0
0.5
1.0
1.5
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep
AT2
mean
2006
phosphate (mg-P/L)
0
1
2
3
4
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep
AT3
mean
2006
phosphate (mg-P/L)
0.0
0.2
0.4
0.6
0.8
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep
CG1
mean
2006
phosphate (mg-P/L)
0.0
0.5
1.0
1.5
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep
GA1
mean
2006
phosphate (mg-P/L)
0.0
0.2
0.4
0.6
0.8
1.0
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep
GA2
mean
2006
phosphate (mg-P/L)
0.0
0.2
0.4
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep
LC2
mean
2006
phosphate (mg-P/L)
0.0
0.1
0.2
0.3
0.4
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep
SJ1
mean
2006
phosphate (mg-P/L)
0.0
0.1
0.2
0.3
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep

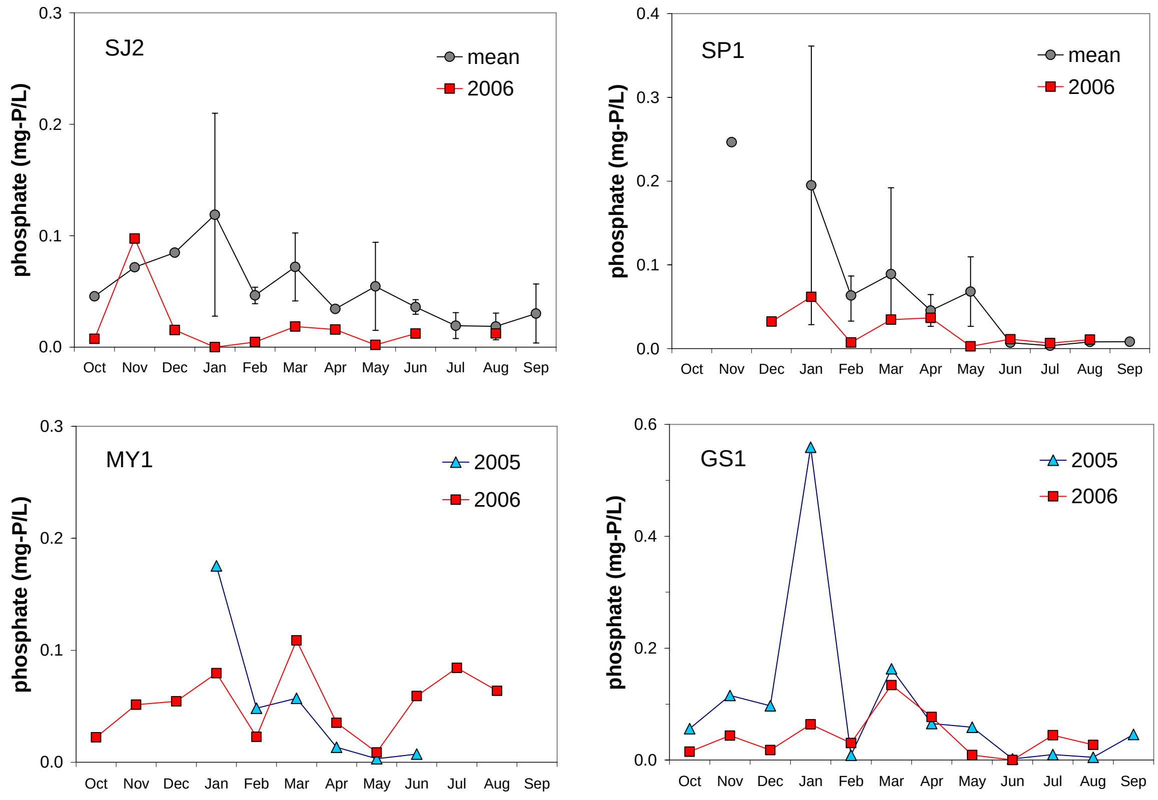


Figure 23. Monthly phosphate concentrations for the Goleta Stream Team sampling locations during the 2006 water-year are shown with average monthly phosphate from 2003-2005. Error bars indicate the monthly maximum and minimum concentrations in previous years. Concentrations at MY1 and GS1 during 2005 and 2006 are shown in the bottom panels.

It is likely that both these factors are to blame. The dry seasons of 2005 and 2006 were characterized by extraordinary algal blooms, and increased uptake of phosphorus undoubtedly played an important role in reducing concentrations. It is biological uptake that gives form to the pattern seen with most of the average monthly data in Figure 23: lower concentrations during the dry season, with a minimum between April and June. Patterns in 2006 roughly follow the shape of the longer term averages and we can see the effect of uptake at a number of locations (i.e., in the phosphate reduction during the February 2006 algal bloom; cf. Figure 12).

Departures from the seasonal uptake pattern, indicated by high concentrations or widely spaced error bars, usually represent samples taken during or soon after storms, when high sediment loads are accompanied by high phosphate concentrations. Phosphate molecules are readily attached to soil particles, and the width and condition of streamside buffer areas, the extent of streambank armoring, the proximity of unvegetated, easily erodable soil to a channel or storm drain inlet, and rainfall intensity determine how much sediment ends up in the creek. This, in turn, determines the extent of the phosphate increase. This is particularly true of the first storm of the season, which typically moves a great deal of sediment and accumulated debris into dry or near stagnant streams, explaining why the highest monthly concentrations are usually seen in October or November.

However, something other than uptake appears to have occurred in 2006. It is probable that increased groundwater inflows from a water table recharged with low-phosphate runoff from 2005 storms played a role, since the effects extend beyond the growing season: shorter groundwater residence times within the underlying geologic strata leading to lower phosphate concentrations. As with nitrate, annual average phosphate concentrations appear to be related to rainfall; the wetter the year, the lower the average concentration. 2004 had higher concentrations than 2003, and both were higher than in 2005 (Figure 24).

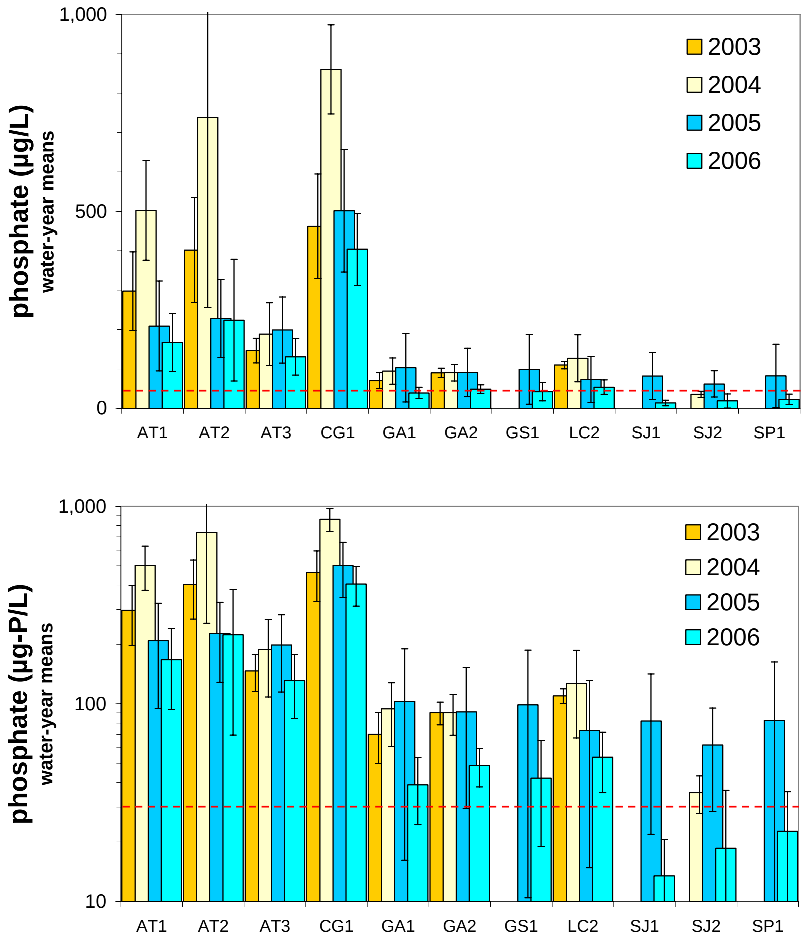


Figure 24. Average annual phosphate concentrations from 2003-2006 at Goleta Stream Team sampling sites (only locations and years with ± year-round flow are shown). Data are plotted as both log and normal values. The error bars indicate twice the standard error of the mean. The lowermost dashed line shows the EPA's proposed limit of 30 µg-P/L for maximum phosphorus in this region.

However, unlike nitrate, which exhibited an increase in 2006 over 2005 concentrations at some locations (cf. Figure 21), phosphate decreased at all sites. In most cases, the decrease was substantial. It may be that, along with phosphate changes in the shallow groundwater table, the *timing* of rainfall in 2006 played a role. Late rains, occurring after the start of the growing season when biological demand for phosphorus is high, may both reduce sediment transport and limit dissolved concentrations in recharge waters; the contrast with concentrations in 2003, a year with slightly higher rainfall (24.2 vs. 21.7 inches), was quite pronounced.

The annual averages in Figure 24 indicate that all sites typically have mean phosphate concentrations above the 0.03 mg/L phosphorus limit. Only in 2006 did some locations fall below this value. However, this decrease does not necessarily represent an improvement since phosphate alone provides only part of the total phosphorus concentration in the stream. Organic phosphorus makes up the remainder. Typically, phosphate represents approximately 90 percent of the total in Goleta nutrient samples, but not always.

Unfortunately, while total dissolved phosphorus (TDP)[15] is measured in the nutrient analyses, the results are unreliable. TDP and phosphate are determined by different tests and sometimes the results show phosphate to be higher than the TDP concentration. Obviously, this cannot be true (a part cannot be greater than the whole); either error occurred or the precision of the analysis was not high enough to produce a satisfactory result.

This is ordinarily expected to happen some of the time, particularly when overall concentrations are high; it happens about 4 percent of the time with nitrate and total dissolved nitrogen samples. Unfortunately, it occurs almost half the time with phosphorus and indicates a real problem, one that the UCSB laboratory has not been able to solve. In 2006, 30 percent of the TDP samples produced unacceptable results.

However, a high percentage of unacceptable results does not mean that an analysis is entirely meaningless. While any single result may be suspect, overall trends in the data are likely to reflect reality, based on the assumption that, in aggregate, "acceptable" results are likely to be either valid or, at worst, contain an error that always *underestimates* TDP, since that is the implication of several samples with TDP higher than phosphate. In 2006, samples with realistic values were concentrated in the months of October, January, February, April and May[16] and almost all samples from these months appear valid. Looking at only those results, the percentage of TDP contributed by phosphate during those months was 68, 78, 64, 51 and 26 percent, respectively. Overall, acceptable 2006 samples contained an average of 59 percent phosphate, considerably lower than the 90 percent of previous years.

The 2006 TDP data reflect exactly what we might expect during a year with extensive algal uptake: more organic phosphorus than phosphate during the most productive months. During their life-cycle, algae and other aquatic organisms preferentially take up phosphate while living and then release organic phosphorus when they shed, die or decay; thus during highly productive periods (i.e., May) phosphate declines while organic phosphorus concentrations increase.

This complicated and convoluted explanation leads to a simple point: although phosphate concentrations declined in 2006, the overall phosphorus situation may not have improved substantially because an increase in organic phosphorus accompanied the phosphate decline. We are unable to accurately measure actual organic phosphorus concentrations because of the problematical TDP analysis, but we know the increase was appreciable. Even considering phosphate alone, only three sites, SJ1, SJ2 and SP1, had 2006 concentrations below the allowable total phosphorus limit. The Atascadero drainage continues to have the highest phosphate concentrations in the slough's watershed; phosphate at these sites greatly exceeds even the 0.1 mg/L "poor" total phosphorus standard proposed for California.

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[15] The difference between TDP and phosphate is considered organic phosphorus.
[16] Results of samples taken later than May were as yet unavailable at the time of this writing.

Combining Nitrate and Phosphate

Living organisms need both nitrogen (N) and phosphorus (P), and it is necessary to consider both nutrients in combination. Absent either nitrogen or phosphorus, a plant or alga needing both can not grow. Oceanic plankton need N and P in a ratio of 16 atoms of nitrogen to one atom of phosphorus.[17] For freshwater organisms, the average ratio is closer to 30:1 (Nordin, 1985; Sterner and Elser, 2002). A ratio of less than 30:1 means that some of the phosphorus goes unused, whereas ratios greater than 30:1 indicate an under-utilization of nitrogen. The first case is called N-limited, the second, P-limited, referring to which nutrient is found in limited amounts and thus controls growth. This is an important concept in stream ecology since unused nutrients cannot contribute to eutrophication and its associated problems (Borchardt, 1996).

However, there are exceptions to this rule. Some aquatic plants and algae do not get their nitrogen from the water but have the ability "fix" nitrogen from the air, or in other words, convert nitrogen gas into ammonia, and then use ammonia for cell metabolism. Ammonia is an important source of N, normally found only in low concentrations in the Goleta tributaries (typically around 1-2 percent of the nitrate concentration). These organisms are literally accompanied by their own nitrogen supply since attached symbiotic bacteria do the actual work. Plants and algae with this relatively rare ability are normally not very competitive in aquatic environments where dissolved nitrogen is abundant, but when nitrogen becomes limiting they come into their own. Because plants, algae and micro-organisms are the foundation of the aquatic food chain, it is important to know which assemblage of species provides this function, and the type of nutrient limitation and its severity help determine this.

The Goleta Stream Team sampling locations provide examples of both N-limitation and P-limitation, and at some sites the situation flips back and forth. Figure 25 shows median nitrate to phosphate ratios for both 2006 and prior years. Error bars mark the quartile points - the middle 50 percent of all monthly results fit between these limits. The Atascadero sites have low ratios, meaning these locations are almost always N-limited – nitrogen is in short supply and limits growth. Conversely, agriculturally dominated sites, such as Glen Annie, Los Carneros and San Jose, are phosphorus limited. At other locations, including Maria Ygnacio and San Pedro, nitrogen and phosphorus are either roughly in balance or the stream bounces back and forth depending on the circumstances.

[17] This 16:1 ratio, the "Redfield ratio," is named after its discoverer (Sterner and Elser, 2002).

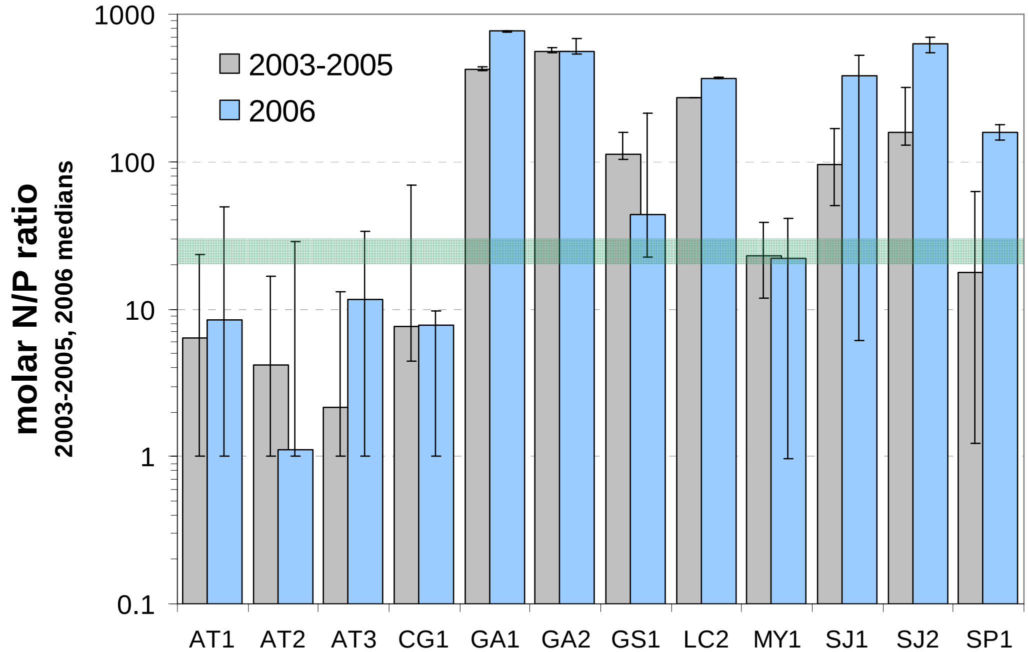

Figure 25. Median nitrate to phosphate ratios for the Goleta Stream Team sampling sites for 2003-2005 and 2006. Life requires both nitrogen and phosphorus, but in different amounts. Plankton, on which the oceanic food chain is based, use nitrogen and phosphorus in a ratio of 16 molecules of N to 1 of phosphorus; this is known as the "Redfield Ratio." In creeks and rivers, the ratio is closer to 30:1 and is roughly indicated by the horizontal bar in the figure (the nitrate to phosphate ratio is being used as an approximation of the nitrogen to phosphorus ratio; on average, nitrate is approximately 85 percent of the total nitrogen and phosphate 90 percent of the total phosphate in Goleta samples). The Atascadero sampling locations (AT and CG) are almost always "nitrogen limited," meaning that while phosphorus is plentiful, nitrogen is often exhausted. Agricultural locations (GA, LC and SJ) are "phosphorus limited," in other words they have more than enough nitrogen but limited phosphorus. The error bars indicate the quartile points, the middle 50 percent of the monthly N/P ratios for that location lie within the band represented by the error bar. In 2006, N/P ratios generally increased above long-term mean values, mainly as a result of lower than usual phosphate concentrations (see Figure 22).

Relatively dry winters tend to produce N-limited conditions, mainly due to reduced inflows of nitrate in storm runoff (recall that approximately 30 times more nitrogen than phosphorus is needed for balance). Wet winters usually produce plenty of high-nitrate groundwater inflows and runoff, resulting in P-limitation. 2006, with its reduced phosphate concentrations, probably shifted the entire system towards P-limitation. Comparing dry season (June-September) nutrient ratios, Figure 26 illustrates the changes that occurred from 2004 (a low rainfall year) through 2006. Only at AT1, however, did a reach appear to undergo a major shift. It is important to stress the word "probably" since we have only limited knowledge of organic phosphorus concentrations: the TDN to TDP ratio is usually a better predictor of nutrient status than the nitrate to phosphate relationship used here.[18]

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[18] Figures 24 and 25 use molar ratios, where concentrations of nitrate and phosphate are expressed in µM – micromoles per liter – before dividing one by the other. The µmole, a measure of the number of atoms, is more useful than weight when comparing the proportions of nutrients; 1 mg/L of nitrate as nitrogen is equal to 72 µM, 1 mg/L of phosphate as phosphorus equals 32 µM.

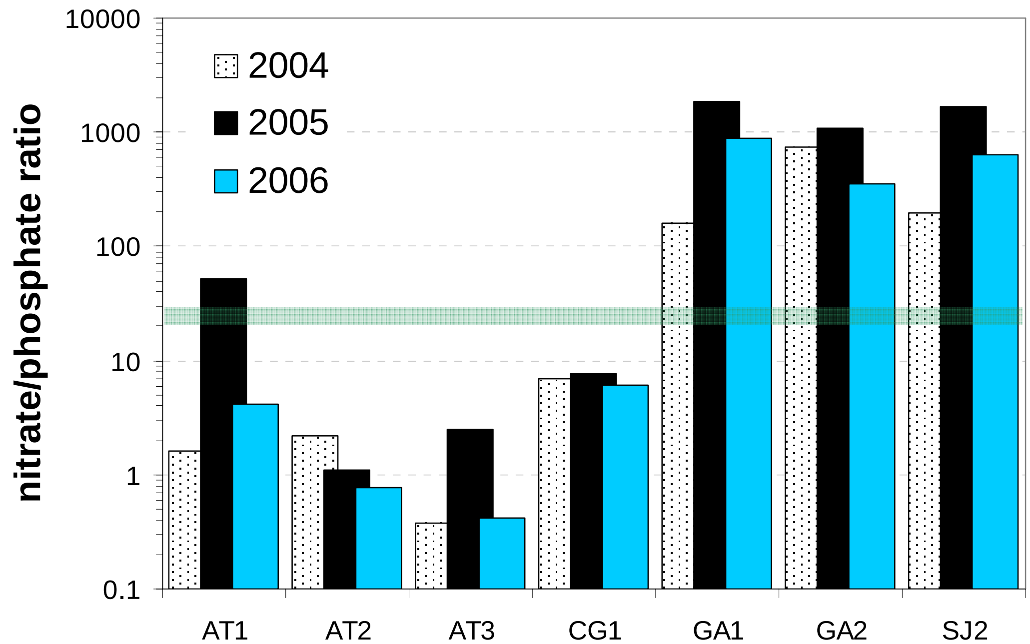

Figure 26. Average dry-season (June through September) nitrate to phosphate ratios for 2004, 2005 and 2006. The horizontal bar marks the approximate 20:1 to 30:1 zone where both nutrients are in balance. In 2005, increased nitrate concentrations and heavy algal growth following a wet winter produced a substantial increase in the N:P ratio at all locations except AT2 (only locations with 2004 dry-season flows are shown in the chart). Wet years flush out nitrogen accumulated during dry spells, increasing nitrate concentrations in both storm runoff and groundwater seepage. Increased algal growth, which follows a wet winter due to greater availability of nitrogen, sunlight and favorable habitat, disproportionately reduces phosphate concentrations. 2006 generally represents a gradual return to the conditions seen in 2003-2004: growing season N:P ratios are still high because of heavy algal growth but have decreased from the level seen in 2005 as nitrate becomes less plentiful and growing aquatic and riparian vegetation reduces available algal habitat.

While nutrient concentrations can determine the nature of the aquatic community and whether or not algae thrive, other factors are equally important. Flow controls the extent of habitat availability, and the amount of sunlight sets an upper limit on primary productivity. In many parts of the watershed, overhanging vegetation and trees restrict available sunlight, retarding algal growth which, given the over-abundance of nutrients in the Goleta system, is no small thing.

Bacteria[19]

Members of two bacteria groups, the coliforms and fecal streptococci, are used as indicators of possible sewage contamination because they are commonly found in human and animal feces. Although generally not harmful themselves, they indicate the possible presence of pathogenic

[19] US-EPA (2002 and 2004), CSWRCB (2003 and 2004), and CRWQCB-LA (2001) were used as references for this section. There are significant differences between EPA indicator bacteria guidelines and current California State regulations. The regulatory situation is in a state of flux and the following narrative should be considered a reasonable overview and not taken as definitive.

(disease-causing) bacteria, viruses and protozoans that also live in human and animal digestive systems. Their presence in water suggests that pathogenic microorganisms might also be present and that contact with these waters could present a health risk. Since it is difficult, time-consuming and expensive to test directly for a large variety of pathogens, water is usually tested for coliforms and fecal streptococci instead.

Channelkeeper analyzes monthly samples for three types of bacteria:

Total Coliform, a large and widespread group of bacteria that occur in human feces but are also found in animal manure, soil, vegetation, submerged wood, and in other places outside the human body. Total coliforms are no longer recommended by the EPA as an indicator for freshwater, but they remain the standard test for drinking water because their presence indicates contamination of a water supply by some outside source. California still requires the total coliform test for recreational waters because the ratio of fecal to total coliforms remains a good indicator of swimming-related illness.

E. coli, a species of coliform bacteria specific to fecal material from humans and other warm-blooded animals, is recommended by the EPA as the best indicator of health risk from body contact in freshwater. California still allows the broader and older fecal coliform test (which includes *E. coli* as well as other coliform species).

Enterococcus is a relatively human-specific subgroup of fecal streptococci with an ability to survive in salt water. Enterococci mimic many pathogens more closely than the other bacterial indicators. The EPA considers enterococci to be the best indicator of a health risk in salt water and a useful indicator for freshwater as well.

Bacteria are reported as the *most probable number* (MPN) of bacteria in 100 milliliters (ml) of water. Channelkeeper uses a statistical test instead of directly counting bacteria, so the reported number is actually a statistical estimate. California Public Health requirements for bacteria counts are complicated and vary somewhat by jurisdiction; what follows is an amalgam of EPA recommendations and various California standards. Generally, there are two limits for each test, a single sample limit and a limit for a geometric average of five or more samples collected over a period of either five weeks or a month.[20]

For freshwater recreational use, the total coliform limits are "not to exceed 10,000 per 100 ml in a single sample, and a geomean of less than 1,000." The geomean requirement for *E. coli* is less than 126 bacteria/100 ml of water and the single sample limit varies from 235 to 576 depending on intensity of use (not to exceed 235 for beach areas, 576 for occasional recreational use). For enterococcus the "geomean average of five or more samples" limit is less than 33 MPN/100 ml and the single sample limit can vary from 61 to 151, again depending on frequency of use.

The total coliform single sample limit of 10,000 MPN/100 ml applies only as long as the fecal/total coliform ratio is less than 0.1, or in other words, as long as less than 10 percent of the coliforms are of fecal origin. If the ratio rises above 0.1, the single sample limit is decreased to 1,000 MPN/100 ml.

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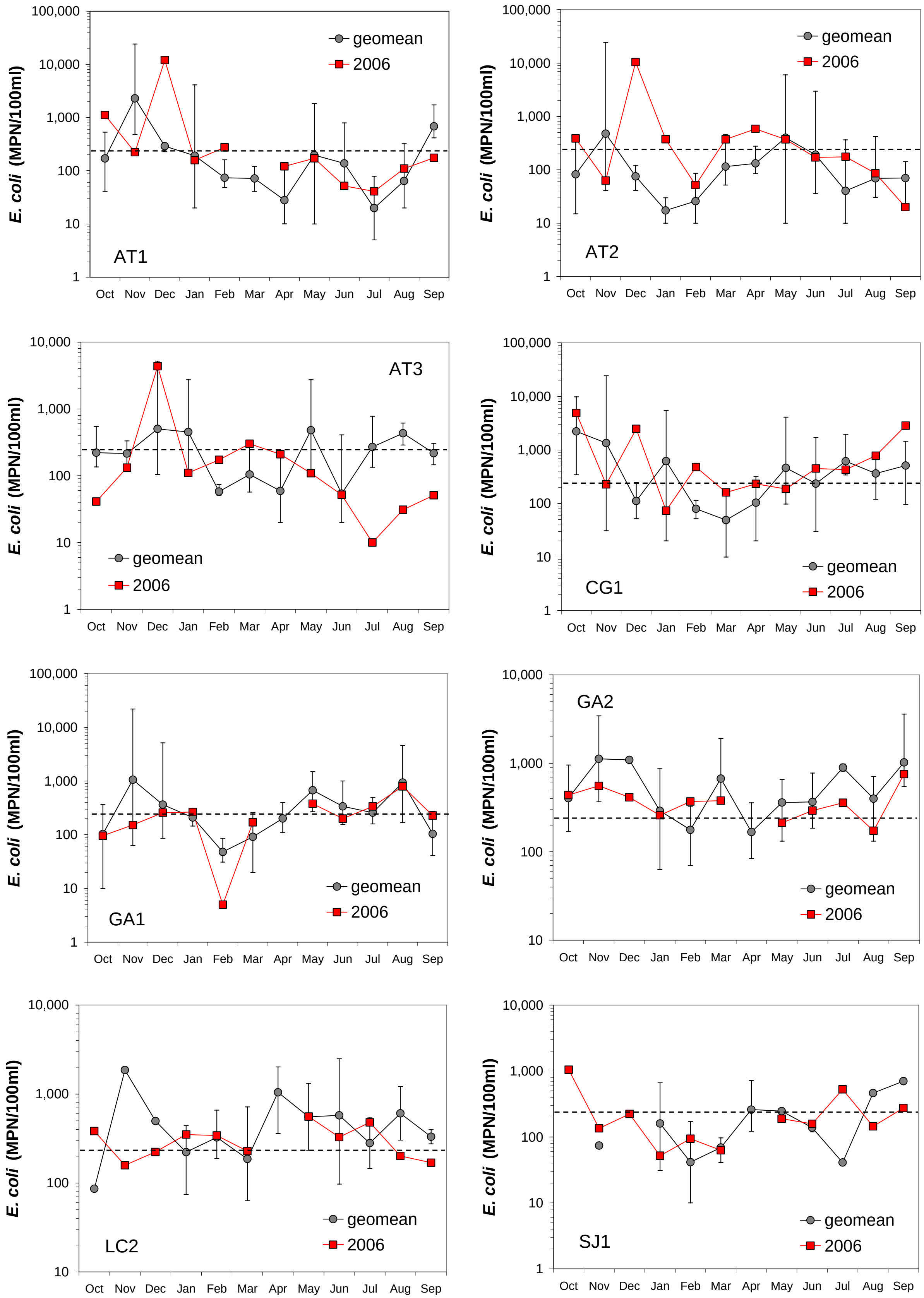
[20] The "geometric average" or "geomean" is calculated by converting bacteria counts into logarithms, averaging the logarithms, and then converting that average back to a regular number. The geomean reduces the influence of very high or low numbers, which might unfairly represent aberrant samples.

Since Channelkeeper only samples once a month, using "average geomean" standards would be inappropriate. However, the geomean concept, that of reducing the importance of occasional very high or very low samples, is a useful tool. Accordingly, monthly bacteria concentrations for each of the Goleta Stream Team sites are shown with monthly geomeans from 2003 through 2005 (error bars indicating maximum and minimum monthly values) for each of the three types of bacteria in Figures 27, 28 and 29. These results are summarized by comparing 2006 geomeans for each location with longer term 2003-2005 geomeans in Figures 30 and 31. Fecal to total coliform ratios for both 2003-2005 and 2006 are included in the lower panel of Figure 30. The single sample standards discussed above are shown as horizontal lines on the chart



AT1
AT2
AT3
CG1
GA1
GA2
LC2
SJ1
geomean
2006
E. coli (MPN/100ml)
100,000
10,000
1,000
100
10
1
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep

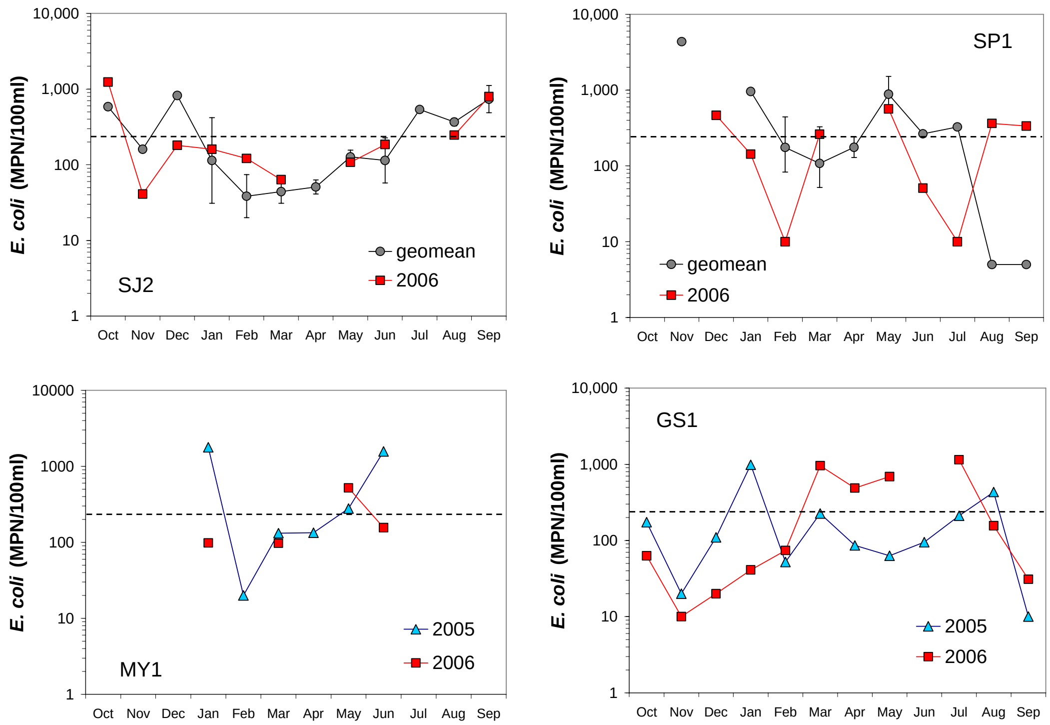
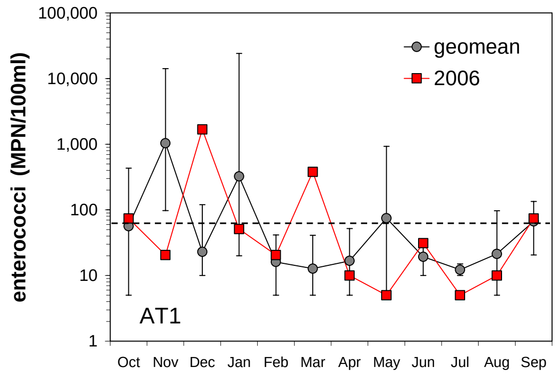
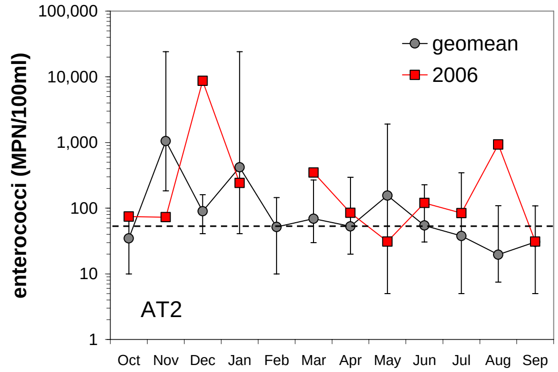
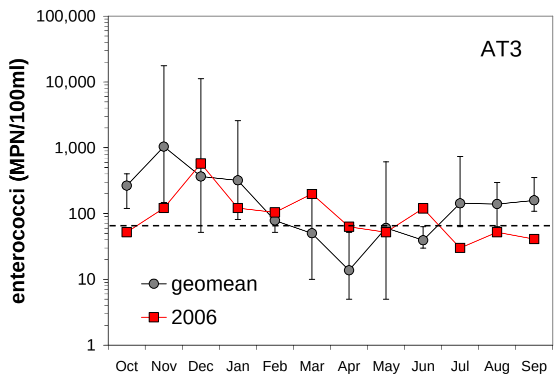
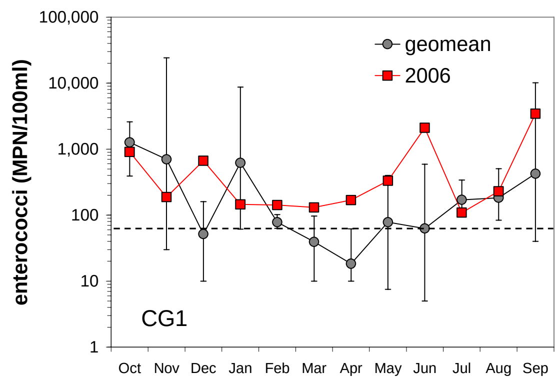


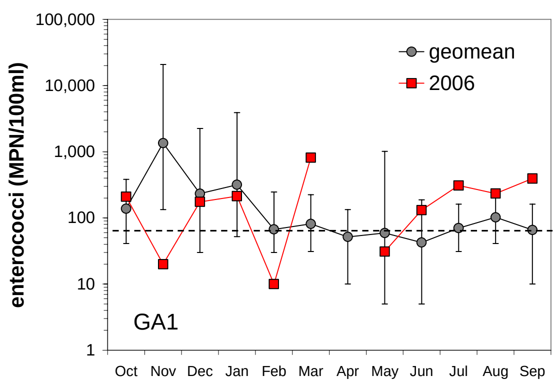
Figure 27. Monthly *E. coli* concentrations for the Goleta Stream Team sampling locations during the 2006 water-year are shown with monthly geomean values from 2003-2005. Error bars indicate the monthly maximum and minimum concentrations in previous years. Levels at MY1 and GS1 during 2005 and 2006 are shown in the bottom panels.

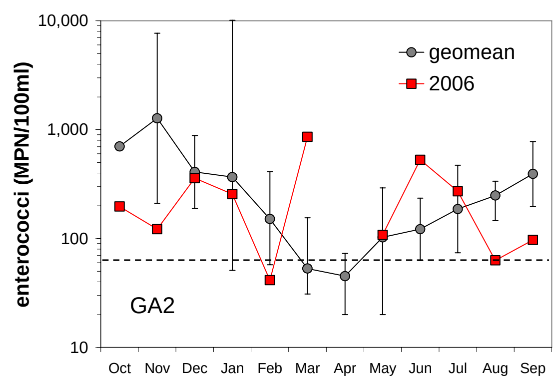

100,000
10,000
1,000
100
10
1
enterococci (MPN/100ml)
geomean
2006
AT1
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep

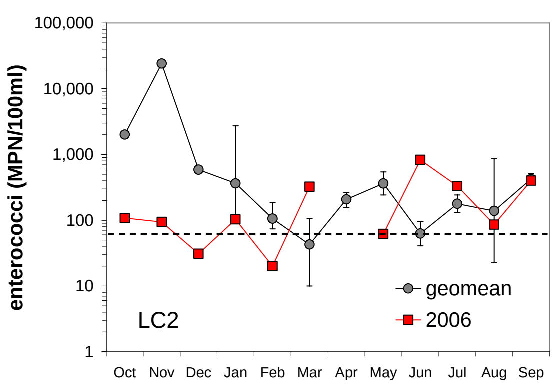

100,000
10,000
1,000
100
10
1
enterococci (MPN/100ml)
geomean
2006
AT2
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep

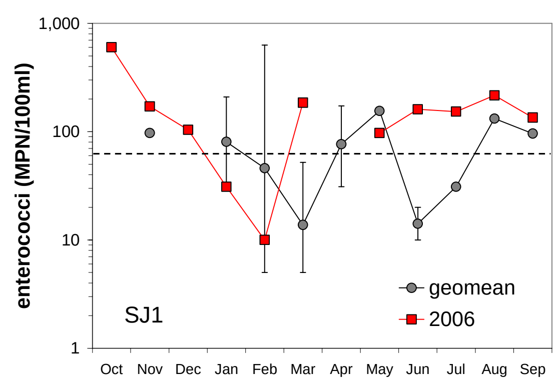

100,000
10,000
1,000
100
10
1
enterococci (MPN/100ml)
AT3
geomean
2006
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep


100,000
10,000
1,000
100
10
1
enterococci (MPN/100ml)
geomean
2006
CG1
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep


100,000
10,000
1,000
100
10
1
enterococci (MPN/100ml)
geomean
2006
GA1
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep


10,000
1,000
100
10
enterococci (MPN/100ml)
geomean
2006
GA2
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep


100,000
10,000
1,000
100
10
1
enterococci (MPN/100ml)
geomean
2006
LC2
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep


1,000
100
10
1
enterococci (MPN/100ml)
SJ1
geomean
2006
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep

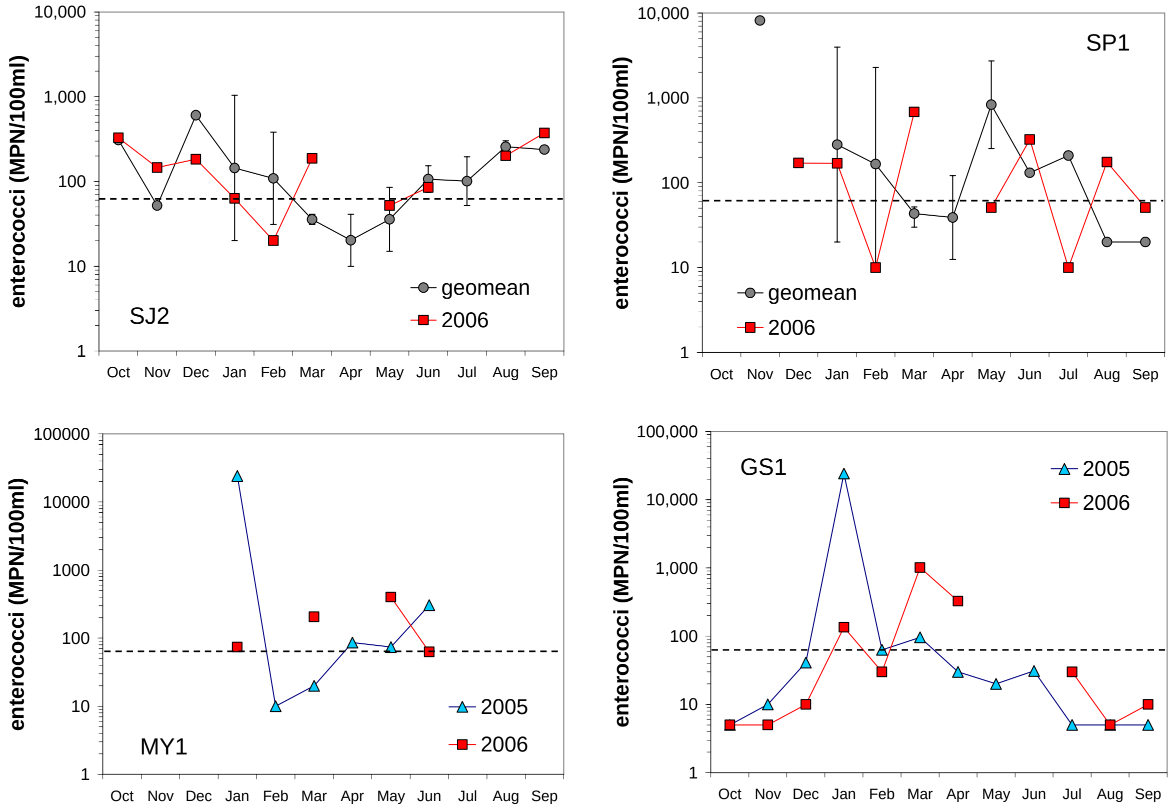
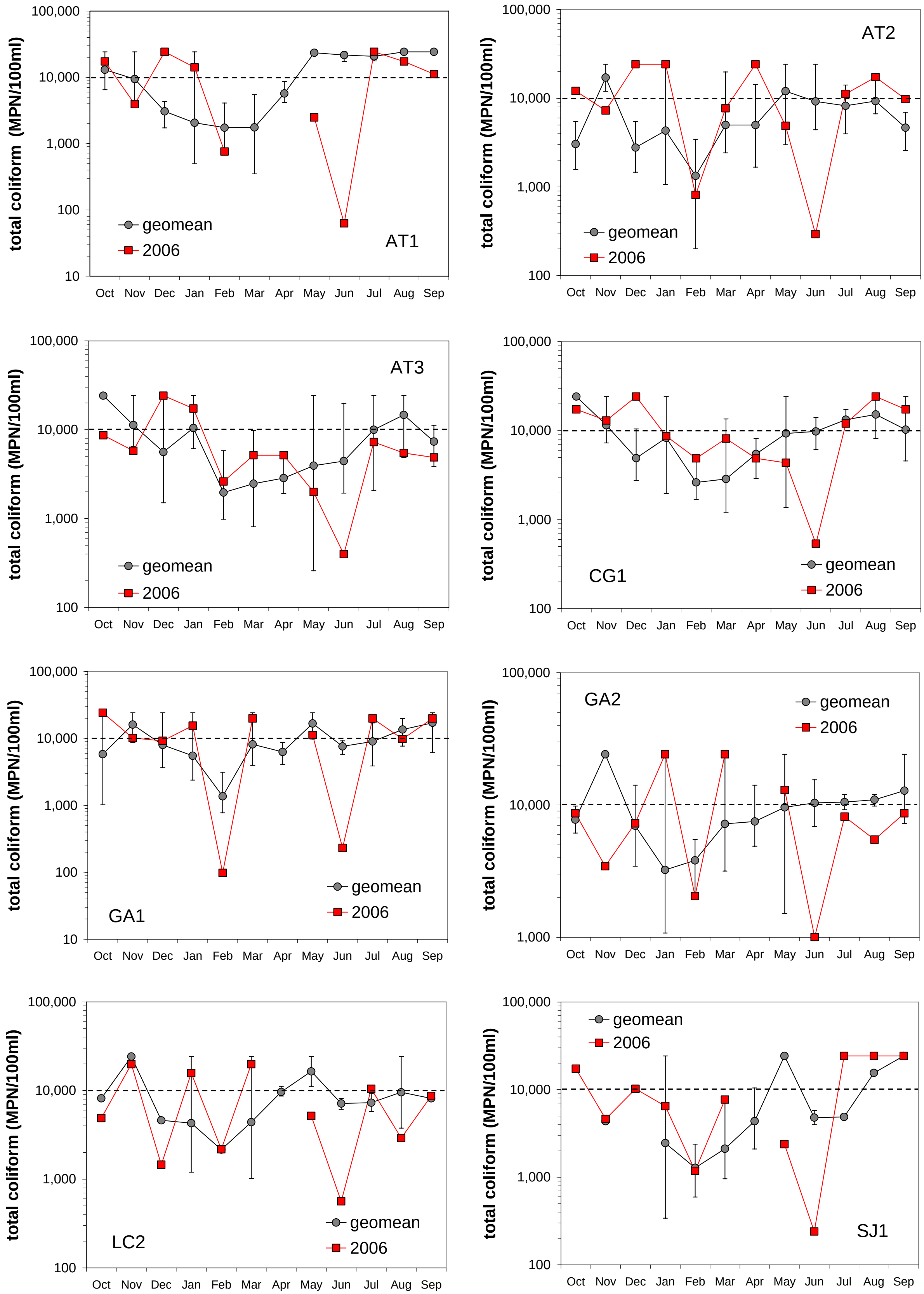


Figure 28. Monthly enterococci concentrations for the Goleta Stream Team sampling locations during the 2006 water-year are shown with monthly geomean values from 2003-2005. Error bars indicate the monthly maximum and minimum concentrations in previous years. Levels at MY1 and GS1 during 2005 and 2006 are shown in the bottom panels.



AT1
AT2
AT3
CG1
GA1
GA2
LC2
SJ1
geomean
2006
total coliform (MPN/100ml)
10
100
1,000
10,000
100,000
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep

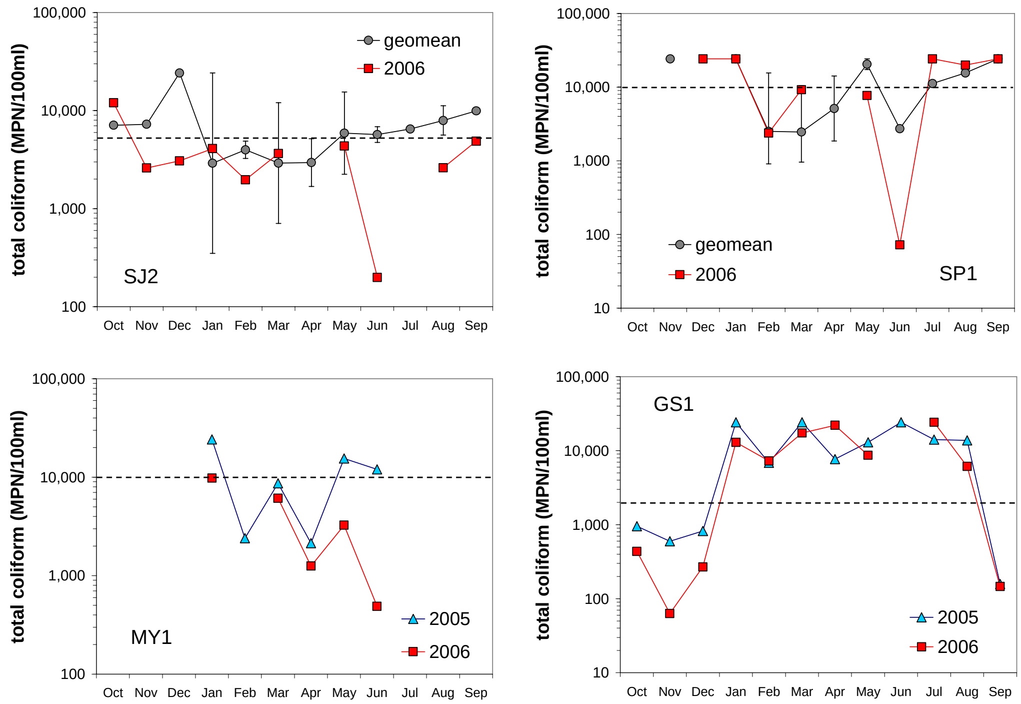
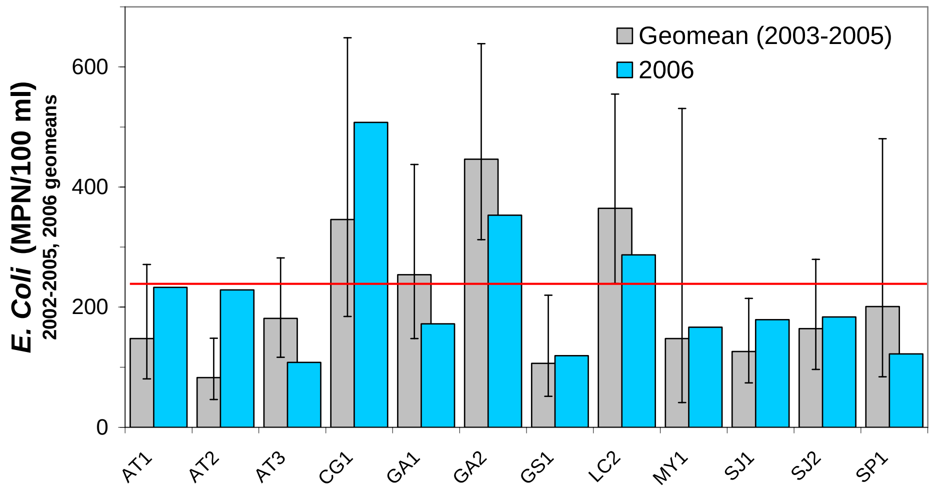


Figure 29. Monthly total coliform concentrations for the Goleta Stream Team sampling locations during the 2006 water-year are shown with monthly geomean values from 2003-2005. Error bars indicate the monthly maximum and minimum concentrations in previous years. Levels at MY1 and GS1 during 2005 and 2006 are shown in the bottom panels.

The error bars in Figures 30 and 31 indicate the 95 percent confidence interval of the long-term geomeans. Both indicate the bounds within which an annual value might be expected to vary. Only on Atascadero did *E. coli* (at AT2) and enterococci (at AT2 and CG1) levels significantly increase. An *E. coli* increase at CG1, although within the confidence interval established by past data, did push the average fecal to total coliform ratio above 0.1. Two other sites, MY1 and SJ2, also had average fecal to total ratios above this limit in 2006, but this is of lesser concern since the higher ratios were caused by lower total coliform numbers and not by appreciable increases in *E. coli*.[21]

[21] Channelkeeper does not actually test for fecal coliform, instead the *E. coli* values have been multiplied by 1.7 to estimate fecal coliform concentrations (this assumes that a fecal coliform sample would consist of approximately 60 percent *E. coli*. This equivalency is the value assumed by most regulatory standards and is a conservative estimate; see also Cude, 2005.



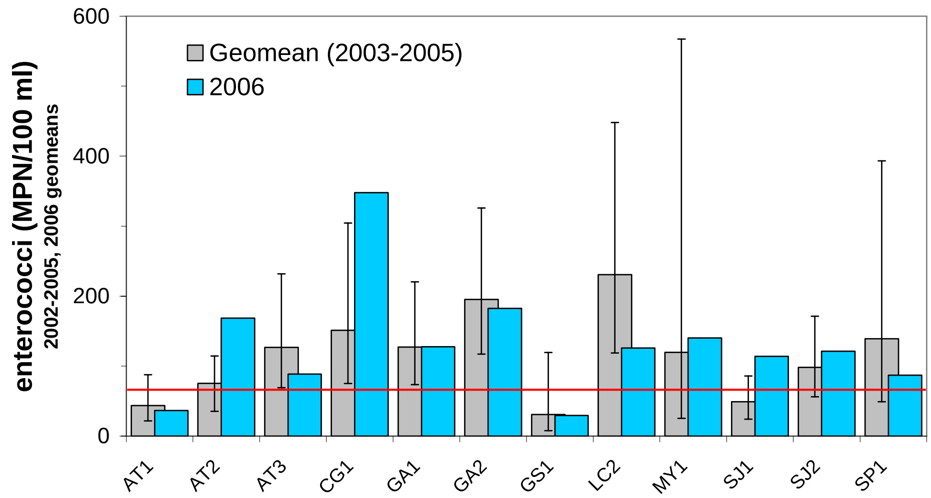


Figure 30 (above). 2006 geomean *E. coli* (upper panel) and enterococci (lower panel) concentrations compared with geomeans from 2003-2005. Error bars represent the 95 percent confidence interval for the long-term geomeans. Horizontal lines mark the EPA's recommended freshwater beach Public Health limits for maximum *E. Coli* (235 MPN/100 ml) and enterococcus (61 MPN/100 ml).

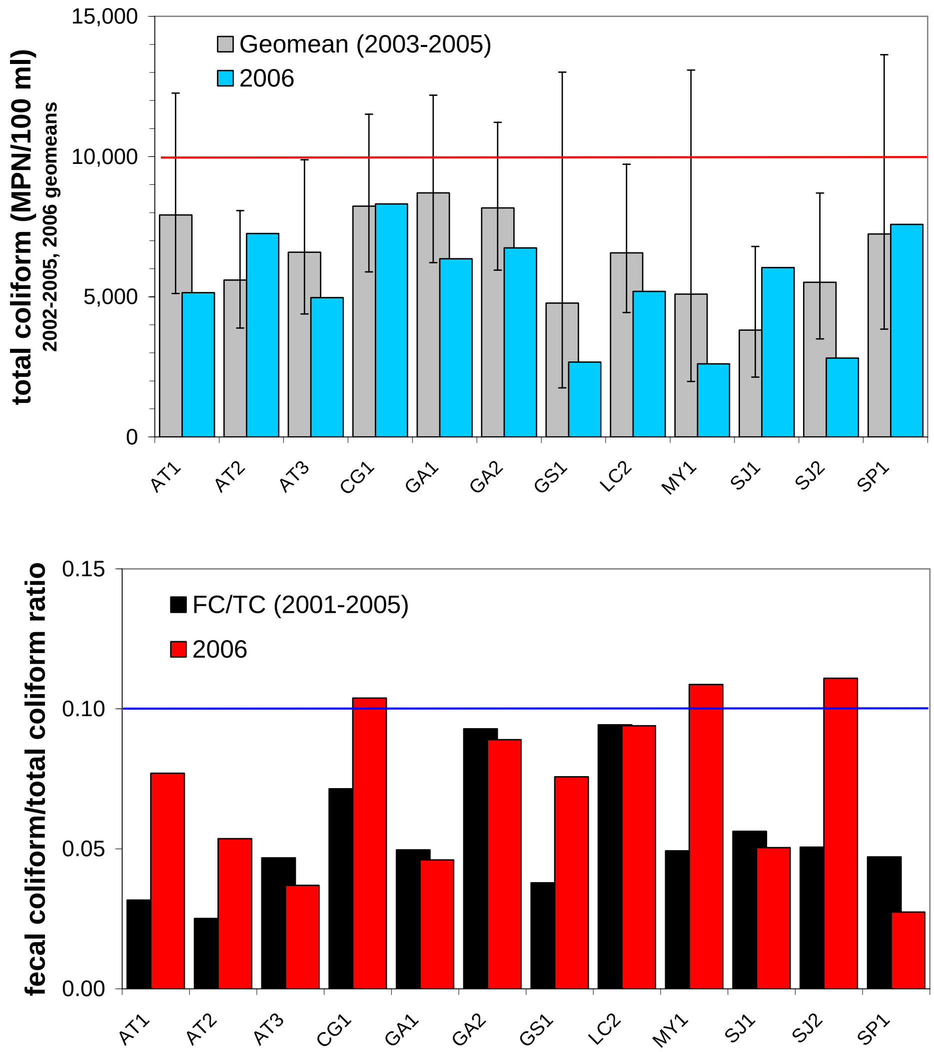


Figure 31. *Upper panel*: 2006 geomean concentrations for total coliform compared with 2003-2005 geomeans. Error bars represent the 95 percent confidence interval for the long-term geomeans. The California limit for total coliform is 10,000 MPN/100 ml. *Lower panel*: 2006 and 2003-2005 fecal to total coliform ratios. The California limit for total coliform decreases to 1,000 MPN/100 ml if the fecal coliform/total coliform ratio exceeds 0.1 (horizontal line).

At sites that display the highest bacteria levels, there is relatively good agreement between all three tests, but for those sites that meet the standards for freshwater recreation (using single sample standards of 61 enterococci, 235 *E. coli* and 10,000/1,000 total coliforms as criteria), the results present a mixed picture. All sites but AT1 and GS1 repeatedly failed to meet the enterococcus standard in 2006, but only CG1, GA2 and LC2 exceeded the *E. coli* limit, and only CG1, SJ2 and MY1 had unacceptable total coliform results.

This is not unusual. Studies show that while there is usually agreement between the three tests at either highly polluted or pristine locations, they can disagree appreciably at sites that lie in the middle (Kinzelman, 2003; Nobel et al., 2003). The possible explanation for why the enterococcus standard is often exceeded in Channelkeeper results when the *E. coli* limit is not is that enterococci are able to live and reproduce in some local waters during the summer. It is primarily predation that removes indicator organisms from open water rather than adverse environmental conditions (Rassoulzadegan and Sheldon, 1986), and research has shown that coliforms and enterococci can often survive, grow (Francy et al., 2000; Nasser and Oman, 1999) and reproduce in plants and soil (Solomon et al., 2002; Hardina and Fujioka, 1991; Marino and Gannon, 1991).

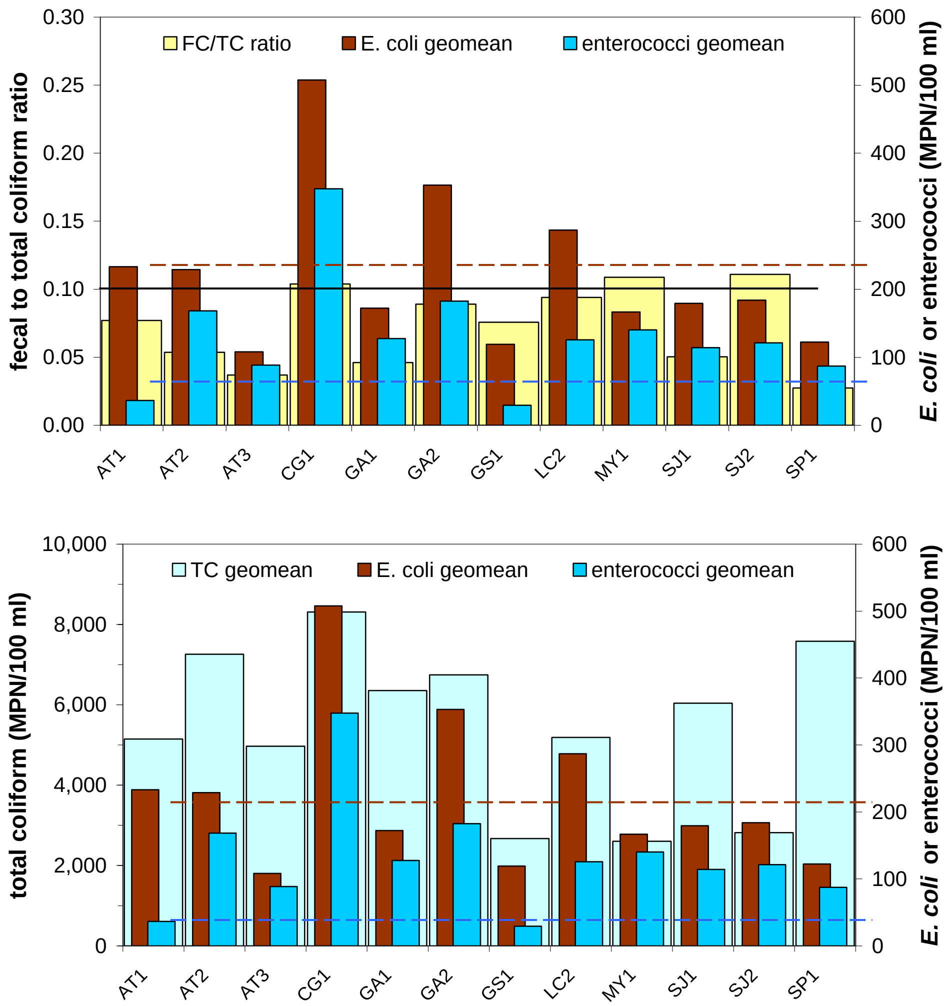


Figure 32. *Upper panel*: The average 2006 fecal to total coliform ratio with geomean *E. coli* and enterococci concentrations. Dashed horizontal lines mark the EPA's recommended freshwater beach Public Health limits for maximum enterococcus (61 MPN/100 ml) and *E. Coli* (235 MPN/100 ml). The California limit for total coliform (10,000 MPN/100 ml) decreases to 1,000 (indicating a pollution problem) if the fecal coliform/total coliform ratio exceeds 0.1 (solid line). *Lower panel*: Total coliform, *E. coli* and enterococci geomean concentrations for 2006.

In any event, all the Goleta Stream Team sites repeatedly fail to meet the standards for water contact recreation, although bacteria counts are usually not high enough to generate grave concern for occasional and intermittent use (*E. coli* greater than 576). Figure 32 presents the

2006 results. Annual geomeans for *E. coli* and enterococcus and the fecal to total coliform ratio are shown in the upper panel, while all three indicator bacteria are shown in the lower.

Goleta Slough Results

Since evaluating the potential impacts on the Goleta Slough from surrounding watersheds is one of the major purposes of Channelkeeper's Goleta Stream Team program, this section separately examines data from the as yet limited sampling conducted at the slough (i.e., GS1). The object is to analyze sampling results for this important location as a totality, rather than parameter by parameter as was done in the previous sections of the report.

The slough and its fringing salt marsh are subject to drastic changes over the course of a year. Tidal inflows, normally the major influence on coastal lagoon/marsh systems, may be reduced or eliminated by the formation of sand berms at the slough mouth. Depending on creek flows and blockage at the mouth, slough water may be alternately brackish [22] or hyper-saline.[23] Moreover, the slough is periodically flushed with freshwater during winter storms. Beyond this extreme seasonal variation, because streamflow exercises a large degree of control on slough conditions, the year-to-year changes resulting from differences in rainfall are also considerable.

Flows from Tecolotito and Los Carneros creeks exercise a primary control on slough conditions. In wet years, there are large inputs of water and nutrients from these streams, and since the mouth of the slough remains open to the ocean for longer periods, tidal inflows continue to play an important role during the summer season. In dry years, the mouth of the lagoon is restricted or closed for longer periods of time while inflows of freshwater and nutrients decrease appreciably. The difference between dry and wet year nitrogen export from Tecolotito and Los Carneros creeks to the slough is substantial, since both streams combine very high nitrate concentrations with drastic changes in flow (USCB-LTER).

Goleta Stream Team began sampling the slough at GS1 (off of the Goleta Beach Bicycle Bridge) in October 2004, and data collected since that time are summarized in Figures 33 and 34. In Figure 33, the standard measurements made during Goleta Stream Team surveys are shown. Conductivity values (upper panel) indicate which water source was dominant: tidal inflows from October through December (> 40 mS/cm), mildly brackish waters through the rainy season, and a gradual increase in salinity from the end of the rainy season to October. This gradual rise in conductivity indicates, if not the formation of a complete sand barrier at the outlet, a highly restricted passage for salt water into the slough. The impact of a big storm can be seen in the January 9, 2005 measurement of 0.8 mS/cm, i.e., the total displacement of salt and brackish waters by freshwater storm runoff.

[22] Low salinity of 5-30 parts per thousand (ppt) or approximately 4-46 mS/cm.
[23] Salinity greater than 40 ppt or 60 mS/cm.

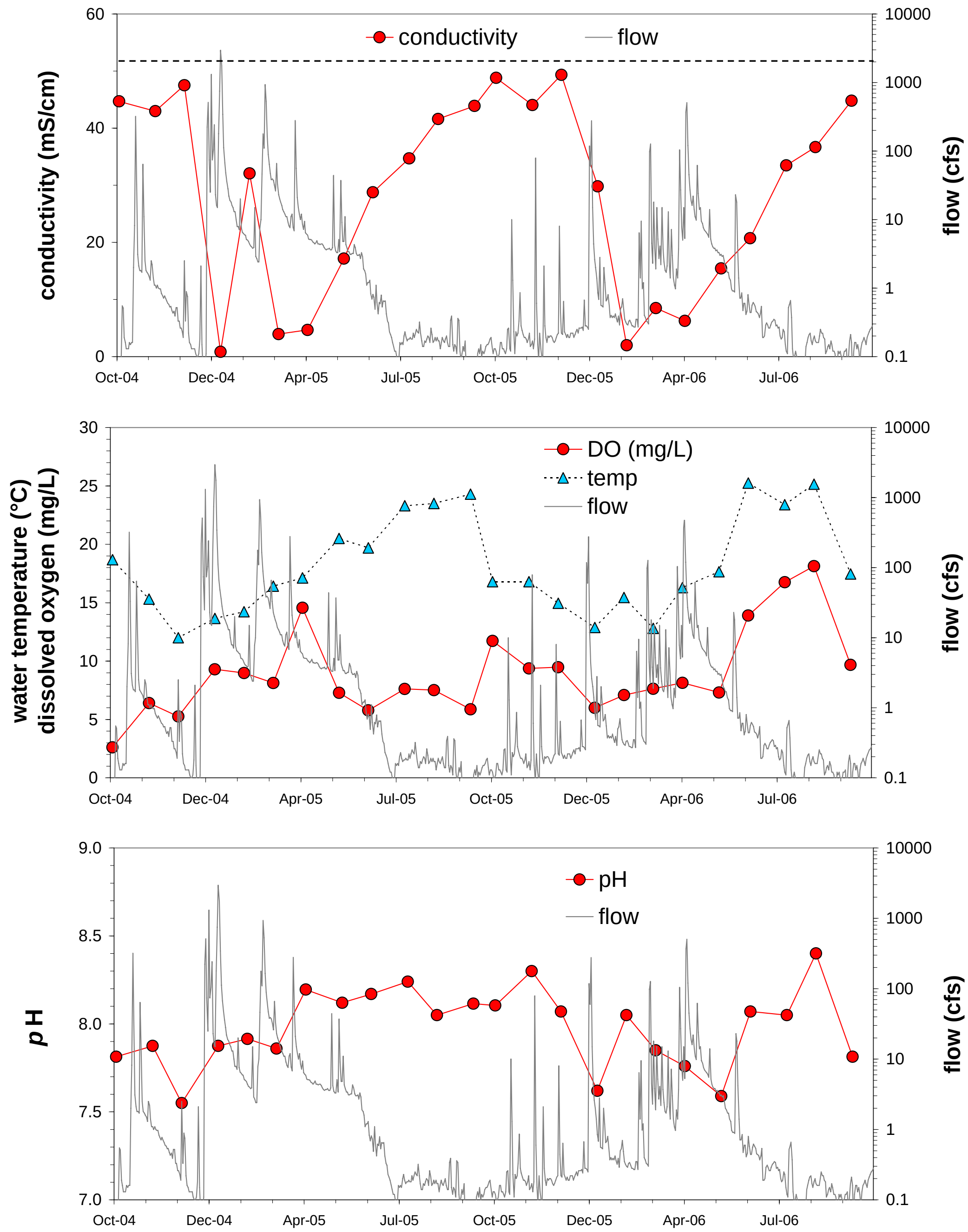


Figure 33. The variation of water quality parameters at Goleta Slough (GS1) in 2005-2006. Flow at Atascadero (AT2) is shown in the background to indicate storm events and the relative contribution of freshwater. Conductivity indicates the relative proportions of fresh and salt water at GS1; the dashed line represents Central Pacific Ocean conductivity. High DO and *p*H in the summer of 2006 are indicators of an extensive algal bloom.

*p*H (lower panel) remained consistently below 8.5 but underwent some relatively dramatic variations that appear to be partly biologically mediated: highs produced by algal blooms (April 2005 and June-August 2006) and lows by appreciable decay of organic matter in relatively stagnant waters (October-December 2004). Differing *p*H values of the various source waters add to the mix: stormflows with *p*H circa 7 and saltwater with values above 8.

With the exception of a worrisome low of 2.8 mg/L in October 2004, dissolved oxygen levels were above 5.5 mg/L. However, night-time decreases in DO were not measured during the major algal episode of July-August 2006, and given the near 200 percent daylight saturation at that time, they may have been appreciable. Comparing temperature and DO variations in the middle panel of Figure 33, it appears that algal growth in 2006 was significantly greater than in 2005.[24]

Nutrient concentrations also reflect changes in the source of slough water during the sampling period. Tidal inflows from October through December were low in nitrate while creek inflows during the rainy season provided high nitrate freshwater during the months that followed (Figure 34, middle panel). The variation in nitrate concentrations during this change-over is extreme, from virtual disappearance (below detection limits) to greater than 5 mg/L, a range of many orders of magnitude. Phosphate exhibits much less variation. Phosphate is almost never limiting in ocean water, and most freshwater inflows in this area are also high in phosphate. Occasional peaks caused by sediment inflows appeared during storm periods (i.e., January 2005 or March 2006) and depressed summer values were due to biological uptake in what is a relatively closed system; note that periods of low phosphate generally coincide with high DO concentrations.

Ammonium concentrations were very high in November-December 2004 (around 0.18 mg-N/L), when ammonium concentrations exceeded those of nitrate. This is a relatively rare occurrence - nitrate concentrations usually greatly exceed those of ammonium - and may have been caused by the release of ammonium from bottom sediments due to disturbance by inflowing tides. The fact that phosphate concentrations were also high in November and December lends support to this assumption, since anaerobic bottom sediments are high in both nutrients. This situation was not repeated in 2006, but high ammonium concentrations were seen from January through July (average of 0.17 mg-N/L, a peak of 0.24 in January).

Ammonium is a nutrient source of nitrogen and, as such, is measured in the UCSB analysis. However, *ammonia*, a very powerful aquatic poison, is not measured. Ammonia (NH_3) is the un-ionized fraction of ammonium. In water, ammonia usually ionizes and becomes ammonium (NH_4^+), gaining a hydrogen ion and becoming an ionized molocule instead of a gas. When we analyze for ammonium we measure both: the result is ammonium plus ammonia. Both always exist together.

While ammonia is not measured, it can be calculated if the temperature and *p*H are also known; as water temperature and *p*H increase, the amount of ammonia also increases. Usually, ammonium concentrations and *p*H are not high enough to even bother making this calculation. However, reasonably high concentrations of ammonium, combined with higher temperatures during a summer period of restricted inflows and higher *p*H values due to daytime algal growth in the slough, make ammonia contamination a real possibility.

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[24] Out of phase in 2005, indicating the expected gas-solubility variation, and in phase in 2006, indicating considerable algal production.

The lower panel of Figure 34 shows calculated ammonia concentrations at GS1. The line indicates the 0.025 mg-N/L ammonia limit established by the Central Coast Regional Water Quality Control Board (CRWQCB-CC, 1994). At no time was the limit exceeded, but concentrations in July of both 2005 (0.015 mg/L) and 2006 (0.011 mg/L) were high enough to warrant further attention to this possible problem in the future.

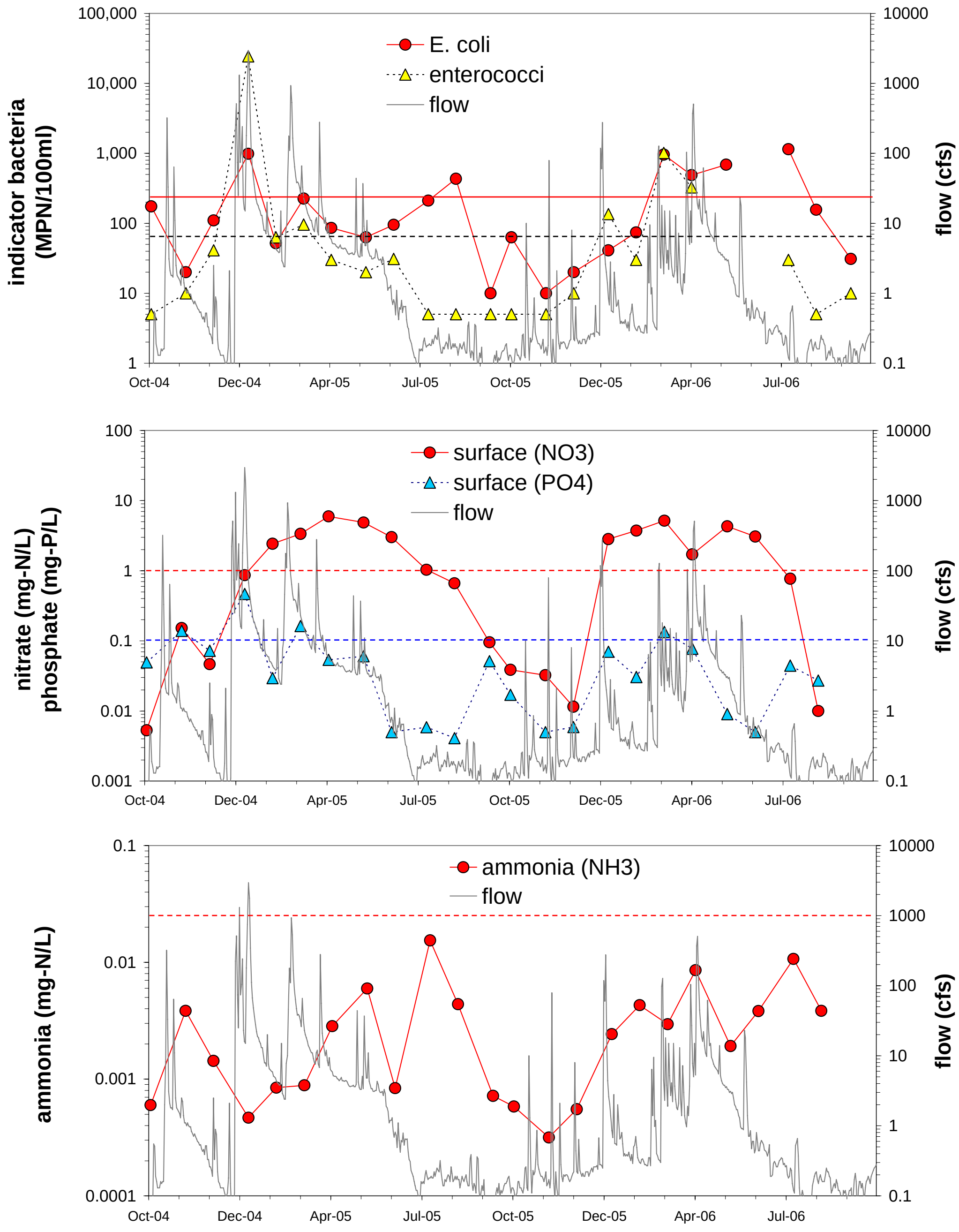

Figure 34. The variation of indicator bacteria (upper), nitrate and phosphate (middle), and ammonia (lower) concentrations at Goleta Slough (GS1) in 2005-2006. Flow at Atascadero (AT2) is shown in the background to indicate storm events and the relative contribution of freshwater. The dashed lines represent, respectively, the single sample Public Health limits for indicator bacteria, the nutrient boundary limits for acceptable esturary waters (1.0 and 0.1 mg/L for N and P), and the Basin Plan limit for ammonia (0.025 mg/L).

Enterococci and *E. coli* levels at GS1 are shown in the upper panel of Figure 34. Winter storm flows produce elevated concentrations in both indicator organisms. This was best seen in January 2005 when a major storm caused a dramatic rise in concentrations: enterococci numbers rose to 16,000 MPN/100 ml (recall that the freshwater beach limit is 61), *E. coli* to 900 (beach limit of 235) and total coliform concentrations were greater than 24,000 (the maximum determinable test concentration; the beach limit is 10,000). There is an interesting reversal in the relative numbers of *E. coli* and enterococci during storm periods. Typically, *E. coli* concentrations are higher than those for enterococci (cf. Figure 32), a relationship also suggested by their respective Public Health limits of 235 and 61. However, during storm periods slough samples show greater increases in enterococci than in *E. coli*. Relatively lower *E. coli* numbers may be evidence that high enterococci concentrations are not necessarily related to pollution problems in Santa Barbara (SBCK, 2005 (b)) and that these organisms are able to reproduce successfully in creek-side and marsh environments.

Metals[25]

"Full suite testing," a range of separate chemical analyses for organic chemicals and metals, was scheduled at a subset of Goleta locations in July 2006. Trace contaminants (volatile organic compounds, pesticides, herbicides, PCBs and metals) are most often found in streams tributary to heavily developed agricultural and urban areas, and the sites selected were GA1, AT1 and two locations in the slough (GS1 and a site further upstream – roughly at the slough's midpoint – labeled GS5). Sampling of sediment in these locations was of special interest to Channelkeeper since the Goleta Slough was recently de-listed for impairment by metals and sedimentation on the State's "303(d) List" of impaired waterbodies (CRWQCB-CC, 2006).

The reason appears to be that sediment is now regarded as coming in two forms: polluted and non-polluted. Non-polluted sediment is not considered a pressing problem. Indeed, it is a lack of non-polluted sediment for beach replenishment that currently receives the primary emphasis. New standards defining sediment pollution problems clearly state that they do not include "(1) sediment as a physical pollutant that causes adverse biological response or community degradation related to burial, deposition or sedimentation, and (2) sediments characterized by less than 10 percent of fines or substrates composed of gravels, cobles or consolidated rock" (CSWRCB, 2006b).

Once the *physical* process of sedimentation in Goleta Slough was no longer considered a pollution problem, it required certifiable evidence of chemical contamination to retain its 303(d) listing. Since the chemical data that led to the original listing could no longer be located, the listing was removed.[26]

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[25] The following websites were used as references in the preparation of this section: US-EPA, Ground and Drinking Water (http://www.epa.gov/safewater/mcl.html#mcls); Agency for Toxic Substances and Disease Registry (http://www.atsdr.cdc.gov/); Ontario, Ministry of the Environment (http://www.ene.gov.on.ca/cons/); and the International Programme on Chemical Safety – ICHEM (http://www.inchem.org/). The subject of trace contaminants is complicated and the regulatory situation is constantly changing. The following narrative should be considered simply as an introduction to the subject of metals contamination and is intended to be neither a complete overview nor definitive in a regulatory sense.

[26] Only metal contamination and sedimentation were removed from the 303(d) List; the slough is still listed as impaired by priority organics and pathogens.

In an effort to repair this regulatory glitch and to gather further data on possible slough contamination, samples of water and sediment were collected on July 19, 2006 and sent for analysis to FGL Environmental (853 Corporation Street, Santa Paula, EPA certification #1563). Unfortunately, due to a misunderstanding with the lab, the anticipated full-suite analyses were not conducted and only tests for metals on the sediment samples and a single water sample were done. Another round of sample collection for full suite testing has been tentatively re-scheduled for January 2007. Meanwhile, results of the July metals analyses are shown in Table 2 and discussed below.

Sediments can accumulate toxic contaminants that may be found only occasionally, or in difficult to identify trace amounts, in the water column. Since they serve as a reservoir and source of contaminants to the stream flowing above, sediment analysis can help to identify problems that would otherwise be missed. And since the stream bottom, an integral and vital part of the aquatic environment, provides habitat for important organisms, its possible contamination is a direct concern.

Stream chemistry determines the rate at which heavy metals[27] are transferred between sediment and the water column. Metals are usually more highly concentrated in sediment because of very low water solubilities and are typically found adsorbed on clays and organic matter. Fine sediment, clays and silts, particularly those with high percentages of organic matter, will adsorb greater quantities than coarser, sand-like particles. Increases in salinity, reductions in redox potential (decreasing dissolved oxygen levels), and decreases in *p*H all cause metals to be released from sediments into overlying waters. Goleta Slough, indeed any estuary, experiences cycles involving all these processes, and the slough's location, down-slope of the Santa Barbara Airport, Highway 101, and the commercial and industrial areas of Goleta – all possible sources of heavy metals – would seem to mandate periodic sampling for these contaminants.

Aquatic organisms can ingest, respirate or even adsorb metals through their bodies, and uptake rates vary by organism and contaminant. Elevated levels of metals in water can cause morphological changes in tissue, suppress growth and development, degrade swimming ability, and change biochemistry, behavior and reproduction. Many aquatic organisms are able to regulate the metal concentrations in their tissues. Fish can excrete excessive amounts of needed metals such as copper, zinc and iron, and some can even get rid of other metals such as mercury and cadmium, in the same way. However, bivalves (clams, scallops, mussels and oysters) are unable to do this and suffer from metal accumulation in polluted waters, and high metal concentrations make shellfish unfit for human consumption. In estuarine systems, bivalves serve as good bio-monitors of suspected pollution. Aquatic plants are generally less sensitive to metals than fish and invertebrates, and thus protecting critters also protects plants.

The California Toxics Rule (US-EPA, 2000c) establishes long-term (chronic) and short-term (acute) aquatic life criteria for metals in salt and freshwater. The chronic criterion is the limiting concentration to which aquatic life can be exposed to without detriment for an extended time (four days), while the acute limit pertains to shorter intervals of exposure (one hour).

[27] Those metals with an atomic weight > 63, which pose the greatest danger to aquatic organisms.

Table 2. *Sediment and water analysis for metals. Goleta Slough (GS) and tributaries (AT1 & GA1), July 19, 2006. PQL is the practical quantitation limit, i.e., the minimum detection limit. The table lists the EPA maximum contaminant levels (MCLs) for drinking water, and the aquatic life acute and chronic limits for both fresh and marine waters. Limit concentrations in* ***bold*** *vary with freshwater hardness; the values listed are based on an estimated hardness of 400 mg/L as CaCO3 (measurements made on Santa Barbara/Goleta creeks in 2001 typically exceeded 500 mg/L). Acute limits pertain to one hour of exposure and chronic limits pertain to four days of exposure. For slough waters, which may vary in salinity, marine values are used for salinities above 10 ppt (17.4 mS/cm), for salinity below 10 ppt, the more critical value - either fresh or marine - should be used (this may require a concurrent measurement of hardness).*

	PQL	drinking water EPA MCL limits	aquatic life EPA acute limits	aquatic life EPA chronic limits	aquatic life EPA acute limits	aquatic life EPA chronic limits	AT1 07/19	GA1 07/19	GS1 07/19	GS5 07/19
			freshwater		marine					
TOTAL METALS (sediment): method EPA 3050B/7471A										
	mg/kg						mg/kg	mg/kg	mg/kg	mg/kg
Cadmium	0.3						ND	ND	ND	ND
Chromium	0.5						6.5	9.9	23.6	15.4
Copper	0.5						4.3	7.8	12.4	9.0
Lead	0.5						2.1	3.4	5.3	3.4
Mercury	0.3						ND	ND	ND	ND
Zinc	1.0						12.0	19.0	41.0	32.0
TOTAL METALS (water): method EPA 3010A/7470										
	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L				μg/L
Cadmium	5	5	7.7	0.6	40.0	8.8				ND
Chromium	10	100	1,773	231	10,300					ND
Copper	10	1,300	49.6	29.3	4.8	3.1				ND
Lead	10	15	280.8	10.9	210.0	8.1				ND
Mercury	0.02	2	1.40	0.77	1.80	0.94				0.02
Zinc	20	5,000	379	382	90	81				ND

For certain metals these criteria are not straightforward but are expressed as a function of hardness (a measure of the amount of calcium and magnesium in water). Hardness is a good surrogate for a number of water chemistry parameters which affect the toxicity of metals: simply put, increasing hardness decreases toxicity. Goleta water can be considered “very hard” (values greater than 180 mg of $CaCO_3$ per liter); measurements in 2001 on Atascadero Creek averaged over 500 mg/L of $CaCO_3$ hardness, and the maximum allowable hardness value of 400 mg/L was used in calculating the limiting concentrations listed in Table 2.

Cadmium: Cadmium is primarily used in metal plating and coating operations (transportation equipment, machinery and baking enamels, photography and television phosphors), in nickel-cadmium and solar batteries, and in pigments. The EPA's maximum contaminant level (MCL) for cadmium in drinking water has been set at 5 µg/L. Short-term human exposure to high concentrations can cause nausea, vomiting, diarrhea, muscle cramps, salivation, sensory disturbances, liver injury, convulsions, shock and renal failure. Over the long term, cadmium causes kidney, liver, bone and blood damage.

The aquatic life criterion for cadmium in water is 5 µg/L (hardness dependent) (see Table 2 for aquatic life criteria for all tested metals; the Table also includes the minimum detection limit (PQL) of each analysis). Various standards have been proposed for sediment, and Table 3 lists a range of these alternatives (NOAA, 2006) Alternatively, the proposed new California sediment guidelines give concentrations below which minimal effects on aquatic life can be expected. For cadmium in southern California, this concentration is 0.09 mg/kg (milligrams in a kilogram of dried sediment, i.e., parts per million or ppm) (CSWRCB, 2006b). No detectable amounts of cadmium were found in either sediment or water samples.

Table 3. *Screening concentrations for metals in sediment (in mg/kg or ppm). The threshold effects level (TEL) represents the concentration below which adverse effects are expected to rarely occur; the probable effects level (PEL) is the level above which adverse effects are frequently expected; and the apparent effect threshold (AET) is the concentration above which adverse effects always occur. The AET is not directly comparable to TELs and PELs since it is derived differently, from bioassays and faunal abundance surveys. Source: NOAA Screening Quick Reference Tables (SQuiRTs), Seattle, WA. (http://response.restoration.noaa.gov/cpr/sediment/squirt/squirt.html)*

	back-ground	freshwater sediments			marine sediments		
		TEL	PEL	AET	TEL	PEL	AET
Cadmium	0.1-0.3	0.58	3.53	3.00	0.68	4.21	3.00
Chromium	7-13	37.3	90.0	95.0	52.3	160.4	62.0
Copper	10-25	35.7	197.0	86.0	18.7	108.2	390.0
Lead	4-17	35.0	91.3	127.0	30.2	112.2	400.0
Mercury	0.004-51	0.174	0.486	0.560	0.130	0.696	0.410
Zinc	7-38	123.1	315.0	520.0	124.0	271.0	410.0

Chromium: Chromium is used in stainless steel, metal coatings, magnetic tapes and in pigments for paints, cement, paper, rubber, composition floor covering and other materials. Soluble forms are used in wood preservatives. For humans, lifetime exposure can cause skin irritations and damage to liver, kidney, circulatory and nerve tissues; chromium is considered a carcinogen. The drinking water MCL for total chromium is 0.1 mg/L. The environmental chemistry of chromium is complicated by oxidation and reduction reactions that convert it between the toxic and soluble hexavalent (Cr(VI), mainly as CrO_4^{2-}) and the nontoxic trivalent forms (Cr(III), which is relatively insoluble except in organic complexes).

The chronic aquatic life criteria for Cr(III) and Cr(VI) in water are 11 and 456 µg/L, respectively (the Cr(VI) criterion is hardness dependent). Chromium was not detected in the GS5 water sample but it was detected in all sediment samples, with the highest level, 23.6 mg/kg, found at the mouth of the slough (GS1, Table 2). This is below the threshold effects level shown in Table 3, the level below which adverse effects are rarely seen.[28]

Copper: Found in natural deposits as sulfides, arsenates, chlorides and carbonates, copper is widely used in household plumbing. Surprisingly, the largest source of copper in the urban environment comes from wear and tear on automobile brake pads. Copper is an essential nutrient required by the human body in very small amounts, but at higher levels it can cause stomach and intestinal distress, liver and kidney damage, and anemia. Copper contamination in drinking water generally occurs from corrosion of copper plumbing, and the metal is rarely found naturally in surface waters above the EPA's maximum containment level goal (MCLG) of 1.3 mg/L. Copper in drinking water is governed by an “action level” rule set at this same concentration of 1.3 mg/L. When 10 percent of samples have concentrations above this limit, remedial action becomes necessary.

The chronic aquatic life limit for copper recommended by the EPA is 24 µg/L (hardness dependent) (cf. Table 2). Copper was not detected in the GS5 water sample (10 µg/L was the detection limit), but it was detected in all sediment samples. Again, as with chromium, the highest level, 12.4 mg/kg, was found at the mouth of the slough (GS1, Table 2). This concentration is below the threshold effects level of 18.7 mg/kg shown in Table 3 (and considerably below the 52.8 upper minimal effects standard given in the proposed California criteria).

Lead: Commonly used in household plumbing materials and water service lines, lead is also found naturally. In drinking water it can cause a variety of adverse health effects, among which are retarded physical and mental development in children and kidney and high blood pressure problems in adults. The EPA's MCLG for lead is zero, and it has an established drinking water “action level” requiring remedial action if more than 10 percent of a utility’s samples exceed 155 µg/L.

The aquatic life standard (chronic concentrations) for Goleta fresh (hardness dependent) and salt water are 10.9 and 8.1 µg/L, respectively. Lead was not detected in the GS5 water sample but was detected in all sediment samples. The highest concentration, 5.3 mg/kg, was again found at the mouth of the slough. This is considerably lower than the threshold value of 30.2 or the proposed California minimal effects limit of 26.4 mg/kg.

Mercury: Mercury is a liquid metal found naturally in the ores of other metals Electrical products such as dry-cell batteries, fluorescent light bulbs, switches and other control equipment account for 50 percent of the mercury used in the United States. Exposure to high levels of mercury can cause kidney damage in a relatively short time and the drinking water MCL has been set at 2 µg/L.

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[28] The proposed California sediment criteria do not contain a standard for chromium.

Environmentally, mercury is an insidious and potent contaminant because of its persistent and bioaccumulative effects. It is perhaps best known for its weakening of bird eggs and subsequent hatching failures. The EPA has a criterion of 0.05 µg/L for waters from which organisms are taken for human consumption, and chronic and acute criteria were established by the San Francisco Regional Water Quality Control Board for San Francisco Bay (CRWQCB-SF, 2004) of 2.1 and 25 µg/L, respectively. The San Francisco criteria are considerably higher that the SQuiRT 1.4/0.77 and 1.8/0.94 µg/L acute/chronic benchmarks shown in Table 2 for fresh and salt waters. Mercury was not found in any sediment samples but was found in the GS5 water sample, albeit right at the detection limit of 0.02 µg/L.

Zinc: Used in the manufacture of plastics, rubber, paper, paints and lubricants, zinc is ubiquitous in the environment. Large amounts originate in mining, ore processing and metal plating operations. Concentrations in freshwater are strongly determined by local geological and anthropogenic influences and vary substantially; natural background concentrations usually vary from <0.1 to 50 µg/L (0.002 to 0.1 µg/L in seawater), and range up to 3.9 mg/L in highly contaminated environments (IPCS-ICHEM). Although the ingestion of large amounts of zinc (150–2,000 mg/day) can lead to vomiting and diarrhea and over the long term, anemia and leucopenia, the amounts found in water are usually too low to cause these adverse effects. Only a secondary EPA drinking water standard of 5 mg/L, designed to control an adverse metallic taste, exists for zinc.

Environmentally, concentrations from 50-100 µg/L can have chronic impacts on freshwater insects, and at 100-200 µg/L, on fish and mollusks. At concentrations above 1 mg/L, these impacts become acute for almost all freshwater species. The hardness-based EPA acute and chronic aquatic life standards for Goleta freshwater are around 380 µg/L (extreme hardness raises the nominal value of 120 µg/L to these higher limits), 90 and 81 µg/L for saltwater.

Zinc was not detected in the GS5 water sample. However, it was detected in all sediment samples. The highest concentration, 41 mg/kg, was yet again at the mouth of the slough. This is lower than the threshold value of 123-124 mg/kg for fresh and salt water or the proposed California minimal effects limit of 112 mg/kg. It is interesting that the GS5 sediment sample was almost as high, while creek samples (AT1 and GA1) were considerably lower. This, and a similar observation for chromium (albeit not as conclusive), would appear to suggest the airport itself as a prime source of these two metals.

Nowhere were metal concentrations in sediment samples at or above the threshold effects level, much less higher levels of concern (PEL and AET concentrations, Table 2). However, copper, chromium and zinc concentrations at the slough mouth were reasonably close: 66, 45 and 33 percent, respectively, of marine limits. In all cases, sediment concentrations were higher at GS1 than further up the slough at GS5, and higher at GS5 than in the tributary creeks. This raises an interesting question of how high concentrations might have been in 2004, prior to the big storms of 2005.

Major rainfall events are what move and remove the majority of sediment from tributary creeks and the slough. Prior to 2005, the last big storm occurred in early March of 2001, so it is a reasonable assumption that sediment had been accumulating in the slough since then, if not since an earlier peak flow that occurred in March 1995. The sediments sampled this past summer were predominately coarse grained, with very small percentages of fines. Fines and organic material had been flushed out during the major storms of 2005, and only at GS1 and GS5 were appreciable amounts of these materials located at the sides of the main channel. The presumption is that only the previous year's accumulation of sediments were sampled and that, should 2007 and subsequent years be characterized by more normal rainfall amounts, sediment metal concentrations might substantially increase.

The fact that metal concentrations in the tributary creeks were noticeably lower than in the slough itself may pinpoint the airport as a major source. Alternatively, it may simply be an artifact of higher percentages of fines and organic material in slough sediment samples. It is interesting that GA1 *always* had higher metal concentrations than AT1; proximity to Highway 101 would provide a reasonable explanation.

Summary of Results: Problem Areas

In this section, the results discussed above are reviewed to identify problems and potential causes. Problem locations indicated by abnormal physical parameter values (conductivity, water temperature, *p*H and turbidity) are summarized in Table 4.

Table 4. *Physical parameters. Numbers in the table are calculated criteria values that identify specific problems during 2006 at the Goleta Stream Team sampling sites. Column headings show the parameters, measurement units and criteria used flag problem areas. Values in parentheses are results from 2003-2005 data. The specific criteria were: (1) median conductivity > 2000 µS/cm; (2) a 90 percent confidence interval for monthly water temperature > 27.5°C; (3) 10 percent of monthly pH values > 8.5; and (4) median non-storm turbidity > 1.9 NTU.*

site	µS/cm median **conductivity**	° C 90% c.i. **temperature**	percent 10 % ≥ 8.5 ***p*H**	NTU median **turbidity**
AT1	2,365 (*2,615*)			3.15 (*2.88*)
AT2	2,648 (*2,440*)			3.43 (*2.80*)
AT3		28.1 (*27.4*)	75% (*63%*)	(*1.91*)
CG1	2,145			3.94 (*4.30*)
GA1	2,380 (*2,590*)			2.04
GA2	2,260 (2,395)			2.32
GS1			17%	5.47 (*6.53*)
LC2	2,465 (*2,815*)			
MY1			25% (*25%*)	(*2.92*)
SJ1			(*32%*)	
SJ2				
SP1			40% (*29%*)	

Excessively high conductivities can signify any combination of waste flows and dry season runoff containing high concentrations of dissolved salts, high evaporation rates occurring under stagnant conditions and possibly, dissolution of cement by trickling flows in concrete channels. Problem locations all feature one or more of these causes: agricultural runoff in Glen Annie (including golf courses and playing fields) and Los Carneros, urban irrigation runoff and nuisance flows in Atascadero, high evaporation at AT1 and LC1, and concrete canals above CG1 and AT2. The criterion used to identify excessive conductivity was a median value greater than 2,000 µS/cm (25 percent above the maximum limit for domestic water supplies).

The criterion for water temperature was a statistical test; if the 90 percent confidence interval for monthly temperature exceeded 27.5°C, it was judged excessive. This standard can otherwise be explained as a 10 percent chance that a sampled water temperature would exceed 27.5°C, or that 27.5° was exceeded 10 percent of the time (27.5° is 15 percent higher than the maximum temperature benchmark of 24°C used earlier). Excessive temperatures are caused by unshaded, shallow trickling flows and the absence of riparian vegetation. Only the open concrete canal site, AT3, had excessive temperatures.

Excessive *p*H was identified as a problem at locations having greater than 10 percent of their monthly values exceeding 8.5.[29] Excess *p*H in Goleta is almost always caused by algal blooms, possibly aided by dissolution of cement in concrete channels. The listed locations share both characteristics, except for GS1 and MY1. While Maria Ygnacio is channelized with concrete over much of its length, high *p*H may have a natural cause: the creek normally flows only during and immediately after sizable storms, and the higher elevation runoff sampled at these times may have acquired substantial *p*H from limestone areas in the upper catchment.

Excessive turbidity was defined as non-storm median values exceeding the suggested EPA limit of 1.9 NTU. The failed sites are all characterized by relatively stagnant waters and excessive biological productivity (the presence of microscopic algae and bacterial films at the site or immediately upstream). Higher turbidity at GS1 may also be partially due to disturbance by tidal inflows into the slough.

Biological problems, identified by aberrant parameter values and concentrations (nitrate, phosphate, minimum dissolved oxygen and excessive DO saturation), are summarized in Table 5. Excessive biological productivity or eutrophication is the major biological problem identified by Goleta Stream Team's sampling. Excessive nutrient concentrations are major causal factors, and both minimum DO values and excessive DO saturation pinpoint the deleterious effects. The criteria used to identify excessive nutrients were median nitrate concentrations above 0.52 mg/L and median phosphate concentrations above 0.03 mg/L. These limits are, respectively, the suggested EPA values for nitrogen and phosphorus in the Goleta area. As applied here, they are less conservative since they evaluate only the nitrate and phosphate fractions of these elements.[30]

Almost all sampling sites had excessive nutrients, and to distinguish particularly problematic situations, concentrations far above the norm are shown in bold, far above the norm being defined as greater than ten times the EPA limits. Agricultural runoff is the major cause of high nitrate, and the worst problems are in Glen Annie/Tecolotito and Los Carneros creeks. This, in turn, creates problems within the slough itself. Although not as egregious, agriculture is also the primary cause of high nitrate in San Jose Creek. The major cause of high nitrate concentrations in the remaining creeks can also be considered agricultural, if the definition of agriculture is extended to include "urban agriculture" - runoff from the fertilization and over-watering of lawns, landscaping, parks and golf courses. There are other contributors to the overall nitrate

[29] 8.5 is the SWQCB-CC upper limit for surface waters.

[30] Alternatively, we could have used the less stringent prospective California state standards of >0.10 mg-P/L and >1.0 mg-N/L, for total phosphorus and total nitrogen, respectively. This would only have produced slightly different results, removing two sites from the nitrate column and three from the phosphate.

problem in Goleta and Santa Barbara, including deposition of airborne pollutants, auto emissions, high groundwater concentrations from past land use, etc. However, the effects of these inputs are mainly observed during storms and the rainy season, whereas the majority of Goleta Stream Team sampling takes place during the dry season when nuisance urban flows and agricultural runoff dominate.

Almost every Goleta creek has problems with high phosphate. However, in contrast with nitrate, the most egregious situation occurs not in an agricultural area but in the Atascadero drainage. While urban agriculture undoubtedly contributes to the problem (fertilizer, pesticides, etc.), the probable main cause is animal waste from domestic pets and horses. High phosphate concentrations at CG1 and AT2 can be directly attributable to the presence of horse corrals and stables adjacent to the creek.

Table 5. *Biological parameters. Numbers in the table are calculated criteria values that identify specific problems at the Goleta Stream Team sampling sites in 2006. Column headings show the parameters, measurement units and criteria used flag problem areas. Values in parentheses are results from 2003-2005 data. The specific criteria were: (1) median nitrate > 0.52 mg-N/L; (2) median phosphate > 0.03 mg-P/L; (3) a 90 percent confidence interval for monthly DO < 5 mg/L and a minimum DO < 4.0; and (4) 10 percent of the monthly values exceeding 120 percent DO saturation. Particularly egregious results (greater than ten times the criterion for nutrients and three or more months of over-saturation) are shown in bold.*

site	mg-N/L median **nitrate**	mg-P/L median **phosphate**	mg/L 90% c.i. (min) **minimum DO**	percent 10% < 120%. **% DO sat.**
AT1	0.58 (*0.83*)	0.14 ***(0.34)***	2.5 (2.88)	**(34%)**
AT2	(*0.86*)	0.14 ***(0.38)***	{*4.4 (4.0)*}	
AT3	0.78	0.12 (*0.15*)		**92% (*88%*)**
CG1	1.50 (*1.97*)	**0.41 (*0.55*)**	{*4.0 (3.5)*}	(*13 %*)
GA1	**12.59 (*12.81*)**	0.04 (*0.06*)		
GA2	**13.26 (*23.03*)**	0.05 (*0.09*)		
GS1	1.71 (0.91)	(*0.06*)	{*4.6 (3.9)*}	**27%**
LC2	**7.27 (*11.86*)**	0.05 (*0.10*)		
MY1		(*0.05*)		**33%**
SJ1	2.24 (*1.64*)	(*0.03*)		**36%** (*20%*)
SJ2	3.53 (*3.28*)	(*0.04*)		
SP1	1.66 (*0.54*)	(*0.03*)		**38% (*29%*)**

Actual algal problems can be identified by dangerously low levels of dissolved oxygen and excessive oxygen saturation. Two criteria were used to identify low DO: (1) minimum concentrations below 4 mg/L, and (2) a 90 percent confidence interval for monthly DO lower than 5 mg/L. The criterion for percent saturation was greater than ten percent of the monthly values exceeding 120 percent saturation. Locations where more than 20 percent of monthly DO saturation exceeded 120 percent are identified in bold.

The DO criteria are somewhat contradictory as excessive percent saturation values are likely to be found only during daylight, while minimum DO concentrations generally occur at night. Since almost all Goleta Stream Team sampling currently takes place during daylight, excessive percent saturation is the better metric. With continued pre-dawn sampling and the further accumulation of this type of data, a better minimum DO criterion can be established. At present only problem locations with relatively deep stagnant waters and high concentrations of bacteria can be identified by minimum DO levels.

It is for this reason that different problem areas are identified by each of the two parameters. In prior years, AT2, CG1 and GS1 were flagged as locations with low DO. However in 2006, only AT1 met the criteria: DO levels below 5 mg/L were found during three of the 12 months sampled. In 2006, MY1 and GS1 joined sites recognized in the past as having excessive oxygen saturation. The situation at AT3 was particularly egregious, and although nitrate concentrations at this location were low, high percent DO saturation (11 out of 12 months) pinpoints this site as having the most critical algal problem in the area.

Table 6. *Public Health parameters. Numbers in the table are calculated criteria values for the 2006 water-year that identify specific problems at the Goleta Stream Team sampling sites. Column headings show the parameters, measurement units and criteria used flag problem areas. Values in parentheses are results from 2003-2005 data. The specific criteria were: (1) geomean > 235 MPN/100 ml for E. coli; (2) geomean > 61 MPN/100 ml for enterococci; (3) geomean FC/TC ratio > 0.1; and (4) total coliform geomean > 10,000 MPN/100 ml, unless FC/TC exceeds 0.1, when it is reduced to 1,000. Geomeans exceeding the EPA standards for "infrequent full body contact recreation" are shown in bold.*

site	MPN/100 ml geomean ***E. Coli***	MPN/100 ml geomean **enterococci**	ratio geomean **FC/TC**	MPN/100 ml geomean **total coliform**
AT1				
AT2		168 (*75*)		
AT3		88 (*127*)		
CG1	508 (*346*)	**348 (*151*)**	0.10	8,311
GA1	(*254*)	128 (*127*)		
GA2	353 (*447*)	**182 (*195*)**		
GS1				
LC2	287 (*365*)	126 **(*231*)**		
MY1		140 (*120*)	0.11	2,605
SJ1		114		
SJ2		121 (*98*)		
SP1		87 **(*139*)**		

Finally, indicator bacteria concentrations and the fecal to total coliform ratio (FC/TC) were used to identify public health threats. Results are summarized in Table 6. Geomean concentrations above acceptable EPA, Santa Barbara County or State of California limits were used as selection criteria to identify locations unsuitable for water contact recreation. This may be too high a standard since these concentrations (*E. coli* < 235 MPN/100 ml; enterococci < 61; total coliform < 10,000, 1,000 if FC/TC > 0.1) are applicable to freshwater public beaches – hardly the situation in Goleta. Accordingly, egregious sites (in bold) are identified as those which exceed a lower standard, identified by the EPA as "infrequent full body contact recreation": *E. coli* < 576 and enterococci < 151 MPN/100 ml.

Although a majority of the sites fail to meet standards for swimming, no locations appear to present a true hazard for occasional recreational users, the most likely form of public contact with these waters. The only exception is CG1, which is located adjacent to an elementary school. *E. coli* is judged by the EPA as the best freshwater indicator of problems, and no site consistently had concentrations exceeding the "infrequent use" standard (the worst site, CG1, exceeded these standards in only four out of the 12 months sampled).

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Appendix: Methodology

Water sampling and chemical analyses

Stream water samples are collected manually at mid-depth near the center of flow. Sample bottles (and caps) of high-density polyethylene (HDPE) are rinsed three times with deionized water before being used, and twice with sample water immediately prior to being filled; samples are placed in coolers as soon as possible and are transported on ice. Once in the laboratory, they are stored at 4°C.

Samples for dissolved constituents are generally filtered in the field through Gelman A/E glass fiber filters, pre-flushed with deionized and sample water. A syringe is used to force the sample through the filter unit. Stormflow samples with high sediment concentrations cannot be field-filtered and are usually allowed to settle before filtration in the laboratory. Samples are analyzed at UCSB for nitrogen (dissolved organic nitrogen, nitrate (NO_3 + NO_2) and ammonium) and phosphorus (soluble reactive phosphate, i.e., SRP). Nitrate, ammonium and phosphate are determined colorimetrically on a Lachat® auto-analyzer. Ammonium is measured by adding base to the sample stream, converting ammonium to ammonia, which diffuses across a Teflon® membrane (Willason and Johnson, 1986) and into phenol red pH indicator. Nitrate is analyzed using a standard Griess-Ilosvay reaction after Cd reduction (EPA, 1983), and phosphate after reaction with ammonium molybdate and antimony potassium tartrate and reduction by ascorbic acid with heating at 45°C.

Detection limits are 0.3 µmol L^{-1} for NH_4^+ and PO_4^{3-} and 0.5 µmol L^{-1} for NO_3^-; accuracy is ±5%. Total dissolved nitrogen (TDN) is determined after persulfate digestion (Valderrama, 1980) followed by measurement of nitrate. The basic persulfate reagent is added to a separate sample aliquot at the time of initial processing or labortory filtration and the digestion completed within one week The detection limit is 0.5 µmol L^{-1} and accuracy ± 10%. Dissolved organic nitrogen (DON) is calculated as the difference between TDN and dissolved inorganic nitrogen (DIN: nitrate and ammonium).

Bacteriological analysis

Water samples for bacteria analysis are collected manually, at mid-depth near the center of flow, in sterile plastic bottles pre-charged with small amounts of sodium thiosulfate to remove residual chlorine (a possible problem below sewage treatment plants and in urban nuisance waters). Samples are placed in coolers, transported on ice, and analyzed within six hours of collection.

Each sample is analyzed for three indicator bacteria: total coliform, *E. coli*, and enterococci using IDEXX Colilert® and Enterolert® methodologies (ASTM #D6503-99). Both methods are approved by the Environmental Protection Agency (EPA, 2003). The sample, diluted with distilled, bacteria-free water (typically using a dilution of 10:1), is used to fill multiple wells in an analysis tray. Colilert uses two indicators, one that changes color when metabolized by total coliform and another that fluoresces when metabolized by *E. coli*; the Enterolert indicator fluoresces when metabolized by enterococci. The number of positive wells after incubation for 18 hours at 35°C (Colilert) or 24 hours at 41°C (Enterolert) provides a statistical determination of concentration. The unit of measure is the “most probable number” of “colony forming units,” abbreviated as either “MPN” or “cfu,” in 100 ml of sample.

Quality control is evaluated by analyzing laboratory "blanks" (zero bacteria samples), duplicate field samples, and by performing multiple tests on single samples. The reproducibility of the bacteria results is evaluated by examining the differences between duplicate field samples; three to four duplicates (consecutive samples taken at the same location), one for each sampling team, are collected during each sampling event.

In-field measurements

Portable, hand-held meters are used to take field measurements for dissolved oxygen, *p*H, conductivity, water temperature and turbidity. Measurements are typically taken near the center of flow, below the surface in the upper half of the water column. The objective is to obtain measurements characteristic of the bulk of streamflow and not a spectrum of variation at the testing location. All instruments are calibrated according to manual instructions using certified laboratory standards on the day prior to sampling. The following list shows the type and accuracy of each meter used:

Meter	*Accuracy*
YSI Model 55 Dissolved Oxygen/Temperature Meter	± 0.3 mg/L or 2 %; ± 0.2°C
Oakton CON 410 Conductivity/TDS/Temperature Meter	± 1 %; ± 0.5°C
LaMotte 2020 Turbidimeter	± 2 % or 0.05 NTU
Oakton Waterproof *p*H Testr2 (prior to April 2005)	± 0.1 *p*H
Oakton *p*H/mV/Temperature Meter (April 2005)	± 0.01 *p*H

At each site, three readings are taken in three different locations with each meter (six for stream temperature using temperature scales on both the conductivity and dissolved oxygen meters). For the turbidimeter, two separate sample vials are tested three times each. All readings are later averaged to produce the final result entered into the database.

After sampling, all results are checked for quality control purposes. Questionable values are re-tested within six hours using a 500 ml sample collected at each location and transported on ice. Questionable results are those that (1) are unusual in light of past measurements at the location, (2) have widely varying multiple measurements, or (3) are expressed in doubtful units (i.e., milli vs. micro, or ppt vs. ppm). The "backup" samples are also used in cases of on-site equipment failure or suspected meter malfunction.