SANTA BARBARA
CHANNELKEEPER®

Goleta Stream Team
2002-2005

Protecting and restoring the Santa Barbara Channel and its watersheds

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Goleta Stream Team
2002 - 2005

A review of the findings of Santa Barbara Channelkeeper's Goleta Stream Team June 2002 - June 2005

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About Santa Barbara Channelkeeper

Santa Barbara Channelkeeper is a local non-profit organization whose mission is to protect and restore the Santa Barbara Channel and its watersheds through citizen action, education and enforcement. We are a member of the international Waterkeeper Alliance, and like the other 157 Waterkeepers across the globe, we work on the water and in our community to monitor local waterways, restore aquatic ecosystems, advocate for clean water, enforce environmental laws, and educate and engage citizens in identifying and devising solutions to local pollution problems. Our efforts are focused on cleaning up the leading sources of pollution that threaten the health of our local beaches, waterways and wetlands, including storm water and urban runoff, sewage, agricultural operations, offshore oil drilling, and large municipal and industrial dischargers.

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EXECUTIVE SUMMARY

Santa Barbara Channelkeeper launched the Goleta Stream Team water quality monitoring program in June 2002. The program has three goals: to collect baseline data on the health of the Goleta Slough watershed; to educate and train a force of volunteer watershed stewards; and to identify sources of pollution in the watershed. Over the past three years, more than 120 local citizens have participated as volunteers in the program, contributing in total more than 1,000 hours of their time. Each month, these volunteers collected valuable water quality data at 14 sites in the Goleta Slough and its major tributaries: Atascadero, Cieneguitas, Glen Annie, Los Carneros, Maria Ygnacio, San Jose, and San Pedro creeks. At each site, volunteers took in-stream measurements on temperature, dissolved oxygen, pH , turbidity, and conductivity, and collected samples that were later analyzed in the laboratory for bacteria and nutrients. Visual observations, such as algae coverage and weather conditions, were also recorded at every site.

The data collected by Goleta Stream Team serve as an excellent source of information about normal, or baseline, conditions throughout the Goleta Slough watershed. In the future, these data can be used as a yardstick to compare how water quality conditions change over time. In addition, the data has enabled Channelkeeper to identify problem areas throughout the watershed, which can also be used to guide future clean-up and restoration efforts by environmental groups and regulatory agencies.

The most egregious problem that Channelkeeper identified through its Goleta Stream Team monitoring efforts was that of nutrient pollution. Throughout the first three years of the sampling program, mean phosphate and nitrate levels far exceeded the limits recommended by the US Environmental Protection Agency at every single sampling site. With nitrate, the most serious problems were seen on Glen Annie and Los Carneros creeks, both of which flow through areas with heavy agricultural use, indicating probable contamination from fertilizers and pesticides. Three golf courses adjacent to Glen Annie, San Pedro, and Atascadero creeks also may contribute high levels of nitrate from over-irrigation and heavy fertilization, as seen from the nutrient data from several of the sampling sites on these creeks. The most serious phosphate problems were found in the Atascadero drainage, home to numerous horse facilities and dense residential developments. Extremely high phosphate levels indicate possible contamination from horse facilities as well as over-watered and over-fertilized residential landscaping. The most serious result of this nutrient pollution is excessive growth of algae, which occurred frequently at many sites. Excessive algal growth can have negative effects on dissolved oxygen levels and pH levels; these side effects have been observed on occasion, particularly at the sampling site at Atascadero Creek at Puente Road.

Although not as serious as the nutrient problem, bacteria levels identified through the Goleta Stream Team monitoring program also present cause for concern. Samples from the majority of Goleta Stream Team sites frequently exceeded public health limits set forth by local and federal regulatory agencies. While the three "indicator bacteria" that Channelkeeper tests for (total coliform, E. coli and enterococcus) are not usually harmful in and of themselves, they do indicate the possible presence of pathogenic bacteria, viruses, and protozoans. Samples taken from nearly every site regularly exceeded the public health standard for at least one of the three indicator bacteria, but the worst bacterial contamination problems overall appear to occur in Cieneguitas, Glen Annie, Los Carneros, and San Pedro creeks. Only three sites did not regularly exceed public health standards: Atascadero Creek at Ward Drive, Goleta Slough at the bicycle bridge, and San Jose Creek at Hollister Avenue. While these standards are meant to protect public health from contact through recreational use of waterbodies, and most Goleta Stream Team sampling sites are not commonly used for human recreation, it cannot be disputed that many of the sites do exhibit problems with bacterial contamination. Possible causes of this bacterial pollution include horse facilities, failing septic systems, pet waste, and general urban runoff.

Other parameters measured by Goleta Stream Team provide clues to additional potential water quality problems. These problems may not be related to contamination in the traditional sense, but rather from physical alterations to

the creek bed. For example, many creeks exhibit temperatures that are too high for the survival of fish such as steelhead trout. This problem is primarily due to the conversion of natural riparian areas to concrete channels, which receive less shade cover. It is also possible that these concrete channels may contribute to elevated pH levels due to dissolution of cement from the channel bottom.

In light of the findings from the first three years of Goleta Stream Team's water quality monitoring efforts, Channelkeeper believes there is cause for concern and grounds for action to address the problems described above. The Goleta Slough is already listed by the State of California as an impaired waterbody, and additional threats to its water quality are imminent. The new City of Goleta is currently formulating comprehensive plans for future land use and development, and the City of Santa Barbara will soon be undertaking major construction to expand the Santa Barbara Municipal Airport, which is located directly in the slough. To mitigate existing and future water quality impairments in the watershed, Channelkeeper recommends that the following actions be taken:

- Regular monitoring efforts by Channelkeeper and other entities should be continued and expanded to assist regulatory agencies in their land use planning and water quality protection efforts.
- Specific pollution sources should be pinpointed by conducting creek walks, testing specific discharge points, and identifying the land uses associated with any contaminated discharges.
- Once specific sources are identified, Channelkeeper and other entities should reach out to the appropriate landowners to educate them about the problems of, and solutions to, the water quality issues associated with their properties.
- Regulatory agencies should strictly enforce existing water quality regulations and ordinances prohibiting illegal discharges, including issuing fines or cease and desist orders when necessary.
- Agricultural operations that have not already enrolled in the Regional Water Quality Control Board's Agricultural Waiver program should be encouraged to do so.
- Regulatory agencies should continue to implement additional treatment methods in problem areas, including active treatment systems such as ultraviolet and ozone systems, and best management practices (BMPs) such as vegetated swales, constructed wetlands, and permeable pavement.
- Regulatory agencies should provide incentives to encourage developers and property owners to implement low-impact development BMPs in new residential and commercial developments (or re-developments).

While this list of recommendations is by no means exhaustive, the implementation of these and related measures will help to reduce the pollution identified by Santa Barbara Channelkeeper's Goleta Stream Team water quality monitoring efforts.

INTRODUCTION

Santa Barbara Channelkeeper's Stream Team is a volunteer-based water quality monitoring program that focuses on two major local watersheds, the Ventura River and the Goleta Slough. The streams and rivers that drain these watersheds transport pollutants such as bacteria and excess nutrients into downstream wetlands and the ocean, and the purpose of Stream Team is to provide a comprehensive and long-term effort to monitor conditions on these ecologically important waterways. Channelkeeper launched its Goleta Stream Team in June 2002, modeled from its highly successful Ventura Stream Team program, which began in January 2001. Both Stream Team programs share the same three goals: to collect baseline data on the health of the Goleta Slough watershed; to educate and train a force of volunteer watershed stewards; and to identify sources of pollution in the watershed.

Goleta Stream Team conducts monthly on-site testing at designated locations on the seven streams tributary to the Goleta Slough, as well as the slough itself. Teams of volunteers measure physical and chemical parameters in the field using portable hand-held instruments. Data collected include on-site measurements of dissolved oxygen, turbidity, conductivity, pH, and temperature. Water samples collected at each site are 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 (ammonium, nitrite plus nitrate, orthophosphate, total dissolved nitrogen and particulate carbon, nitrogen and phosphorus) through cooperation with the Santa Barbara Channel – Long Term Ecological Research Project (SBC-LTER) at the University of California, Santa Barbara (UCSB). Visual observations such as vegetation and aquatic life are also recorded monthly at each site. To ensure quality control, all meters are checked and calibrated against factory standards prior to every sampling event.

To date, over 120 volunteers have participated in Goleta Stream Team.

Citizen volunteers are a critical element in the success of Goleta Stream Team. To date, over 120 volunteers have participated in the program, contributing over 1,000 hours of their time. Volunteers include a wide range of local residents, from UCSB and high school students to public officials. While some volunteers come to earn community service hours for school, most participate to gain experience and knowledge and to make a contribution to their community. Many of our volunteers are users of coastal resources - hikers, surfers and fishermen who are eager to "give something back."

BACKGROUND

The South Coast [1]

Climate

The climate of the South Coast, from Point Conception to Ventura, is considered "Mediterranean," typified by relatively mild winters, hot dry summers, and coastal fog during much of the dry season. Rain generally occurs only between the months of November and March, and temperatures at lower elevations are almost always above freezing. High pressure systems which develop over Utah and Nevada are strong enough to keep the weather warm and sunny for much of the summer and fall. These systems also divert rain, and consequently there is little summer precipitation in the region. Higher watershed elevations may have summer daytime temperatures of 85-100o Fahrenheit (F), while the coastal regions are generally about ten to fifteen degrees cooler. Fall daytime temperatures are generally 70-90o F in inland areas, but are considerably colder at night. In the fall, Santa Ana winds can blow hot and dry from desert regions to the east. These warm winds and the prevalent dry conditions often combine to exacerbate wildfires, usually a natural part of the ecosystem. Winter is characterized by periodic bouts of heavy rainfall, often dropping several inches of precipitation in each storm. The upper mountainous regions have more rainfall than lower coastal areas as Pacific storms are uplifted over the coast range. Higher elevations, on average, see about 22-29 inches of rain a year, while rainfall amounts near the ocean are closer to 15 inches. Snow can fall at high elevations during particularly cold winter storms.

Geology

South Coast drainages lie within the western Transverse Ranges of California, mountain ranges notable for easily eroded sedimentary rocks. These ranges have been produced by clockwise crustal rotations between the Pacific and North American plates (the same plate movements that produced the infamous San Andreas fault). California's largest earthquakes have rotated and uplifted the region's coastal mountains (Jaeger and Smith, 1988; Michaelson, 2004), and they are still being uplifted, at rates of 1-3 mm per year (Keller and Capelli, 1992). Regional tectonics have produced numerous faults and folds, and some of the youngest sedimentary rocks have been deformed until they stand nearly vertical. The rocks near the surface are usually recent sedimentary layers of marine origin (Cenozoic – younger than 65 million years): hard sandstones alternating with weak shales and mudstones. The surrounding geology is responsible for much of the character of local streams. Steep mountains with easily eroded rocks yield "flashy" creeks (quick to rise as rain begins, quick to fall when it ends) with some of the largest sediment loads in the world (Scott and Williams, 1978; Taylor, 1983; Hill and McConaughy, 1988). In addition, fragile marine sediments cause high background conductivities and total dissolved solids (high in sulfate, calcium, magnesium and chloride).

Land Use

Land use in the region is primarily open space, agriculture and urbanized development. Higher elevations are usually covered in native chaparral with areas of oak woodland and tree-lined riparian corridors. In the foothills, many areas have been converted to exotic grass rangeland and avocado and citrus orchards. The coastal lowlands have been put to numerous uses, including urban, agriculture (row crops and greenhouses) and orchards; light industry and oil production exist in some areas. Nearly half the coastal watershed – mainly at higher elevations – is within the boundaries of the Los Padres National Forest. A number of coastal margin wetlands can be found at the mouth of streams. Most are small and are completely flushed during winter rains, but the Carpinteria Salt Marsh, Goleta Slough, Devereux Slough and the Gaviota Marsh have appreciably larger associated wetlands.

Vegetation

Numerous plant communities are found within South Coast watersheds: non-native annual grasslands, Venturan coastal sage scrub, chaparral, coast live oak woodland, and three types of riparian woodland (south coast live oak, central coast cottonwood-sycamore, and southern willow scrub). Each of these habitats have evolved to the specific conditions of the coastal climate of Southern California, and the plants of all communities show traits adapted to fit their niche. Elevation, aspect (shade or sun), rainfall and water availability are the primary determinants of where each community exists.

Plants play a crucial role in the ecology and hydrology of the watershed. They provide habitat, food and shelter for the dozens of animal species that inhabit the region. Plants help to prevent soil erosion by literally holding the soil together with their root systems. Leaf and branch canopies also reduce the impact of rain, and by absorbing rainfall from the soil, they also minimize runoff.

An ongoing problem in these watersheds is the invasion of non-native species of plants – foreign plants that have been introduced, intentionally or unintentionally, and then thrive in local environments, often because of the absence of natural predators. In the process of replacing native species, they present problems for local animals that are not adapted to living with, and on, these invaders. Invasive, non-native species damage the biodiversity of both plants and animals in the region.

Riparian Zones

The riparian zone is the vegetative corridor at the boundary of a body of water. Often unique and different from the surrounding vegetation due to its proximity to water, it acts as the interface between terrestrial and aquatic zones. During the dry season, the riparian zone bordering a stream is usually the only area with green plant growth. Riparian areas are often the only home for deciduous trees, like sycamores and willows, which need year-round water to survive. This growth helps to preserve threatened aquatic species like steelhead trout by providing shade and lower water temperatures. By preventing erosion, riparian plants keep water silt-free for trout eggs to hatch, and by providing shade, stream temperatures stay cool enough for spawn to survive. Riparian areas also provide protected habitat and travel corridors for much of the area's terrestrial wildlife, and frequently serve as habitat for endangered and threatened species. Studies have shown that as much as 85% of a region's wildlife inhabit riparian zones at some point in their life cycle. Riparian areas also serve as a buffer between land use and the stream, filtering out pollutants before they reach the water and acting as a bacteriological and chemical factory to cleanse stream water as it moves between channel and stream bank.

Hydrology[2]

The dominant hydrologic characteristic of the Santa Barbara/Goleta area, and indeed, of all streams in coastal Southern California, is extreme inter-annual variation in rainfall and watershed runoff. Using the Ventura River, with its long data record, as an example, mean annual flows have varied from 5 to 3,400 cubic feet per second (cfs) (e.g., a 700-fold variation) over the last 75 years (USGS-NWIS).

Since 1868, the average winter rainfall in downtown Santa Barbara has been 18 inches (SBC-PWD). However, "average" in this case does not convey the extreme annual variability (Figure 1, upper panel). Very few years actually have average rainfall; most are drier, and a relatively few very 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 a "big" year is defined as having rainfall at least 150% above the average (greater than 27 inches), there have been sixteen "big" years since 1868, approximately one every 8.5 years. The 1990s were unusual in that three big years (1993, 1995 and 1998) occurred 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 winter rain) northward, while the "warm" phase pushes it, and rainfall, southward – giving Southern California wetter winters.

Figure 1 (lower panel), a plot of cumulative departure from the mean for downtown Santa Barbara rainfall (CSB-PWD), attempts to show the influence of this pattern by plotting the cumulative rainfall excess or deficiency. Stated another way, the graph displays a running summary of how much each year's rainfall affected long-term departures from the 18 inch per year average. The plot shows a pattern of alternately rising and falling trends, where rainfall was either generally above or generally below average, lasting decades. The 1880s, the 1910s and the 1930s had increasing rainfall trends, trends generally caused by an increased frequency of big years. Between these intervals there were strong decreasing trends. The general pattern between 1944 and 1968 was for below average rainfall (a decreasing trend), but from 1968 to 1998 the trend reversed, except during the California drought of 1987-1992.

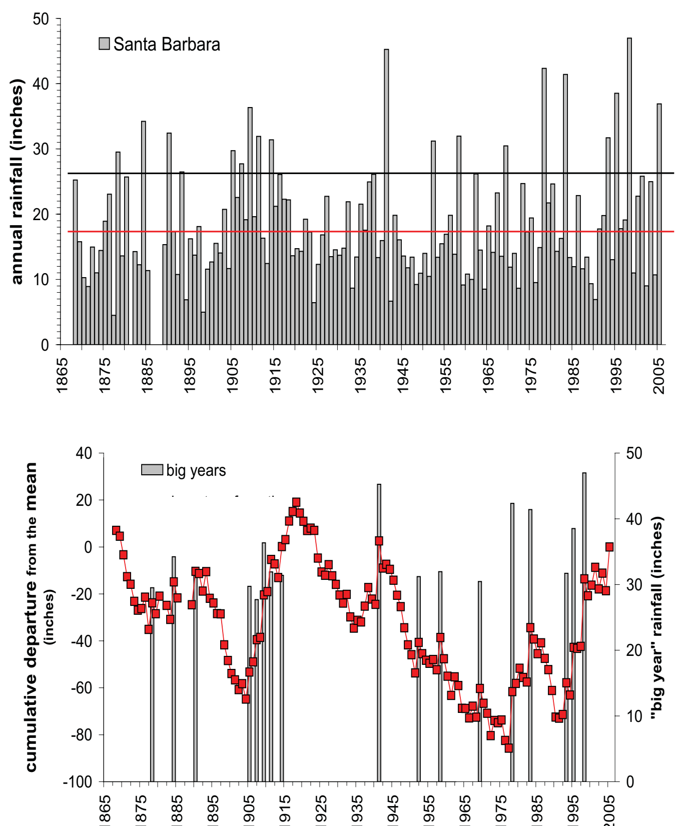


Figure 1. Upper panel: Annual (water-year) rainfall in downtown Santa Barbara: 1868-2005 (CSB-PWD). The lower line represents the average rainfall of 18 inches, the upper, 27 inches or 150% of average. Lower panel: The cumulative rainfall excess or deficiency – e.g., a running total how much each year's rainfall varied from the 18 inch overall average. The plot reveals a pattern of alternately rising and falling trends, generally lasting decades. Also shown are "big years," years when rainfall exceeded 150% of average. Big years, many of which coincide with major El Niño episodes, heavily influence the rainfall record; a grouping of big years, which are not evenly spaced, causes an increasing rainfall trend.

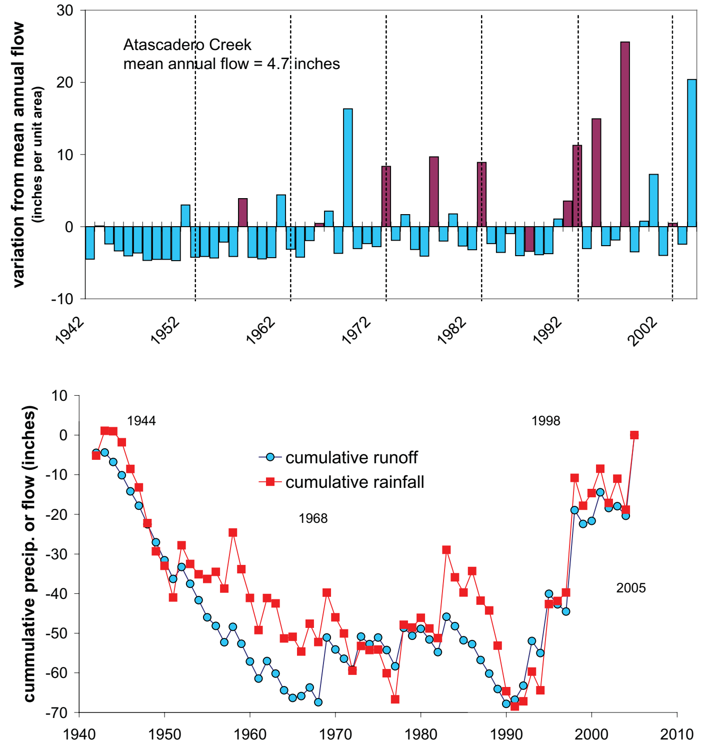


Figure 2. Upper panel: Mean annual flow on Atascadero Creek (at Patterson Avenue) is 4.7 inches per unit area (6.6 cfs). The distribution is skewed – "above the mean" years tend to be very large. Years shown as dark bars were El Niño episodes. Lower panel: The cumulative flow excess or deficiency – how much each water year's flow (measured in inches of runoff at Patterson) varied from the 4.7 inch overall average – has been added to the cumulative rainfall plot (for 1942 - 2005) from Figure 1. 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 (e.g., the 1960s and 1970s).

Annual flows in Atascadero Creek (measured at Patterson Avenue, USGS-NWIS) mimic the Santa Barbara rainfall record. Figure 2 (upper panel) shows how much each year's flow differed from the mean flow of 4.6 inches per unit drainage area – 6.6 cubic feet per second (cfs). Median annual flow is 2.1 inches (2.9 cfs), less than half of the average, indicating the high degree of skew in the runoff record. The years from 1942-1967, and the 1980s, were periods of below average flow. The lower panel of Figure 2 displays the cumulative flow excess or deficiency – the running total of how much each water year's flow (measured in inches of runoff at Patterson Avenue) moved the long-term trend away from the 4.6 inch overall average, and in which direction. Plotted with cumulative rainfall excess from Figure 1, it shows the same pattern of rising and falling trends. Declining flows appear more pronounced than trends in rainfall (e.g., the 1960s and

1970s), and the recovery in annual runoff at the reversal of a cycle seems to lag behind that of rainfall.

The long-term ratio between mean runoff and mean rainfall for Atascadero Creek indicates that only about 25% of the rain is ever discharged into the stream. As for the remainder, most is evaporated or transpired by plants and trees, and a smaller part recharges the groundwater table or is stored as soil moisture.

In spite of heavy rainfall in 2005, we appear to have entered a new PDO cold phase after 2000. With less rainfall, we can expect conditions similar to those of the 1950s, when lower flows were more common. More wildfires, increased summer fog and extended drought conditions may also be anticipated.

The Goleta Slough Watershed[3]

The Goleta Slough is almost entirely surrounded by urban development, some of which extends into areas that were once wetlands. This includes the Santa Barbara Airport to the north, public utilities and light industrial uses to the east, a public beach between the ocean and the slough, the campus of UC Santa Barbara to the south and west, and residential and light industrial operations extending beyond the immediate vicinity on all but the southern ocean boundary.

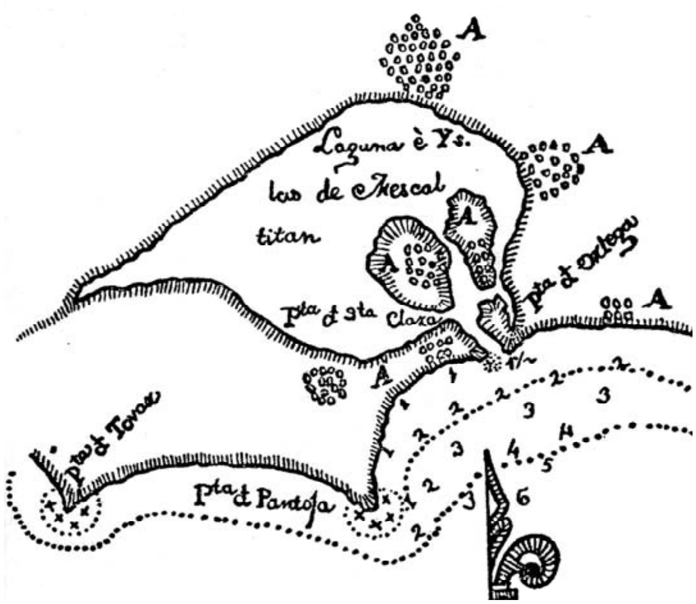


Figure 4. The villages of Mescaltitan, the earliest known map of the Goleta Slough by Pantoja y Arriaga, 1792.

It is estimated that Native American peoples began inhabiting the area some 9,000 years ago. Early European explorers used the embayment as an anchorage for large ships until the 1860s, when severe storms in the winter of 1861-62 filled the bay with sediment. Cattle ranching in the surrounding area began in 1846, followed by agricultural development on the uplands around the slough. Agricultural use of the slough began in the 1870s, and the following decades saw the construction of berms, dikes and roads that further extended this development. A whaling camp was established around 1870, asphalt mining commenced in the 1890s, development of small farms expanded to cover the entire mesa in the 1920s, and rapid urbanization began in the 1940s. In 1928, a landing strip was established in the northeastern portion of the slough; it was expanded in 1942-43 during construction of a Marine Corps Air Station, and is now the Santa Barbara Airport.

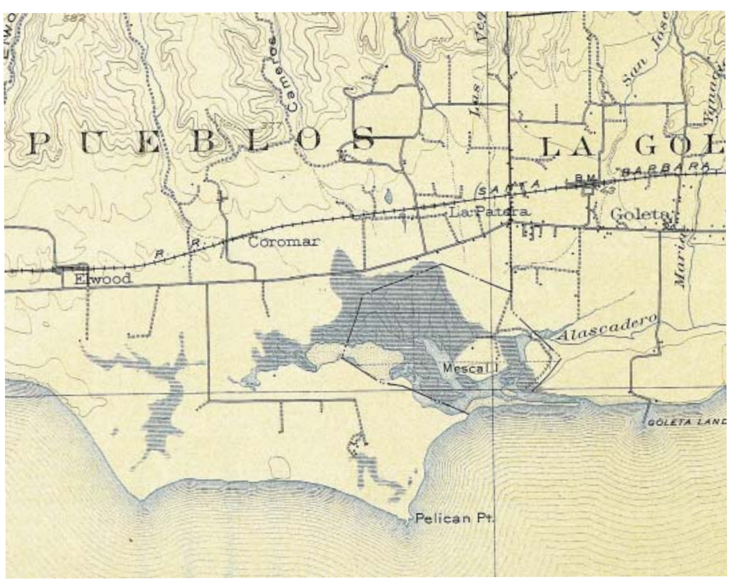


Figure 3. 1903 USGS map of the Goleta Slough area.

The slough now includes approximately 430 acres of wetland habitat – drastically reduced from its estimated 1,150 acre historical size. Figures 3 and 4 are historic maps of the slough that document some of these changes. Extensive areas of the historic marsh that were below the high-tide line are now isolated from tidal influence by berms and dikes. Tidal flooding is currently limited to the south-central portion of the slough; while tidal flooding still extends up into several of the major tributaries, its amplitude has been greatly diminished. During the summer months, tidal flows become reduced and eventually eliminated by formation of a sand berm at

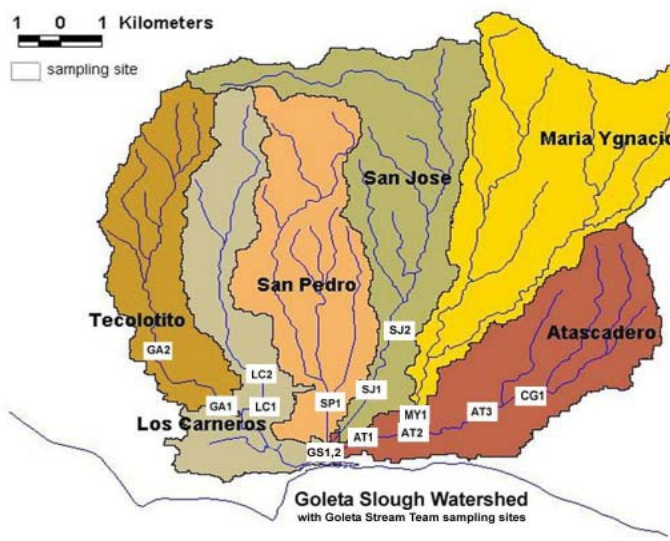


Figure 5. Map of the Goleta Slough watershed with Stream Team sampling locations.

the mouth of the slough. This beach berm is often mechanically breached to maintain water quality in the slough.

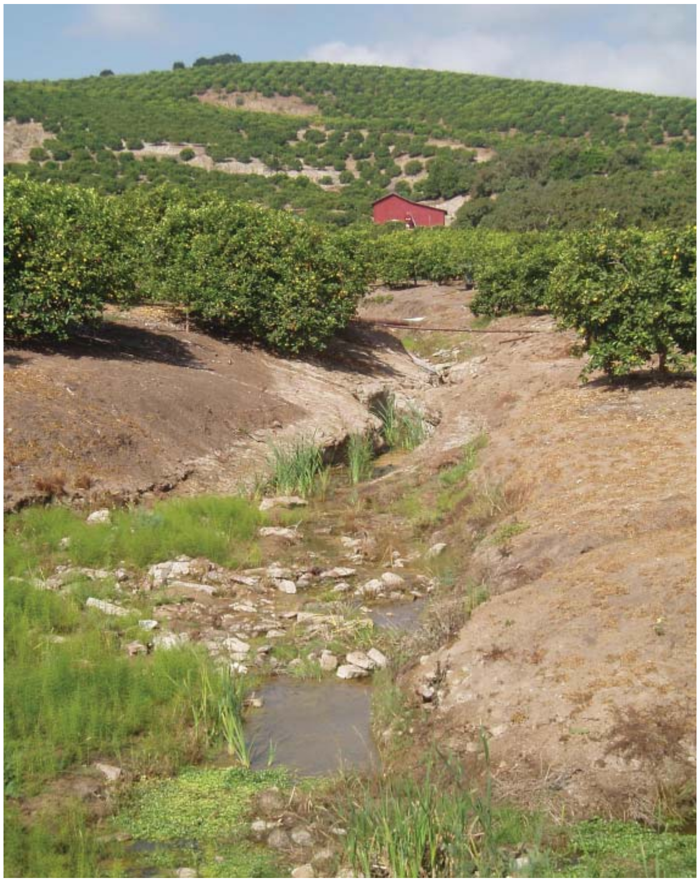
A 1996 document reported that 279 bird species have been observed at Goleta Slough; of these, 121 are water-associated, including 18 species of special status: California brown pelican, southern bald eagle, peregrine falcon, snowy plover, sand-hill crane, common loon, American white pelican, double-crested cormorant, white-faced ibis, fulvous duck, harlequin duck, northern harrier, golden eagle, osprey, long-billed curlew, California gull, elegant tern, and black skimmer (CERES).

The slough has a watershed of 47 square miles, distributed among six major drainages. Table 1 shows the drainage area of each of these creeks and the percentage of land in major land-use classifications for each; these drainages are shown in Figure 5. Atascadero Creek is the most urban, while Los Carneros Creek is the least urban. Although the table shows Los Carneros as the most agricultural, this is somewhat misleading as the agricultural classification includes both grazing and more intensive agricultural practices such as orchards, greenhouses and row crops. Glen Annie Creek has the most intensive agricultural use (citrus and avocado orchards), but all the creeks have at 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 flows in the mountains, it rarely reaches the foothills during the dry season, and most of the slough's tributaries run dry relatively early. The major exceptions are Glen Annie and Atascadero creeks, where agricultural runoff and urban seepage and landscape watering ("urban nuisance" water) provide low flows throughout the year.

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 in the watershed – areas from which almost all of the rainfall runs off onto surrounding lands and into the creek, including streets and sidewalks, roofs, parking lots, etc.*

watershed	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	4.4	8.2	0.9	52.6	26.0	10.8
San Jose	8.9	.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
Glen Annie/ Tecolotito[4]	5.8	11.0	12.0	6.2	34.0	14.2	30.4
Los Carneros	5.6	5.1	4.0	2.6	34.3	11.8	45.1

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 creeks 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, Glen Annie and Los Carneros, although smaller streams, enter on the northwest corner and have much greater influence on water quality in the slough.



Of all Goleta Stream Team creeks, Glen Annie contains the most intensive agricultural use. Runoff from orchards often transports pollutants to creeks and the slough. This photo was taken upstream of Goleta Stream Team's GA2 sampling site.

Sampling Locations

As mentioned above, Goleta Stream Team was established in the spring of 2002 following the success of Channelkeeper's Ventura Stream Team program. Originally, 10 sites were selected to exemplify the range of conditions found on tributaries to the slough. The goal was to sample at least two locations on each stream, one just above the tidal limit, as close to the slough as possible, and another as far up the drainage as practical, preferably above the urban boundary. During the beginning of the program it was not always possible to achieve this goal due to inconsistent volunteer participation. However, over time, participation has improved and additional sites have been added to the sampling program: a second Glen Annie Creek location was added in January 2003, an upper San Jose Creek site in January 2004, and two sites near the slough outlet in October 2004. In the future Channelkeeper hopes to add additional sites within the slough itself. A list of site names and abbreviations is shown in Table 2. A map of the watershed and sampling locations is shown in Figure 5. Aerial photos of each watershed on the following pages are followed by brief site descriptions.

Table 2. *Goleta Stream Team site names and abbreviations.*

Site Name	Abbreviation
Atascadero Creek at Ward Avenue	AT1
Atascadero Creek at Patterson Avenue	AT2
Maria Ygnacio Creek at Patterson	MY1
Atascadero Creek at Puente Drive	AT3
Cieneguitas Creek at Nogal Drive	CG1
San Jose Creek at Hollister Avenue	SJ1
San Jose Creek at North Patterson Avenue	SJ2
San Pedro Creek at Hollister Avenue	SP1
Los Carneros Creek at Hollister Avenue	LC1
Los Carneros Creek at Calle Real	LC2
Glen Annie at Hollister Avenue	GA1
Glen Annie at Cathedral Oaks Road	GA2
Goleta Slough at the bicycle bridge	GS2 and GS2

Atascadero Creek

(with Maria Ygnacio and Cieneguitas creeks)

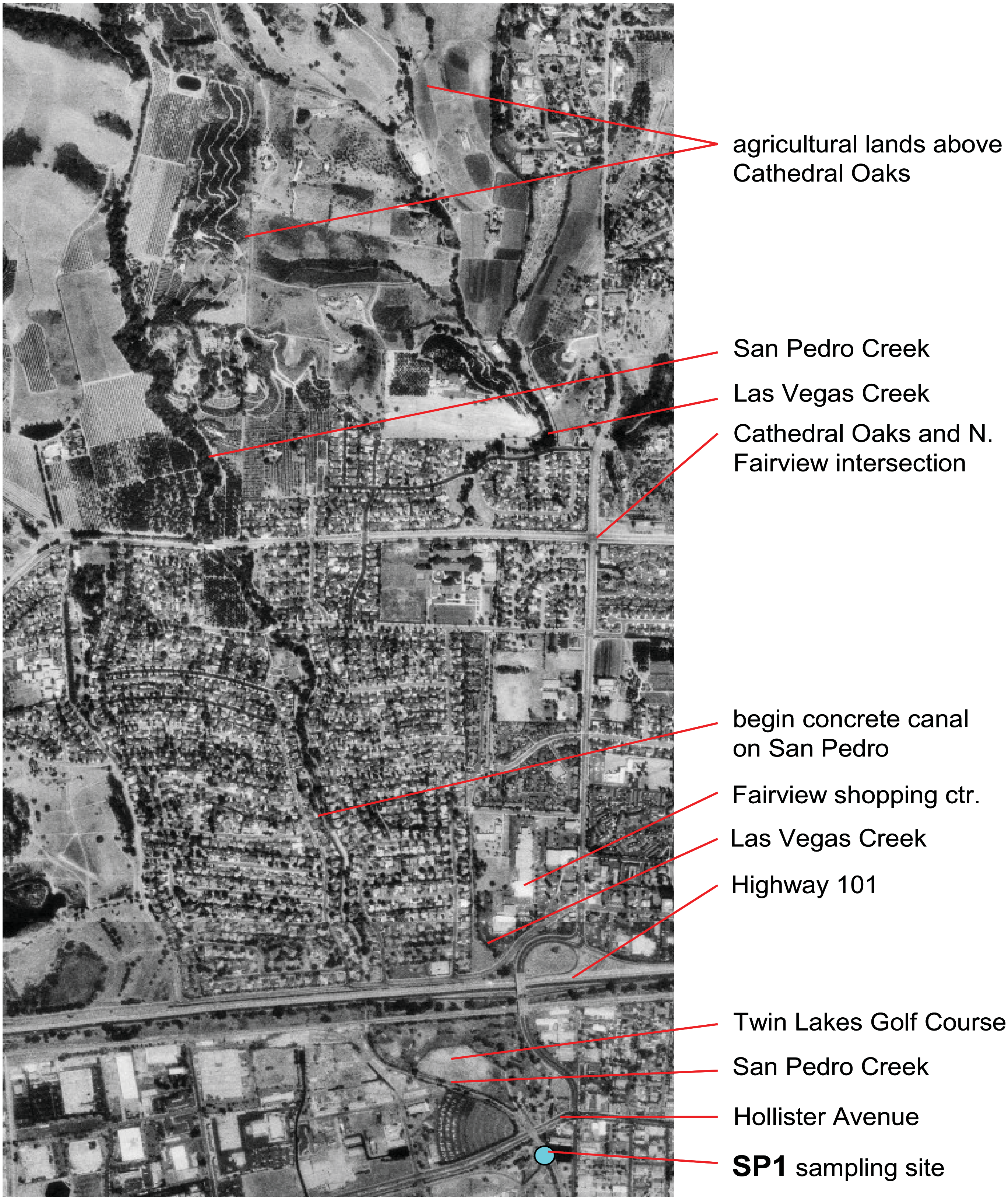
from Goleta Slough to Modoc Road

Problems: high nitrate and phosphate from urban landscaping and horses, critical dissolved oxygen and *p*H

San Pedro Creek

from the foothills to Hollister Avenue

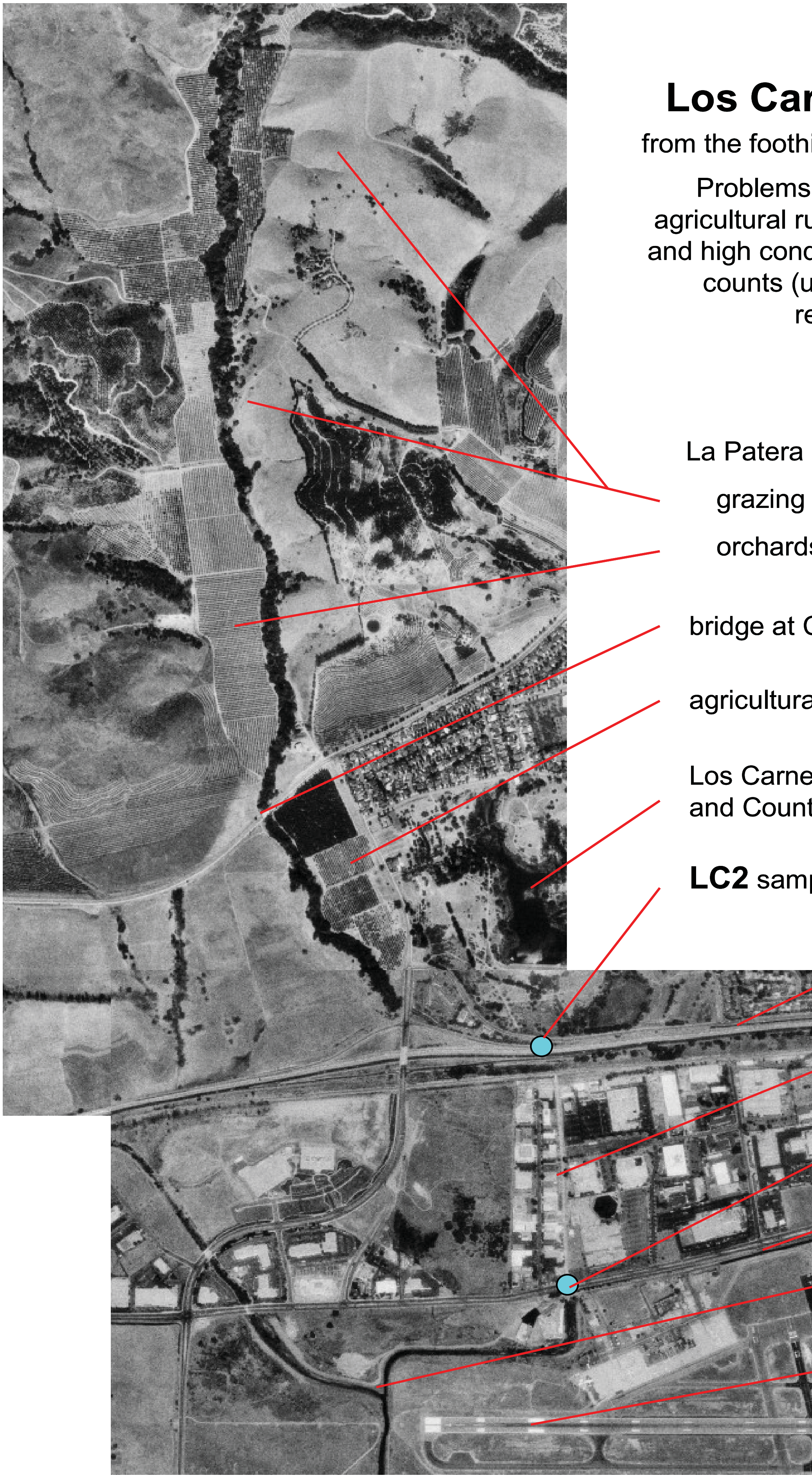
Problems: high nitrate and phosphate, excessive algal growth and high bacteria counts (unsafe for contact recreation).



Los Carneros Creek

from the foothills to Hollister Avenue

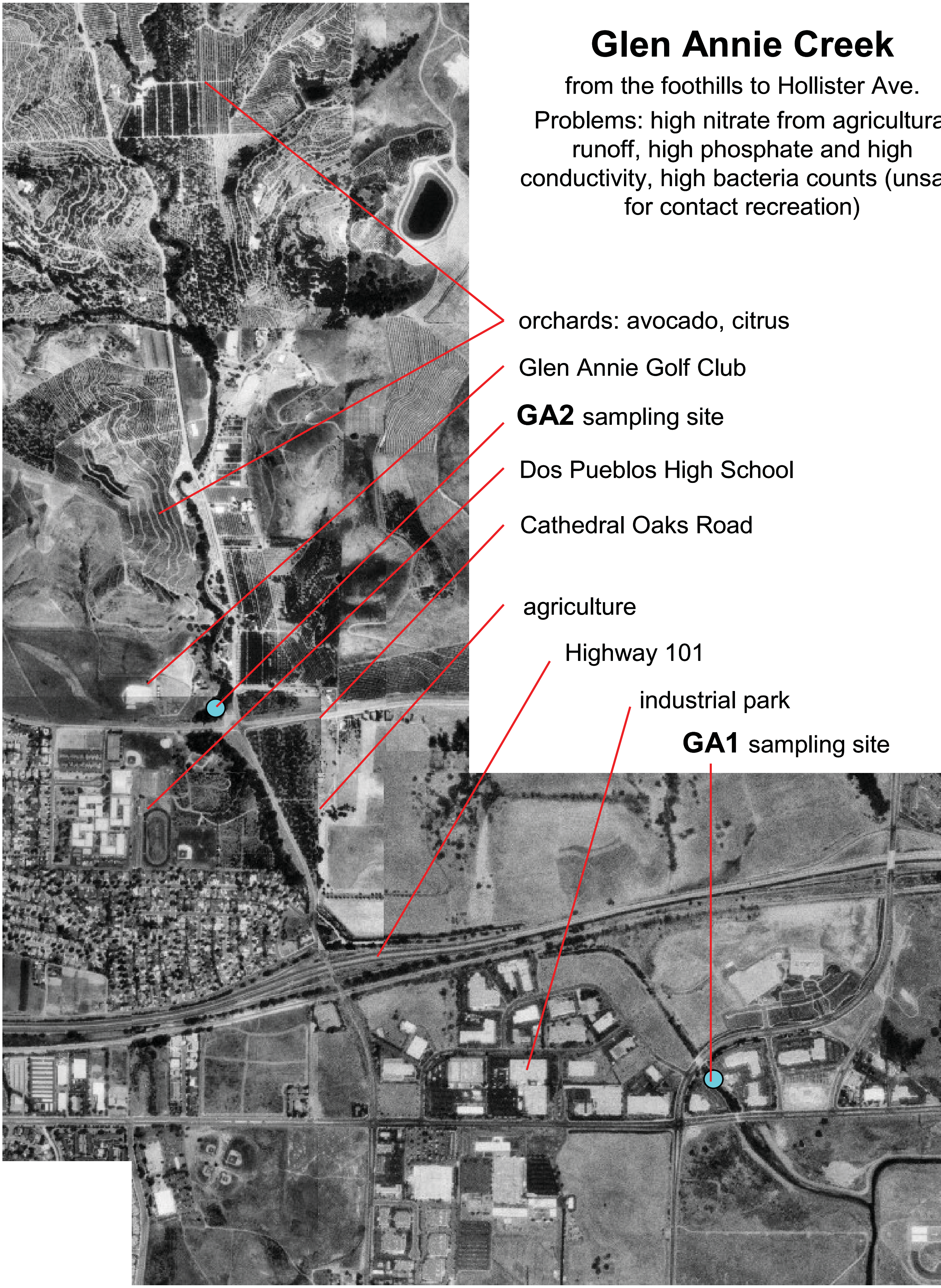
Problems: high nitrate from agricultural runoff, high phosphate and high conductivity, high bacteria counts (unsafe for contact recreation)



Glen Annie Creek

from the foothills to Hollister Ave.

Problems: high nitrate from agricultural runoff, high phosphate and high conductivity, high bacteria counts (unsafe for contact recreation)



San Jose Creek

from the foothills to Hollister Avenue

Problems: high nitrate and phosphate from agricultural and urban runoff, high pH due to algae at SJ1, high enterococcus counts at SJ2.

Atascadero Creek at Ward Drive (AT1) is reached from Hollister Avenue by turning towards the ocean on Ward and continuing to the end of the road. Atascadero Creek is directly across the road barrier and bike path. We sample a short distance upstream of this point, on the upstream side of the small concrete and rock dam (weir) which separates the fresh creek water from the tidally influenced Goleta Slough. Atascadero is the largest creek in the Santa Barbara and Goleta area and the greatest exporter of nutrients and sediment to the ocean. Sampling at AT1 enables us to measure the combined chemistry of Atascadero and its major Maria Ygnacio tributary, and to observe the effects of the agricultural use along the creek between this site and the next upstream sampling site (AT2). During storms, AT1 is very dangerous due to deep high-velocity flows and has to be sampled with a cup or sample bottle attached to an extension rod.

Atascadero Creek at Patterson Avenue (AT2) is also reached from Hollister Avenue by turning towards the ocean on Patterson. The site is located under the bridge where Patterson crosses the creek, just after the bike path crossing. The sampling location under the bridge also marks the junction of the two major branches of Atascadero Creek: Atascadero itself, and Maria Ygnacio Creek. The center bridge pier is the dividing line; before, or north, of the pier is Maria Ygnacio, past the pier is Atascadero. We sample both creeks at this location. Sampling them separately (AT2 and MY1) is valuable because each represents a different kind of stream with different land uses. The Atascadero branch is unusual because, unlike most South Coast streams, it doesn't extend up to the crest of the mountains, but has its origins just above Cathedral Oaks Road. Thus, we get a relatively "pure" pollution signal from suburban Santa Barbara at this location: residential housing, horse corrals, commercial uses around Hollister and Modoc, and the Hidden Oaks Golf Course.

Maria Ygnacio Creek at Patterson Avenue (MY1) is located adjacent to AT2, on the north side of the center bridge pier. The Maria Ygnacio branch of 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, has a more natural channel than Atascadero Creek, and a more substantial buffer area protects the creek from adjacent uses. During storms, both AT2 and MY1 have to be sampled from the bridge because of dangerous high flows by lowering a bucket on a rope. In addition, a USGS gauging station at the center pier records the combined flow from both creeks. That flow data is accessed through the internet (USGS-NWIS).

Atascadero Creek at Puente Drive (AT3) can also be reached from Hollister Avenue by turning towards the ocean on Puente. We sample just downstream of the bridge where Puente crosses the creek, past the bike path crossing. Here the creek is contained within a steep-sided concrete channel. Besides being the largest system in the Santa Barbara area, Atascadero has the longest continuous stream of water during the dry months. Heading upstream, AT3 is the third location that we sample (MY1 is usually dry in the summer). AT3 is above a golf course and agricultural areas and provides a relatively "pure" urban Santa Barbara pollution signal in the water.

Cieneguitas Creek at Nogal Drive (CG1) is accessed from Hollister Avenue by turning towards the ocean on Nogal (just before Hollister splits into State Street and Modoc). The sampling location is near the bike path crossing, below the bridge that crosses the creek. The best way to access the creek is across the bridge and along the left-hand abutment. We sample just upstream of, or underneath, the bridge. Cieneguitas Creek is a major tributary of Atascadero and is sampled for urban runoff from the upper State Street area.[5]

San Jose Creek at Hollister Avenue (SJ1) is reached from Hollister by turning toward the ocean on Kellogg and making a quick left into the shopping center and "Sizzler" parking lot. A bridge crosses San Jose Creek at the end of the parking area. Climbing over (or crawling under) the gate on the far side of the bridge accesses a ladder to the concrete channel. After the rainy season this creek is often dry and cannot be sampled.

San Jose Creek at North Patterson Avenue (SJ2). We access this site from Cathedral Oaks, turning towards the mountains on Patterson and stopping just past the bridge over San Jose Creek. We sample underneath the bridge. This location, added to the program in January 2004, is near 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 at which we currently sample. A nearby USGS gauging station provides flow data (USGS-NWIS).

San Pedro Creek near Hollister Avenue (SP1). Turning toward the ocean on Fairview Road, San Pedro Creek runs along the west (right-hand) side of Fairview. The sampling site is approximately ¼ mile past the intersection. During the dry season, flow disappears and the creek cannot be not sampled. This location is downstream of the Twin Lakes Golf Course (located on the uphill side of Hollister). 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% of the Goleta Slough watershed. These two creeks have interesting contrasts: San Pedro is more industrial and agricultural, with added nutrient pollution from the golf course, while San Jose is more residential.

Los Carneros Creek at Hollister Avenue (LC1) is accessed by turning toward the ocean on Aero Camino then making an immediate left on the frontage road, stopping near the small bridge that crosses the creek. Los Carneros empties into Goleta Slough just downstream of the bridge. We sample on the upstream side. Sampling is difficult because there is no easy access down to the creek. We sample two sites along Los Carneros; this is the lowermost (downstream) site. At this point, Los Carneros Creek is a cement channel containing little or no vegetation. Businesses and parking lots line both sides of the creek just above this point. During the dry season the site often has low to no flow and cannot be sampled. Los Carneros and Glen Annie 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 Glen Annie, Los Carneros is less developed and has fewer commercial or residential areas within its watershed. Sampling at both LC1 and LC2 also provides a measure of the impact of Highway 101 on this water source.

Los Carneros Creek at Calle Real (LC2) is reached by turning off of Hollister Avenue towards the mountains on Los Carneros Road. Continuing over Highway 101 to the intersection with Calle Real, we access the creek via a large dirt pullout area on the left-hand side. During the dry season flow here is often low, but there is usually enough water to sample. This is the uppermost (upstream) Los Carneros site. Since the Los Carneros watershed is relatively undeveloped, sampling here, above the Highway 101 intersection, provides some idea of what runoff into the slough must have been like prior to urban development further downstream. This site serves as a yardstick to gauge how much the other tributaries may have been impacted by this type of development.

Glen Annie Creek at Hollister Avenue (GA1). To access this site, we turn towards the mountains on Los Carneros Road, then turn right at the first traffic light into a small business park. Along the eastern edge of the parking lot there is a manicured dirt pathway between the parking area and the creek. Near the mid-point of this path is a clearing in the vegetation with a rough path down to the creek. The creek is always deep and wide at this point and flows year-round. We sample at two sites along Glen Annie; this is the lowermost (downstream) site. Glen Annie 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. Glen Annie and Los Carneros creeks, although smaller than the other tributaries, supply most of the wetland's freshwater. Of the two, Glen Annie is the source of most of the slough's nutrient contamination.

Glen Annie Creek at Cathedral Oaks Road (GA2). We access this site from Hollister Avenue, turning towards the mountains on Storke/Glen Annie Road and continuing across Highway 101 until the traffic light at Cathedral Oaks. Immediately past the intersection, we turn left into a large dirt pullout, follow a poorly maintained pathway leading into the brush and then turn to the right (toward the mountains) toward an old metal retaining wall along the creek. Continuing upstream leads to the end of the wall and a less steep section where the creek can be accessed. This is the uppermost (upstream) Glen Annie site. Here we sample the bulk of the agricultural and golf course runoff that strongly impacts Goleta Slough. The creek between the two locations flows with water throughout the summer because of these sources.

Goleta Slough at the bicycle bridge (GS1 and GS2). These two sites are reached by walking from the Goleta Beach parking lot along the bike path toward the airport to the bridge over the slough. This location is 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.

The Goleta Stream Team sampling sites represent six distinct creeks or sub-watersheds. Sampling is usually accomplished by two or three teams, with Group I sampling the five Atascadero and Maria Ygnacio locations, Group II sampling Glen Annie, San Pedro, and Los Carneros creeks, and Group III, San Jose Creek and the Goleta Slough sites. However, since many of the Group II and III sites are often dry in the summer, these two groups are often combined into a single team.

In this report, the sampling locations are also sub-divided into three groups, dividing the Goleta watershed into distinct geographic and ecological units: (1) the four sampling sites along the Atascadero/Cieneguitas system (AT1, AT2, AT3, and CG1), (2) the agricultural drainages of Glen Annie, Los Carneros and San Pedro (GA1, GA2, LC1, LC2, and SP1) and (3) thirdly, Goleta Slough and the less impacted Maria Ygnacio and San Jose streams (GS1, GS2, MY1, SJ1 and SJ2). Whenever possible, this grouping is used to display and discuss the variation of a measured parameter with time. Data for GS2 and LC1 will not typically be shown. GS2 data are nearly identical to those for GS1, and LC1 resembles that of LC2 (in addition, sampling at LC1 was discontinued, except for storm events, in February 2004). Data for some locations are limited. Flow at MY1 has become extremely rare with the passage of time (a similar situation has developed at other sites; more on this topic later): from June 2002 to December 2004, only three months of flow were observed. We have as yet sampled too few times at GS1 and GS2 to draw many conclusions. All sampling locations, past and present, will be included when overall averages are presented. Three sites, AT2, AT3 and GA1, exemplify conditions found in all local streams and are highlighted during the discussion of the results.

Cycles of Change

The extreme rainfall variability experienced along the South Coast 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.

A majority of the Goleta Stream Team sampling locations can be described as "natural" streams (e.g. GA1, GA2, CG1 and SJ2). These sites generally have rocky or sandy bottoms and banks and at least minimally functioning riparian areas. Major winter storms, such as those that occur during severe El Niño years, begin a transformational cycle in these types of streams. Heavy flows scour streambeds of vegetation and fine sediment, clearing the way for a takeover by filamentous algae.[6] However, sooner or later a low runoff year occurs as two out of three years have less than half the average runoff (Figure 2, upper panel). In the absence of severe winter floods, sediment accumulates in the channel and exuberant plant growth begins the competitive replacement of algae by aquatic vegetation (Leydecker and Altstatt, 2002). Where the growth of taller riparian vegetation appreciably blocks sunlight, algae may disappear entirely.

"Hardened" sites such as SJ1 lack many of the characteristics of more natural streams. They typically have little to no riparian cover, and lack rocky or sandy bottoms and banks.

Over the years these processes increasingly stabilize the channel and elevate the threshold flow of any future scouring storm.

Other sampling sites in the engineered and "hardened" urban creeks (e.g., 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 for the rooting of plants accumulate on concrete streambeds, every year is dominated by algal growth.

In the past three years, Goleta Stream Team has sampled a wide variety of conditions dictated by annual variations in rainfall. The previous "big" rainfall event, the last big 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 2002-2005, Goleta Stream Team has observed and documented these changes (SBCK(b)).

Figure 6 shows the variations in both monthly and annual rainfall that have occurred during the study period. One year was slightly above normal (2003) and two were appreciably below (2002 and 2004), one of which (2002) had less than half the annual mean rainfall (9 inches) and could thus be characterized as a drought year. However, 2005 was a special year.

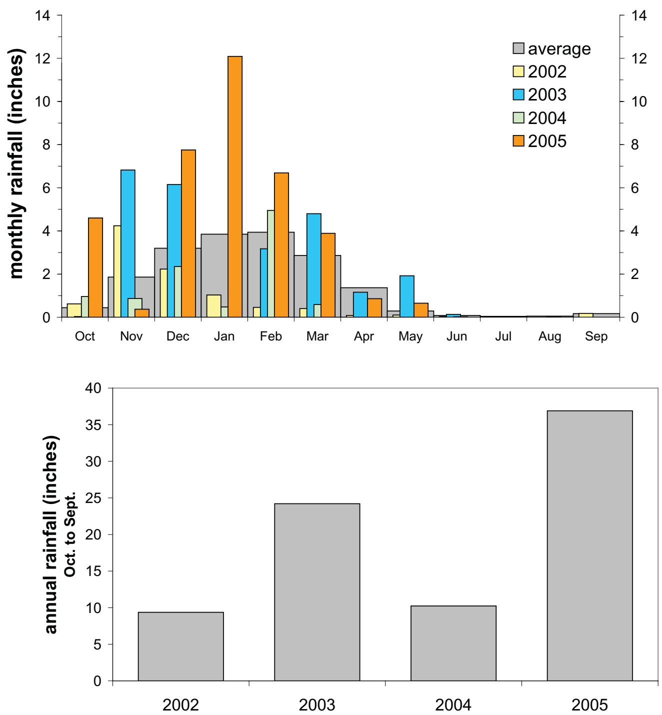


Figure 6. Monthly (upper panel) and yearly (lower panel) rainfall for the years of the Goleta Stream Team surveys. The data are for downtown Santa Barbara, and water-year 2005 only includes rainfall through May. 2005 was an extraordinarily wet year: rainfall throughout the region, as of the end of April, varied around 200 to 250% of the annual average (222% in Oxnard, 268% in Los Angeles, 204% in Santa Barbara and 239% at Cachuma Lake). The heavy line in the lower panel represents the average annual Santa Barbara rainfall of 18.15 inches.

The 2005 water-year, characterized by very weak El Niño conditions in the Pacific, began with expectations of 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 both storm phases (Figure 7, upper panel). By the end of January, a total of 24.4 inches had fallen since the beginning of the rainy season, compared with the annual mean of 18.1 inches. As storms coming out of the Pacific were uplifted over the coastal mountains, even larger amounts of rain were released; San Marcos Pass received 18.2 and 24.6 inches during the first and second storm phases.

However, as shown in the upper panel of Figure 2, not all big years are severe El Niño years. At times, some very wet winters are caused by a much shorter weather cycle of 30-60 days called the "Madden-Julian Oscillation." Simplifying the process 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, rainfall that continued through March and April.

The hydrographs in Figure 7 portray how stream flow changed with time. The upper panel represents the variation in depth of Atascadero Creek flow at Patterson Avenue (AT2) during the storms. Stage is simply the term for how

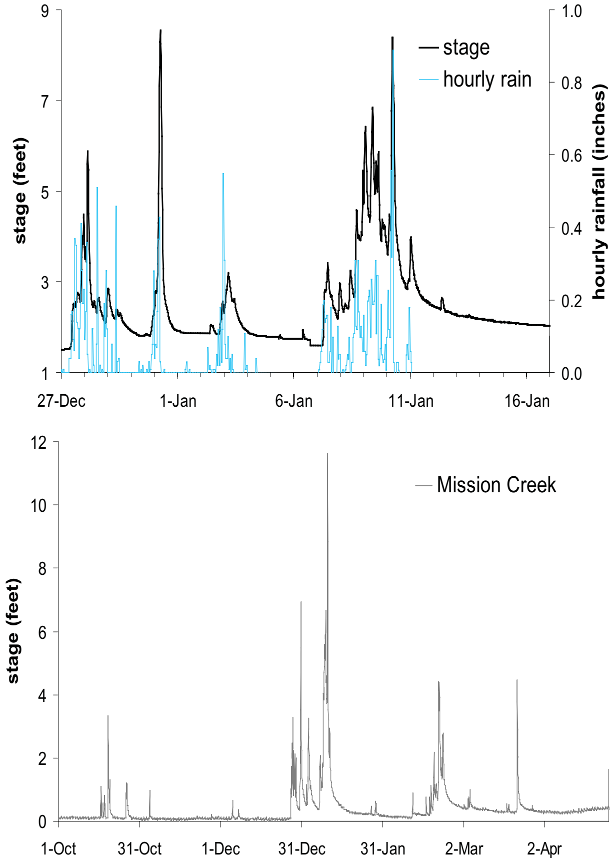


Figure 7. Upper panel: Stage (water height) in Atascadero Creek at Patterson Avenue (AT2) and hourly rainfall in downtown Santa Barbara during the December 2004 series of winter storms. Lower panel: Stage during the winter of 2005 at Mission Creek (Montecito Street, Santa Barbara; UCSB-LTER).

the primary cause of flooding on the coastal plain. Figure 8 (lower panel), using cumulative rainfall and runoff along with the hydrograph for Maria Ygnacio Creek, makes the same point. By January 6, 2005, half the holiday interval's rain had fallen, but only 20% of the total discharge had flowed down the creek; most of the runoff (80%) occurred during the second storm pulse. The significant difference between the total rainfall (more than 19 inches) and runoff (4.2 inches) indicates the appreciable water holding capacity of the area's higher elevation soils.

The lower panel of Figure 7 shows the stage hydrograph for Mission Creek (in downtown Santa Barbara, UCSB-LTER) during the entire 2005 rainy season. It high water levels rose at the USGS gauge; when the gauge reads 1.5 feet, the creek is dry. The chart also shows hourly Santa Barbara rainfall.

Atascadero reacted rapidly to changes in rainfall. This is what is meant by the term "flashy" – water levels are quick to rise and quick to fall. All the Goleta creeks are relatively short and steep and thus flashy. Peak flow during the holiday storms reached 8,600 cfs – equivalent to a wall of water seven feet high and a hundred feet wide, moving at over eight miles per hour. Only two years in the 53-year Atascadero record have seen greater peak flows (Figure 8, upper panel). A comparison of the peak flow chart with that for rainfall (Figures 1 and 8) shows that very high peak flows have become increasingly common in the last 10-15 years. This is a product of increasing development in the Goleta basin. The USGS considers 1970 as the year when the Atascadero catchment could no longer be considered "natural." The absence of a pattern of increased peak storm flows in recent years for San Jose Creek, a less developed stream (Figure 8, upper panel), reinforces this conclusion.

Figure 7 (upper panel) shows an increase in the amount of Atascadero runoff for similar amounts of rainfall during the latter half of the holiday storm period. The coastal mountains that form the upper portions of the Goleta Slough watershed contain a thin but highly porous layer of soil. This layer acts like a sponge during the first storms of the season, absorbing rainfall and limiting the amount of runoff that originates at higher elevations. But when these soils become saturated they deliver copious amounts of runoff to the valley below, and mountain rainfall becomes

Site AT2 during the January 9, 2005 storm. Peak flow reached 8,600 cubic feet per second during the winter storms.

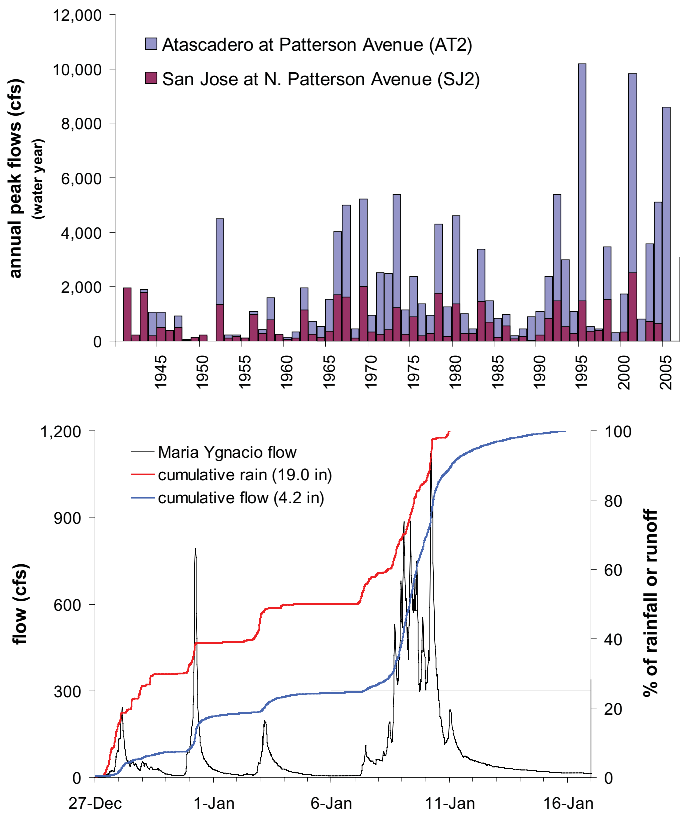


Figure 8. Upper panel: Annual peak flows (cfs) in Atascadero Creek at Patterson Avenue (AT2) and San Jose Creek at North Patterson Avenue (SJ2). Lower panel: The flow hydrograph for Maria Ygnacio Creek (at University Drive) during the January 2005 big storm interval. Cumulative rainfall (19 inches total) and cumulative runoff (4.2 inches total) are also shown. By January 6, half the rain had fallen, but only 20% of the total runoff had appeared; 80% of the runoff came during the second storm pulse.

demonstrates that large storms continued throughout February and March (with occasional rainfall as late as May), making 2005 one of the largest rainfall years on record. Rainfall throughout the region varied around 200-250% of the annual average (by the end of April, 222% of the average had fallen in Oxnard, 268% in Los Angeles, 204% in Santa Barbara, and 239% at Cachuma Lake). The 2005 water-year is now the second wettest year in the century and a half history of Los Angeles weather. Thus, 2005 became the new transformational year; the year that begins the cycle anew.

During the large storms of January 2005, sampling was conducted by lowering buckets from bridges.

RESULTS

Conductivity[7]

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 carry an electrical charge when put into solution. 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 such as 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 cause 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 in the range of 0.5-3 µS/cm. The conductivity of rivers in the United States generally ranges from 50-1,500 µS/cm. Drinking water typically must meet a standard of 1,000 mg/L total dissolved solids and a maximum conductivity of 1,600 µS/cm (CSB-PW, 2004).

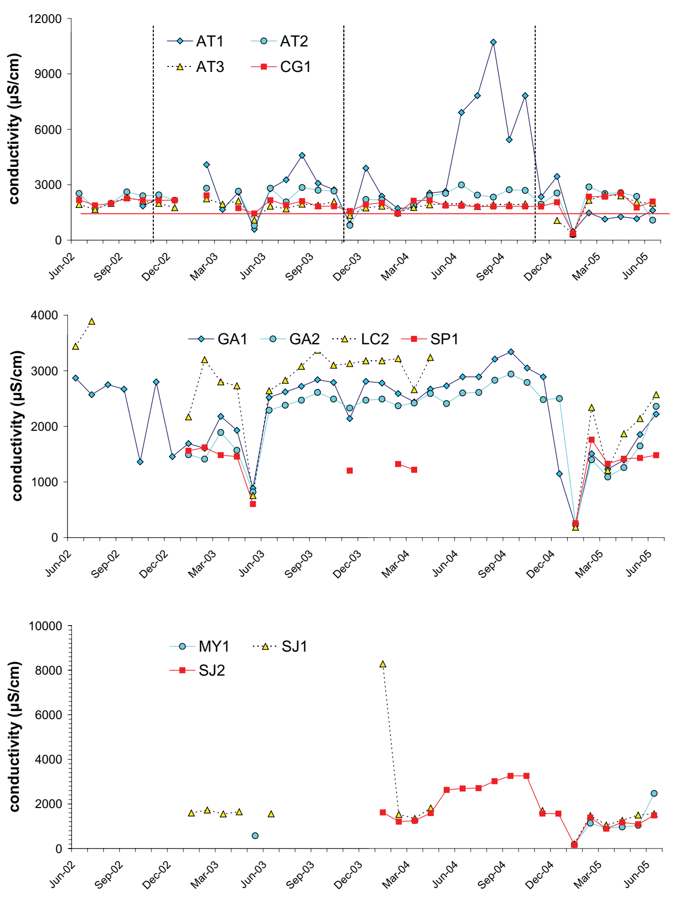


Figure 9. Conductivity, June 2002 to June 2005. Dashed vertical lines mark the start of each water-year. Glen Annie Creek (GA1, GA2) has had an increasing trend with time; very low values usually mark storm events, e.g., January 2005 or, in some cases, meter error. The red line indicates a typical Public Health drinking water limit of 1,600 µS/cm.

Conductivity in Goleta streams is usually above the 1,600 µS/cm limit for a number of reasons. One, these waters have naturally high mineral content due to easily eroded marine sediments in the coastal mountains that form the upper watersheds. Two, runoff from agricultural and suburban irrigation carries high mineral content into streams. Three, summer evaporation in very low and shallow flows concentrates dissolved solids in the water; and four, these same flows in paved channels often pick up noticeable amounts of calcium, carbonate and sulfate from concrete. In spite of the 1,600 µS/cm drinking water limit, high conductivity waters are not necessarily unhealthy ecologically. As long as there are acceptable reasons for higher values, as there are for some of the Goleta creeks, high conductivity is not necessarily associated with increased pollution.

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

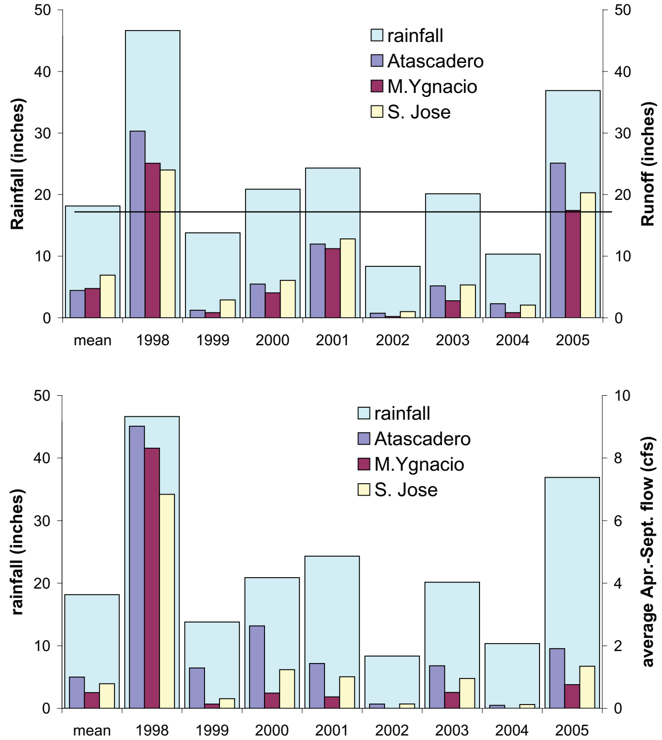


Figure 10. Annual water year rainfall (Santa Barbara/Goleta) is plotted for the severe El Niño year of 1998 and every year since. Annual runoff (in inches) for the three USGS gauging stations in the Goleta Slough watershed is shown on the right-hand axis in the upper panel, and the average April to September flow in the lower (July through September flows for 2005 were estimated from the historical record). The horizontal line represents the mean annual rainfall of 18 inches. (Flow data from http://nwis.waterdata.usgs.gov/ca/nwis/monthly/)

conductivity; groundwater has higher conductivity than water in the soil, and older groundwater has higher conductivity than younger. Channelkeeper's Ventura Stream Team discerned a long-term trend towards rising conductivity up until the winter of 2005 (SBCK, 2004). This trend was caused by increasingly depleted and generally older groundwater inflows, enhanced uptake by growing riparian vegetation, and a relative increase in evaporation as dry-season flow diminished since the last big year (the high El Niño rainfall of 1997-98).

Such a clear trend in conductivity does not emerge in the Goleta data (Figure 9), but there is a suggestion of it in Glen Annie (GA1 and GA2) and San Jose (SJ2) creeks. Evidence for the gradual drying out of Goleta watersheds is shown in Figure 10. The figure plots the average annual rainfall since 1998, the last strong El Niño year, with annual (upper panel) and dry-season flows (April through September, lower panel) in Atascadero (at Patterson Avenue, AT2), Maria Ygnacio (at University Avenue) and San Jose (at North Patterson Avenue, SJ2) creeks. These streams have USGS gauging stations recording flow every 15 minutes; this data, updated in near-real time (with a typical delay of a few hours), is available on the internet (USGS-NWIS).

While annual runoff has been roughly proportional to annual rainfall, the ratio of dry-season runoff to annual rainfall has been decreasing appreciably since 1998. Dry-season flows in 2001 were lower than in 2000, even though 2001 had almost 20% more rainfall, and 2004, with 25% more rainfall, had less flow than 2002. Monthly flows for the three gauging stations for 1998 and every year of Goleta Stream Team monitoring (along with mean monthly flows), shown in Figure 11, indicate that the creeks have become relatively drier as the years go by, particularly during summer.

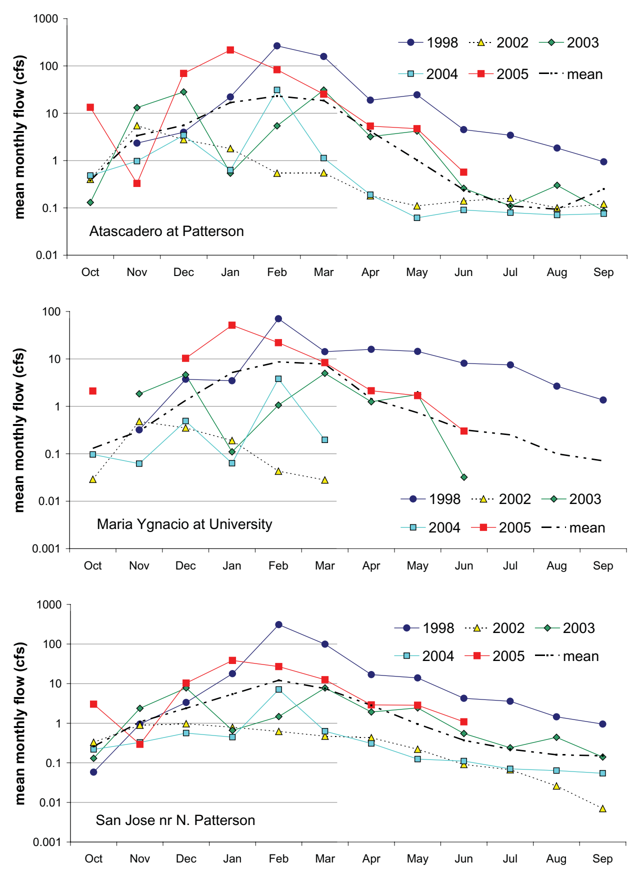


Figure 11. Monthly flows during the years of the Goleta Stream Team sampling with mean monthly flows from the historical gauging station record (since 1942 for San Jose and Atascadero, since 1971 for Maria Ygnacio). The further in time from the last big rainfall year (e.g., the 1998 El Niño), the lower dry-season flow (April to September) becomes, e.g., progressively less of the previous winter's rainfall flows during the summer. Even with greater rainfall, streams were drier in 2004 than in 2002.

However, any pattern of rising conductivity was abruptly terminated with the advent of the winter storms of early 2005. Conductivity measurements in January 2005 were made during a major storm and exhibit the low values expected during rainfall (Figure 9). However, low values in many cases have continued into June. High creek levels, caused by increased flow from higher elevations (which generally have lower conductivities) and increased amounts of lower-conductivity shallow ground and soil waters are probable causes.

An occasional sharp dip in monthly conductivity usually indicates a sample taken during, or shortly after, a storm. Recent rain dramatically lowers stream conductivity; rainfall is as young as water ever gets, with a conductivity in the Santa Barbara area of around 20 µS/cm. Even though conductivity increases as storm runoff moves by various pathways to streams, it still remains much lower than normal during storms. Along with January 2005 data, all sites show the drop in values measured during a storm on May 3, 2003. Other abrupt decreases may be due to error; in October 2002, a greater than 50% decrease in conductivity was recorded at GA1 (Figure 9, middle panel). No other locations showed a corresponding decrease, and therefore the accuracy of this measurement must be doubted.

Conductivity results are summarized in Figure 12. The median is the middle value in a series of measurements: half the monthly measurements were 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. A large difference between the average and the median (as was noted for annual flows at Patterson Avenue) indicates an unbalanced distribution of data.

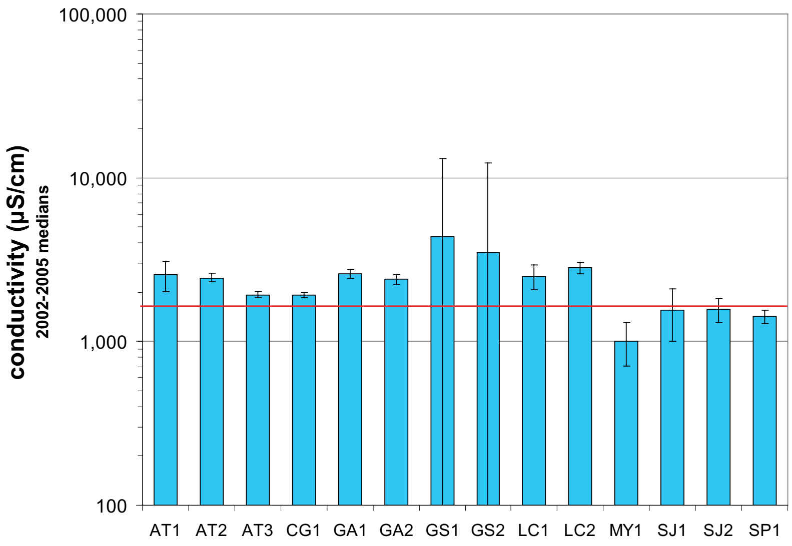


Figure 12. Median conductivity values, June 2002 to June 2005. The "error bars" indicate the standard error of the median. The vertical line represents a generally accepted upper conductivity limit of 1,600 µS/cm for drinking water. GS1 and GS2 measure salt/brackish water near the mouth of the slough.

The error bars in Figure 12 show 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. Almost all the Goleta sampling sites had median conductivities above the 1,600 µS/cm drinking water limit. The sites that did not (MY1, SP1 and SJ1) were often dry between storms and their measurements reflect the lower conductivity values of storm flow. High conductivity readings at GS1 and GS2, measured near the mouth of the slough, reflect the highly brackish (mixtures of salt and fresh water) environment of this location: sea water has a specific conductivity of around 53,200 µS/cm. The implications of the high standard error for the GS1 and GS2 measurements will be discussed later.

Temperature

Temperature is the simplest water quality parameter measured, yet one of the most important. The expected annual pattern is straightforward: temperature rising from winter lows to summer highs, and then decreasing in early fall, paralleling seasonal changes in air temperature. This pattern is observed at all the Goleta Stream Team sites (Figure 13), although at some locations (SP1 and AT3) the pattern is more erratic. At these sites, the temperature of shallow streamflows in unshaded channels reflect changes in daily conditions (e.g., fog or sunshine) as much as seasonal trends.

The temperature graphs show three horizontal lines, which 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 provides excellent conditions for spawning and incubation (Brungs and Jones, 1977; Armor, 1991; McEwan and Jackson, 1996; Sauter et al., 2001). As temperatures rise, fish have increasing trouble extracting oxygen from water, while at the same time, the maximum amount of oxygen capable of being held in solution decreases.

Consideration of the conditions necessary for good steelhead habitat are often used as water quality criteria in this report, since water good enough for steelhead is very good water indeed, and since a widespread return of these symbolic fish to the Santa Barbara area is a popular enthusiasm (NMFS, 1996). This does not mean that steelhead are present in these creeks, nor that they would return if water quality were good enough – other questions such as water availability and barriers to fish passage are equally, if not more, important. However, water meeting criteria for steelhead can be considered high quality water.

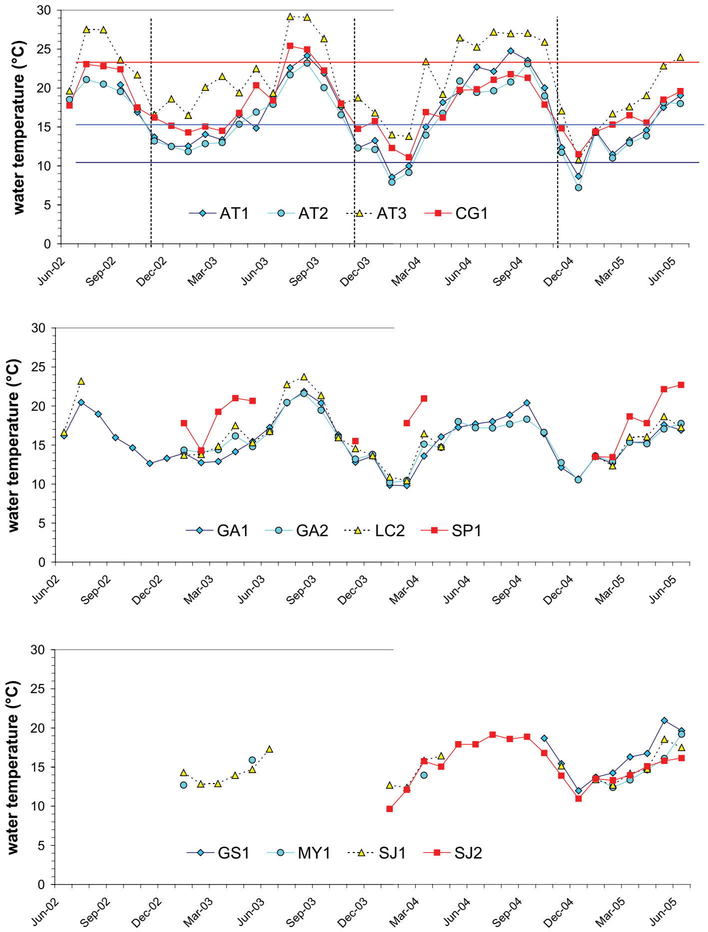


Figure 13. Stream temperature, June 2002 to June 2005. Dashed vertical lines mark the start of each water-year. The three horizontal lines mark important trout and steelhead temperature milestones: above 24°C leads to death; below 16°C indicates good dry season conditions; and below 11°C is excellent for spawning and incubation.

Sites with more natural stream conditions, such as GA2, exhibit less extreme temperature variations.

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. Furthermore, fish are not passive participants but are free to seek out more favorable conditions (Matthews and Berg, 1997; Stoecker, 2002).

As might be expected, temperatures are often warmer where flow is confined in open concrete channels (LC2 and AT3). The more natural sites (usually in shaded ravines) exhibit less extreme temperature variations - cooler in summer, warmer in winter (GA1, GA2 and SJ2). Flow generally warms as it transits an urban area (SJ2 to SJ1, GA2 to GA1), but the urban nuisance waters that typically flow in the Atascadero drainage exhibit some interesting fluctuations. From CG1 to AT3, flow becomes considerably warmer, and then cools as it further moves to AT2, and finally warming again as it passes to AT1. These variations reflect the changing channel environment: shaded at CG1, shallow and exposed in the concrete canal around AT3, and shaded and deeper at AT2. The water stream then warms during its passage through the long, skinny, lake-like environment between AT2 and AT1. Because it moves so slowly, passage through this stretch can take days, or possibly even weeks, compared to the minutes and hours in which we usually measure the travel time of water in creeks. Even though this reach is shaded and deep (conditions usually equated with cooler water), the extremely low and slow flow provides opportunity for summer warming.

Dissolved Oxygen

Aquatic organisms rely on the presence of oxygen in streams; not enough oxygen and they will relocate, weaken or die. On land, oxygen makes up 20% of the surrounding atmosphere, whereas in water, oxygen is a dissolved gas with a maximum concentration of about 16 parts per million (a maximum of 0.0016%) – not at all plentiful. Water temperature, altitude, time of day, and season all affect the amount of oxygen in the water; water holds less oxygen at warmer temperatures and higher altitudes. Dissolved oxygen (DO) is measured either in milligrams per liter (mg/L) or "percent saturation."

Milligrams per liter is the weight of oxygen in a liter of water.[8] Percent saturation is the amount of oxygen dissolved in water relative to the total amount of oxygen that can be held under equilibrium conditions at that temperature. When dissolved oxygen levels in water drop below 5 mg/L, aquatic life is put under stress (although warm-water fish can probably tolerate levels as low as 4 mg/L). Cold-water fish (trout and steelhead) need levels above 6 mg/L, and DO above 8 mg/L may be required for spawning (Davis, 1975; EPA, 1986; Bjornn and Reiser, 1991; Deas and Orlob, 1999). Oxygen levels that remain below 1-2 mg/L for a few hours can result in large fish kills.

The dissolved oxygen trends for the Goleta creeks are shown in Figure 14. As for temperature, three important benchmarks are shown as horizontal lines: above 8 mg/L represents near-ideal conditions; at 6 mg/L hypoxia begins and fish begin to feel stress (but no lasting harm is done in the short term); and below 4 mg/L lies severe damage and death. As before, these markers are for 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.

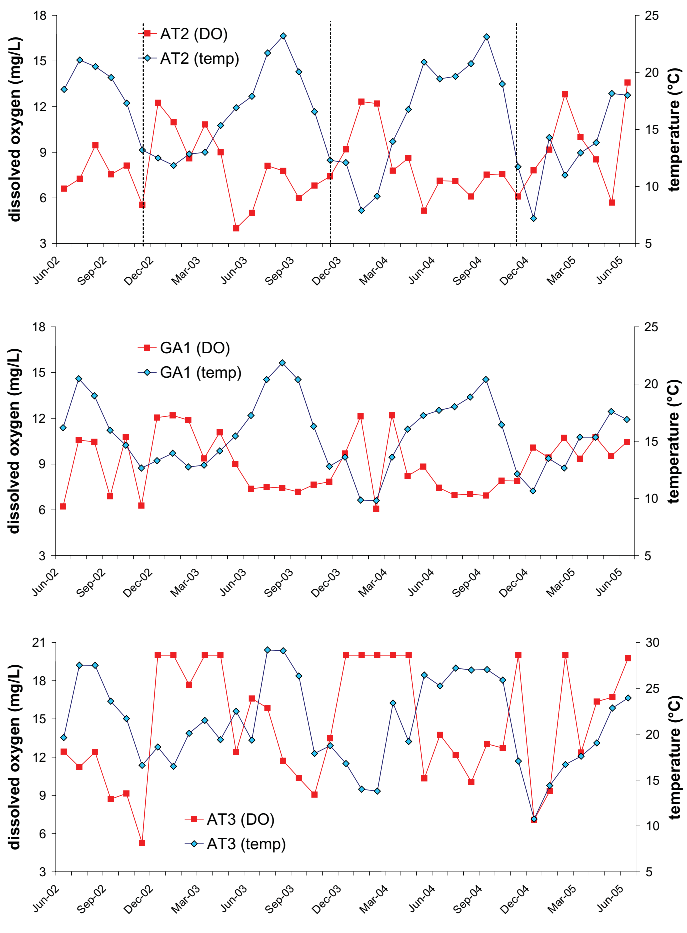


Figure 14. Dissolved oxygen, June 2002 to June 2005. Dashed vertical lines mark the start of each water-year. The three horizontal lines mark important trout and steelhead DO milestones: above 8 mg/L represents near ideal conditions; at 6 mg/L hypoxia begins and fish start to feel stress; and below 4 mg/L lies severe damage and death.

At first glance, Goleta stream conditions look fine: very few samplings showed DO concentrations below 3 or 4 mg/L, and even readings below 6 mg/L were relatively rare. Although there does not seem to be a clear annual pattern, there appear to be two general trends in the data: (1) higher winter concentrations (December-March) give way to lower values in summer and fall (e.g., CG1, SJ2, GA1 and GA2); and (2) there were lower overall concentrations in 2004 than in 2003. Lower flows in 2004, and lower amounts of algae resulting from this, probably account for the second trend. As flows decrease, streams become more sluggish and there is both less opportunity for water to pick up increased oxygen through re-aeration (e.g., riffles and cascading white water) and more time for aquatic species and biochemical processes to extract it.

However, there are potential problems that are not immediately apparent. Ironically, very high DO concentrations can indicate trouble. Goleta Stream Team sampling takes place during daylight. While the sun is out, algae and aquatic vegetation photosynthesize, removing carbon dioxide from the water column and replacing it with oxygen. This process is reversed at night as oxygen is removed and carbon dioxide added (Carlsen, 1994; NM-SWQB

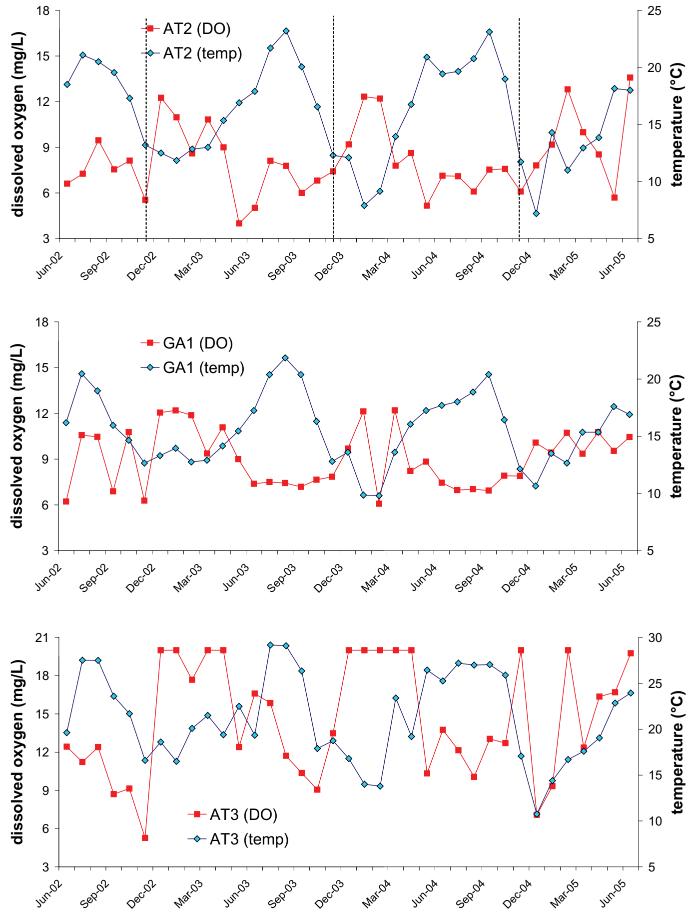


Figure 15. Dissolved oxygen and temperature for three sampling locations, June 2002 to June 2005. Dashed vertical lines mark the start of each water-year. Under ideal conditions, as temperature rises DO should fall, and vice versa; the absence of this pattern in the upper panel indicates problems with algae.

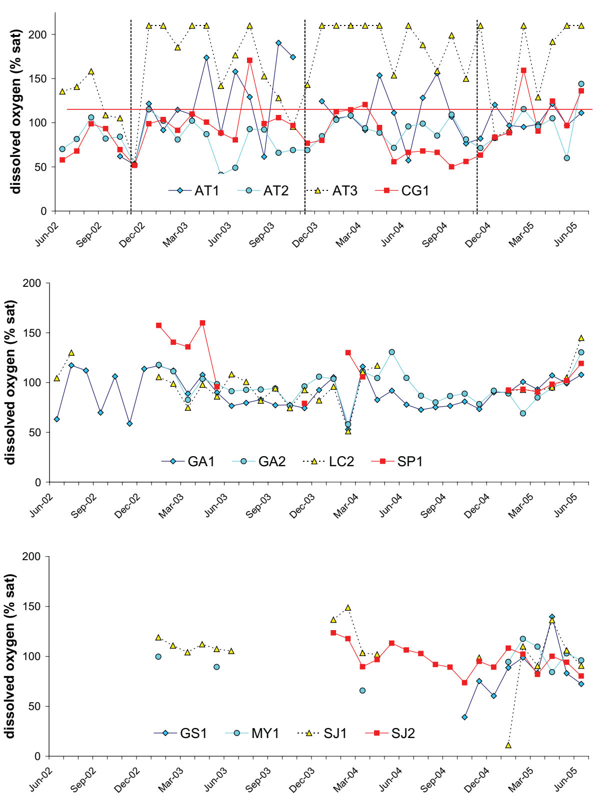


Figure 16. Dissolved oxygen measured in % saturation, June 2002 to June 2005. Dashed vertical lines mark the start of each water-year. Concentrations above 120% saturation typically indicate problems with algal growth: over-saturation during daylight is followed by depleted concentrations at night.

2000). Thus very high daytime oxygen concentrations can indicate an overabundance of algae. Under these conditions, oxygen falls to a minimum just before sunrise, and it is concentrations during this critical period that determine the actual threat to fish and other aquatic species, a threat that is usually not evaluated but probably should be (Windel et al., 1987; Deas and Orlob, 1999; PIRSA, 1999). Almost all the Goleta Stream Team sites showed a periodic overabundance of oxygen.

The absence of a clear annual DO pattern is also a cause for concern. Oxygen has a greater solubility in colder water, and as temperature increases DO should decrease, and vice versa. If DO and temperature are plotted on the same graph, they should appear roughly 180° out of phase, e.g., like opposing waves, one going up as the other goes down. To demonstrate, both DO and temperature are plotted for three sites in Figure 15. Note the absence of this expected pattern during some years, or portions of years, at all three locations, particularly at AT3 (lower panel, Atascadero at Puente

Drive). This is evidence of algal dominance: warmer, more sluggish summer waters producing high daytime DO concentrations. The actual situation at AT3 is worse than portrayed on the graph. Channelkeeper meters can only measure DO concentrations up to 19 mg/L, and the 20 mg/L values shown on the chart are simply an estimate; concentrations were above 19 mg/L, but how high above remains unknown. The thin, warm flows in the concrete canal at this location are choked with algae.

Site AT3, with warm, shallow flows in a wide concrete channel, is often choked with algae.

A DO meter also measures percent saturation,[9] or in other words, the oxygen excess or deficiency when compared with equilibrium conditions. Typically, a dissolved oxygen concentration in excess of 120 percent of saturation is a good indicator of algal problems.[10] The Goleta Stream Team data (Figures 16 and 17) confirm problems with algal growth at AT1 and AT3, and often at SP1 (when water is flowing). Finally, DO and temperature results are summarized by showing the mean, and minimum and maximum, measured values (Figure 18).

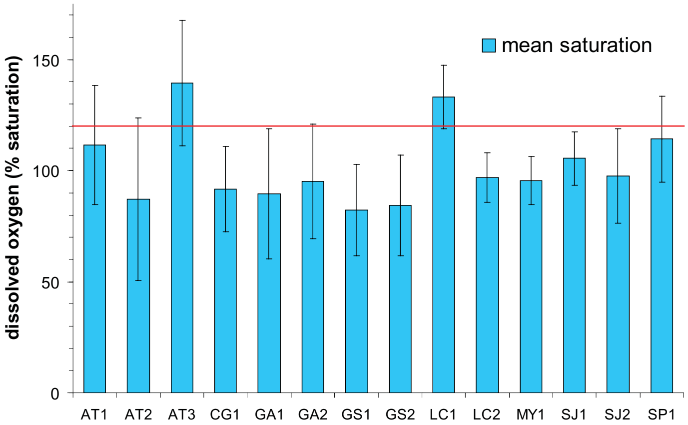


Figure 17. Mean dissolved oxygen (in % saturation): June 2002 to June 2005. Concentrations above 120% saturation (red line) usually indicate problems with algal growth: over-saturation during daylight is followed by depleted concentrations at night. The error bars indicate ± the standard deviation of sampled concentrations at each site (e.g., 67% of the monthly samples will have values between the error bars). AT1, AT2, AT3, LC1 and SP1 have severe periodic problems with algae.

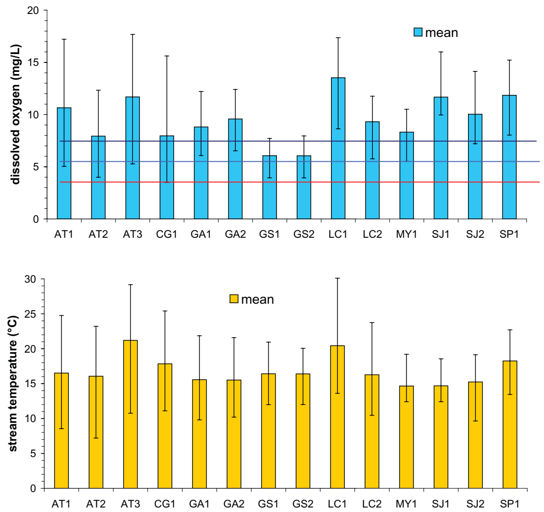


Figure 18. Upper panel: Average dissolved oxygen, June 2002 to June 2004. The three horizontal lines mark important DO milestones- above 8 mg/L represents near ideal conditions; at 6 mg/L hypoxia begins and fish start to feel stress (but no lasting harm is done in the short term); and below 4 mg/L lies severe damage and death. Lower panel: Average stream temperature, June 2002 to June 2005. Above 24°C leads to steelhead death; below 16°C indicates good dry season conditions; and below 11°C is excellent for spawning and incubation. The "error bars" represent the maximum and minimum measured values. Extreme values become critical at locations with measurements below (for DO) or above (for temperature) the red line.

pH

pH is a relative measure of alkalinity and acidity, an expression of the number of free hydrogen atoms present. 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. Blood (pH of 7.5), seawater (9.3) and household ammonia (11.4) are all alkaline or basic; urine (6.0), orange juice (4.5), Coca Cola Classic (2.5) and human stomach contents (2.0) are acidic. pH numbers represent a logarithmic scale, so small differences in numbers can be significant: a pH of 4 is a hundred times more acidic than a pH of 6. All plants and aquatic species live within specific ranges of pH, and altering pH beyond these ranges causes injury or death. Pollutants can push pH toward the extremes, and low pH in particular is highly dangerous because it allows toxic elements and compounds to mobilize (go into solution) and be taken in by aquatic plants and animals. A change of more than two full points on the pH scale can kill many species of fish. The EPA and Regional Water Quality Control Board (RWQCB-CC) regard a change of more than 0.5 pH units as harmful (RWQCB-CC, 1994).

Deciding what is an unsuitable pH is difficult, as there are numerous standards. Fish can tolerate a range of 5-9, but the best conditions lie between 6.5-8.2. The Los Angles Regional Water Quality Control Board uses 6.5-8.5 (RWQCB-LA, 1994), and the EPA recommends 6.5-8.0 as optimal for aquatic animals. The Central Coast Regional Water Quality Control Board has a number of pH limits (RWQCB-CC, 1994). The two that are most applicable to Goleta streams are 7.0-8.5 for either cold or warm water habitat, and 6.5-8.3 for contact or non-contact water recreation. Combining both standards would suggest 7.0-8.3 as a desirable range.

Figure 19 shows the variation in pH at the Goleta Stream Team sampling locations.[11] No obvious pattern emerges from the data. One would expect to see lower values occurring around the beginning of the new water-year with the start of winter rains, with the highest values occurring in spring or early summer. Rain has a lower pH than baseflow in the Goleta tributaries (rain is usually slightly acidic with a pH of 4-5 in the Santa Barbara area), and the first few storms typically lower creek pH values. A spring/summer increase can be caused by the same algal and plant growth responsible for increasing daylight dissolved oxygen.

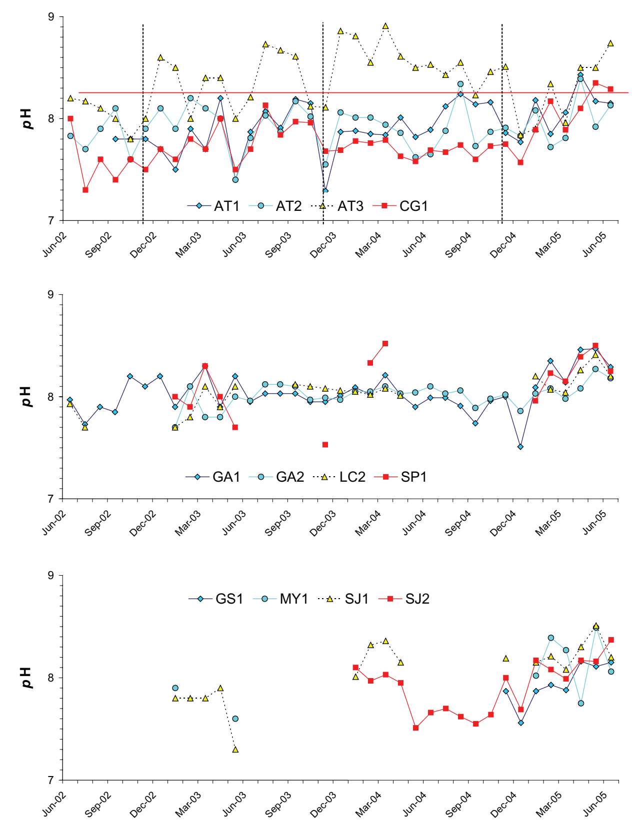


Figure 19. pH concentrations, June 2002 to June 2005. Dashed vertical lines mark the start of each water-year. The horizontal line marks the Regional Water Quality Control Board's upper pH limit for cold or warm water habitat (8.3).

Photosynthesis withdraws carbon dioxide from the water at the same time that it releases oxygen. Removing carbon dioxide is the same as removing acidity, thus it increases pH (PIRSA, 1999; NM-SWQB, 2000). Normally, absent this process and the storm-influenced changes described above, there should be little change in pH. The same dissolved minerals that give local streams high conductivity usually "buffer" the river against large variations (Goleta waters are very high in carbonates; acid neutralizing capacity (ANC) is typically in the range 5,000 to 10,000 μeq/L), but changes in dissolved carbon dioxide are a major exception.

Figure 20 shows a similarity in the patterns of DO and pH variation for three Goleta Stream Team sampling locations. Similarity in the temporal patterns of these two parameters is an indicator of algal growth: the simultaneous addition of DO and removal of acidity (increasing pH). AT3 is the best example; this removal of acidity by photosynthesis is responsible for a majority of the very high values seen in the data. In the dissolved oxygen discussion, large variations in the Atascadero drainage were noted, and equally noticeable pH variations exist at the same sampling points (Figure 19, top panel). There is a one unit pH increase in water moving from CG1 to AT3, a ten-fold decrease in acidity in what is essentially the same water (very little additional runoff enters the creek between these two points). This can only be caused by the removal of carbon dioxide. pH then decreases as water moves to AT2, as the stream undergoes a transition to a deeper, slower and more shaded environment less conducive to algal growth. Depending on the time of year, pH either decreases or increases during flow to AT1. During winter and spring, when flows are higher, conditions are unfavorable for algal growth in this shaded, lake-like segment, although in the summer, as water temperatures increase and flow stagnates, pH rises and this section takes on the appearance of a biological soup.

Examining Figure 16, reasons for the absence of a pattern in the pH data begin to become clear. There is a surprising amount of algal activity during the winter - high dissolved oxygen concentrations from December

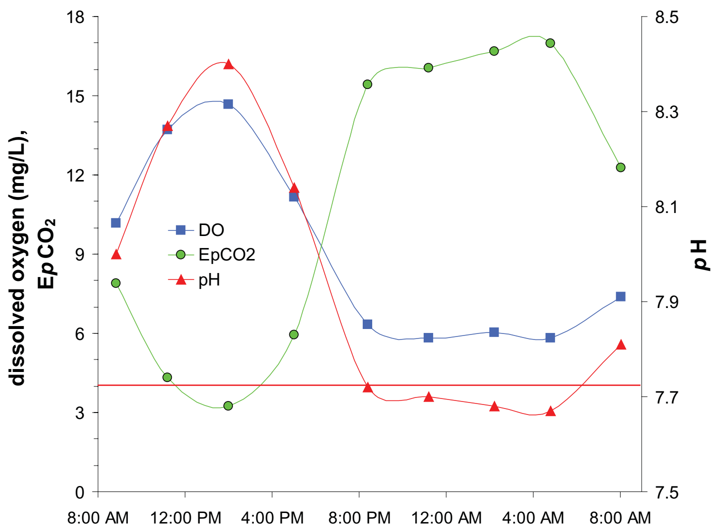


Figure 21. The chart shows results from a 24 hour sampling on the Ventura River at Foster Park on September 10-11, 2003. These measurements provide a look at daily (diel) changes during an episode of abundant algal growth. The grey area on the chart indicates nighttime. Dissolved oxygen changed from a high of 15 mg/L in the early afternoon to a low near 5 at night. The change in acidity (pH) follows the change in DO: from a high of 8.4 to a low of 7.6. EpCO2 is the ratio of measured CO2 to what would normally be dissolved in water of the same temperature at equilibrium. CO2 varied in opposition to DO and pH, from 3-times the equilibrium concentration during the day to 17-times greater at night. These changes are caused by algal photosynthesis: the removal of carbon dioxide from water during sunlight during the creation of biomass. During photosynthesis algae generate oxygen: increasing dissolved oxygen concentrations as they decrease CO2. At night, algae respire, reversing the process by removing oxygen and increasing CO2.

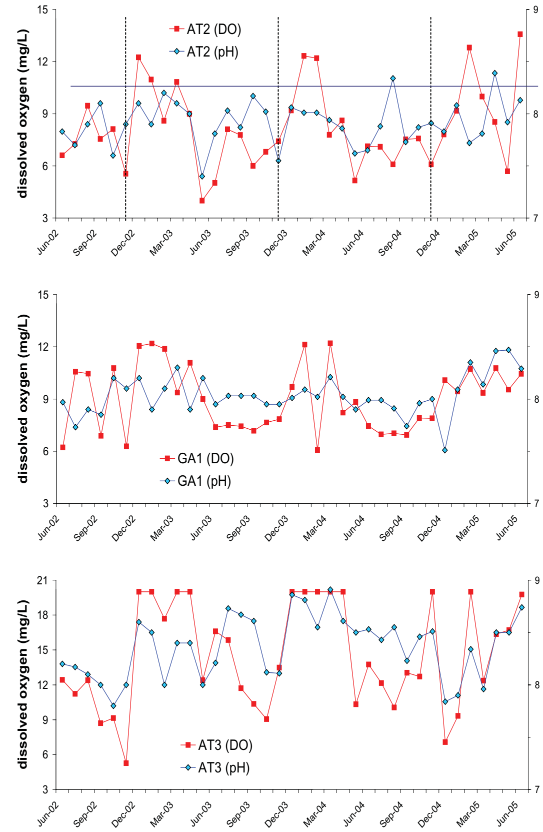


Figure 20. Dissolved oxygen and pH for three sampling locations, June 2002 to June 2005. Dashed vertical lines mark the start of each water-year. Ordinarily, pH should bare little resemblance to DO. However, significant algal growth causes similar patterns in both parameters as carbon dioxide removed from water by photosynthesis (decreasing acidity) is replaced by oxygen.

through April match high pH values (in Figure 16, most percent saturation values greater than 100% occur in late winter). The tendency towards increased pH due to early photosynthesis appears to balance the expected storm- and winter-flow related decrease, smoothing out the expected seasonal pattern; this is particularly noticeable in the 2003 and 2004 data. Interestingly, 2005 does show the expected pH pattern - heavy winter storms and higher flows reducing the amount of early photosynthetic activity.

Were Channelkeeper to sample the Goleta streams around the clock during the algal season, noticeable and similar variations in both pH and DO would be observed over a 24-hour period (Carlsen, 1994; Windell et al., 1987). Daylight to night-time changes would be appreciable at sites with severe algal problems, and relatively muted in locations with normal conditions. This kind of testing would be one of the better ways of estimating the extent of over-fertilization and algal growth on these streams. An example of this type of sampling, performed on the Ventura River, is shown in Figure 21. With the expectation that 2005 algal problems would be unusually severe, pre-dawn sampling of DO and pH at a number of Goleta Stream Team sampling locations was conducted on June 15 (Figure 22). At present, only AT3 exhibits appreciable degradation in water quality due to algae, even though algal growth is also heavy at other locations.

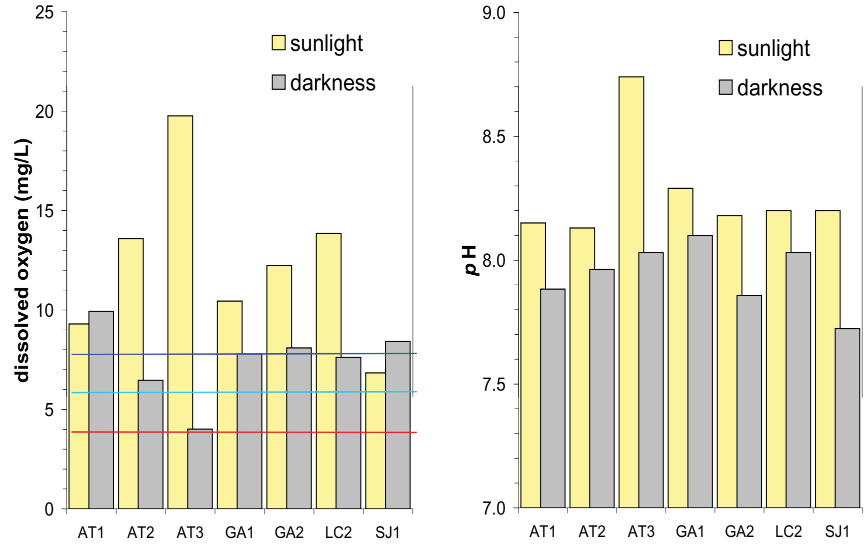


Figure 22. Sunlight vs. pre-dawn values of dissolved oxygen concentration and pH at selected Goleta sampling locations (values represent the mean of three measurements). Daylight values are from the regularly scheduled Stream Team monthly sampling between the hours of 9:30 AM - 12:00 PM on June 5, 2005; the pre-dawn measurements were collected between 5:00 - 6:00 AM on June 15, 2005. The three horizontal lines on the dissolved oxygen chart mark the steelhead milestones used previously: above 8 mg/L as near ideal, below 6 mg/L for the beginning of hypoxia and below 4 mg/L for severe damage leading to death. The two lines for pH indicate the Regional Water Quality Control Board's upper pH limits for aquatic life (7.0 to 8.5, cold or warm water habitat) and for water recreation (6.5 to 8.3, contact or non-contact; SWQCB-CC, 1994). On June 15, only AT3 exhibited severe water quality problems due to excessive algal growth: pre-dawn DO levels at the hypoxia border-line (range of 3.32 to 4.44 mg/L), daytime pH in excess of 8.5 (8.74) and a pH fluctuation greater than half a unit (0.71). Although three other sites also had excessive algal growth (AT1, AT2 and GA2), neither DO nor pH approached critical values.

Average results for all sampling sites, with maximum and minimum recorded values, are shown in Figure 23. Only at AT3 were values persistently above the 8.3 limit, but the other concrete channel locations, LC1 and SJ1, also showed episodes of high pH. Although all these canal sites, with warm, trickling waters and plenty of sunlight, are ideal for algal growth, it is possible that some of the increase in alkalinity may be due to dissolution of cement from the channel bottom. Only a complete analysis of the major ions in creek water at and above the sampling points would allow us to determine the viability and extent of this possibility.

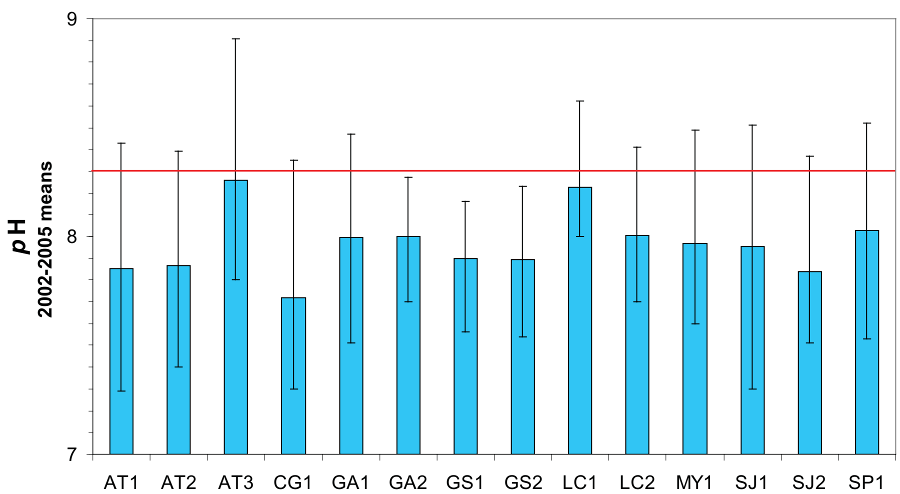


Figure 23. Average pH values, June 2002 to June 2005. The "error bars" indicate the highest and lowest values measured at each sampling location. The vertical line represents the Central Coast Regional Water Quality Control Board's upper pH limit (8.3 for warm or cold water habitat; from the Basin Plan). Average pH is equivalent to the mean hydrogen ion concentration.

Turbidity

Turbidity is a measure of the amount of sediment in the water column, and sediment has 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 stream-bed gravel and rocks, 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 to see and feed. Water quality begins to be degraded by suspended sediment somewhere between turbidities of 3 - 5 NTU (Nephelometric Turbidity Units), and with turbidity above 25 NTU, impacts on steelhead and trout begin to be noticeable. These limits should be considered applicable only to the dry season and periods between storms. During storms in the Santa Barbara/Goleta area, limits become meaningless as local suspended sediment concentrations reach tens of thousands of milligrams per liter – turbidity readings in the hundreds of thousands if turbidity meters were capable of measurements in these conditions. Fortunately, on the Goleta Creeks, turbidities rapidly drop soon after the end of rainfall, and return to near-background levels within three to five days of a storm. However, in the slough itself, more of a problem exists; the Slough is listed as an impaired waterbody on the State's 303(d) List of Water Quality Limited Segments and one of the pollutants of concern identified is sediment.

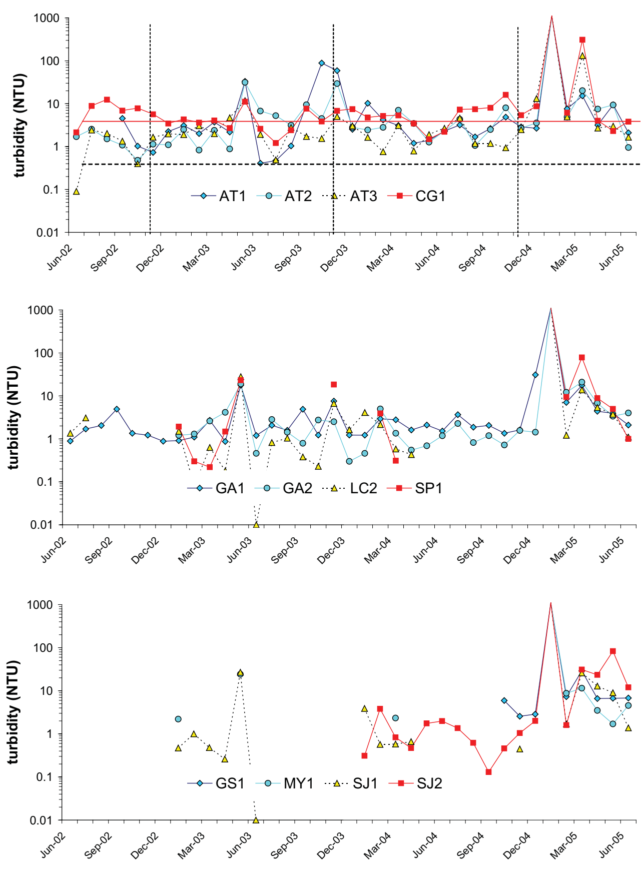


Figure 24. Turbidity, June 2002 to June 2005. Dashed vertical lines mark the start of each water-year. The two horizontal lines mark Public Health drinking water quality benchmarks: a maximum turbidity of 5 NTU, and no more than 5% of monthly samples with greater than 0.5 NTU. The off-scale points are turbidities > 1,100 NTU, greater than the turbidity meter's maximum reading.

Turbidity results are shown in Figure 24. Normally, readings are below 5 NTU (CG1 is an unusual exception because bacteriological films often cover the water in this reach), but if sampling is done during or soon after a storm, they reach into the hundreds and often far higher – above the ability of optical meters to record a value. Almost all of the very high values in Figure 24 occurred during these times. The maximum turbidity reading on Channelkeeper meters is 1,100 NTU and off-scale readings during storms were simply assigned this number.

Turbidity values have increased appreciably since January 2005. This is due in part to an increased number of regularly scheduled sampling days that have happened to coincide with storms or higher turbidity after-storm flows. However, increased flows (greater depths and velocities) during the late winter and spring of 2005 also generated higher sediment loadings. For the most part, the May and June 2005 measurements have shown a return to lower, more normal, turbidity values.

The horizontal lines on the turbidity figures represent typical Public Health drinking water limits: less than 5 NTU with no more that 5% of samples exceeding 0.5 NTU (EPA, 2005; CSB-PW 2004). As long as it's not raining, water in the Goleta tributaries often meets these standards. Results are summarized in Figure 25; this figure also shows a line for a third typical standard: no higher than 1 NTU for 8 hours.

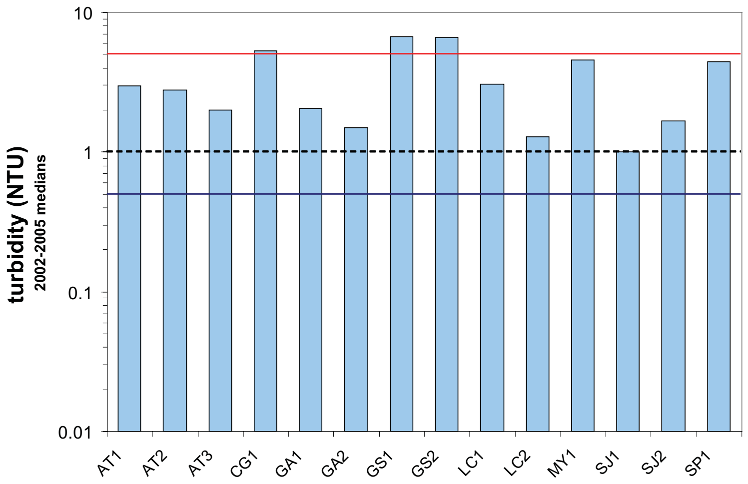


Figure 25. Median turbidity values, June 2001 to June 2005. The three horizontal lines mark typical Public Health drinking water quality benchmarks: a maximum turbidity of 5 NTU; no higher than 1 NTU for 8 hours; and no more than 5% of monthly samples with greater than 0.5 NTU.

Figure 25 shows median turbidity concentrations. As with conductivity, the median is a better indicator of "average" conditions than the mean when a dataset is complicated by a few extraordinarily high readings such as we see during storms. The EPA has suggested a turbidity limit of 1.9 NTU for streams in this region. The median values for upper Glen Annie (GA2), San Jose (SJ1 and SJ2) and Los Carneros (LC2) creeks meet this criterion. If storm-affected values are eliminated from the calculated medians, AT3, GA1 and SP1 also have turbidities below this standard. There are several reasons why some locations persistently have turbidities greater than 2 NTU: intense biological activity with planktonic algae and bacterial films above sites AT1, AT2 and CG1; similar productivity combined with tidal movements on the mud flats of the slough at GS1 and GS2; and the increased sediment concentrations of storm-related winter flows at sites that are usually dry at other times (LC1 and MY1).

Nutrients

Phosphorus and nitrogen are essential nutrients for aquatic plants and animals. Nitrogen is used for protein synthesis, and phosphorus for energy transformation in cells. However, in excess amounts they cause severe problems (Sterner, 2002).

Phosphorus is the nutrient in short supply in most fresh waters, and even modest increases in phosphorus can, under certain conditions, set off a whole chain of undesirable events including accelerated plant growth, algal blooms, low dissolved oxygen, and the death of oxygen-dependent aquatic life. This nutrient over-fertilization is called eutrophication (Carpenter et al., 1998; Smith et al., 1999).

Phosphorus in the Goleta creeks can come naturally from soil and rocks, decaying plants and animal waste, or unnaturally from runoff from pastures, fertilized lawns and cropland. Wastewater treatment plants and failing septic systems are other sources, as are disturbed land areas and drained wetlands. Phosphorus, both as phosphate and in organic molecules, can be found in solution or attached to suspended particles within the water column.

One possible source of phosphorus is animal waste from pastures and other horse facilities. This facility, like many others, is immediately adjacent to Atascadero Creek (indicated in this photo by the line of trees bordering the rear fence).

Nitrogen moves with water as dissolved inorganic nitrogen (nitrate, nitrite and ammonium) and as dissolved or suspended organic nitrogen (complex molecules associated with living, or once living, tissue). Nitrates are the most common form of nitrogen found in tributaries to the Goleta Slough. Together with phosphorus, nitrogen in excessive amounts can also cause eutrophication. In addition, nitrate may also cause cancer and can be toxic to warm-blooded animals, particularly babies, at higher concentrations (greater than 10 mg/L; EPA, 2005). Nitrate sources 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 Goleta streams, comprising approximately 85% of the total dissolved nitrogen in creek samples (ammonium contributes less than half a percent and organic forms make up the rest). Although nitrogen is vital for life and growth, there is a nearly universal Public Health limit of 10 mg-N/L (10 milligrams of nitrogen per liter).

However, 10 mg/L is far too much nitrate in terms of eutrophication and stream health. The EPA has suggested standards for various eco-regions in the United States, and the goal for Ecoregion III, the xeric (dry) west, in which Santa Barbara and Goleta are located, is less than 0.38 mg/L of total nitrogen (US-EPA, 2000). Note that this is less than 4% of the Public Health nitrate limit (e.g., RWQCB-CC, 1994). Ecoregion III has been further divided by the EPA into sub-regions, and the sub-region in which Santa Barbara and Goleta lie (Sub-region 6) may end up with a slightly higher 0.52 mg/L limit. Sub-region 6 also has a suggested nitrate limit of 0.16 mg/L. To simplify, only the 0.16 mg/L suggested nitrate limit is shown on the charts.

As it turns out, a fine line is not necessary to determine which sampling locations have unhealthy amounts of nitrogen: almost all sites show excessive nitrate during at least some part of the year (Figure 26). The situation on Glen Annie is particularly egregious, with samples almost always exceeding the 10 mg/L Public Health limit for nitrate. There appear to be two different seasonal trends in the data: (1) a slow rise during the winter to peak values at the end of the rainy season, followed by a slow decrease throughout the growing season (AT1 and AT3, upper panel); and (2) lower winter values followed by rising concentrations through the growing season (GA2 and LC2, middle panel).

These two patterns are caused by the two different types of source waters entering these creeks, and differences in relative amounts of flow. The first pattern, characteristic of urban runoff and very low summer flows, is produced by increasing amounts of high nitrate soil and groundwaters entering the stream as the rainy season progresses; levels then gradually decline as plants, algae and bacteria remove nutrients throughout the subsequent growing season. Low flows enhance this effect.

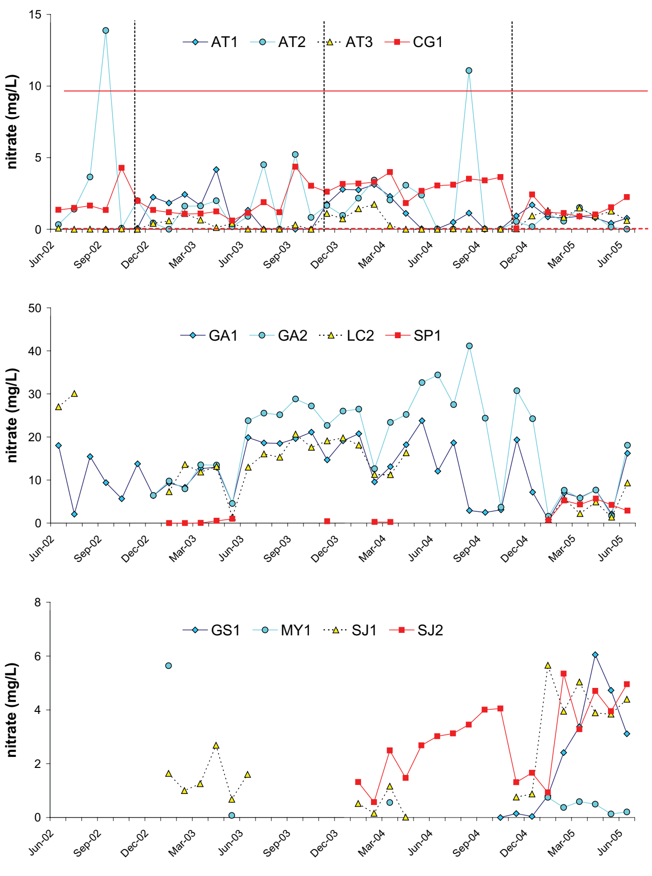


Figure 26. Nitrate concentrations, June 2002 to June 2005. Dashed vertical lines mark the start of each water-year. The horizontal lines mark the EPA's proposed limit for maximum nitrate in this region, 0.16 mg/L (dashed), and the Public Health limit of 10 mg/L (solid). Note that the graphs use different vertical scales.

The second pattern is caused by agricultural runoff, which is high in nitrate. Very high baseflow nitrate concentrations are diluted by winter storm runoff and groundwater inflows. Then, as natural stream flows decrease during the growing season and irrigation wastewaters become the major source of flow, nitrate concentrations rise. Flow in these streams is usually higher than in urban drainages, and the total amount of nitrate remains excessive. This "agricultural" pattern can also be seen in urban areas: golf courses and parks are fertilized and irrigated as much as, and perhaps more than, farm fields and orchards (Schueler, 2000). The Glen Annie Golf Club likely contributes heavily to nitrate at GA2, as does the Hidden Oaks Country Club Golf Course to AT2. CG1 also appears to have an agricultural pattern, caused by the watering of lawns, playing fields and horse corrals adjacent to the creek above this location.

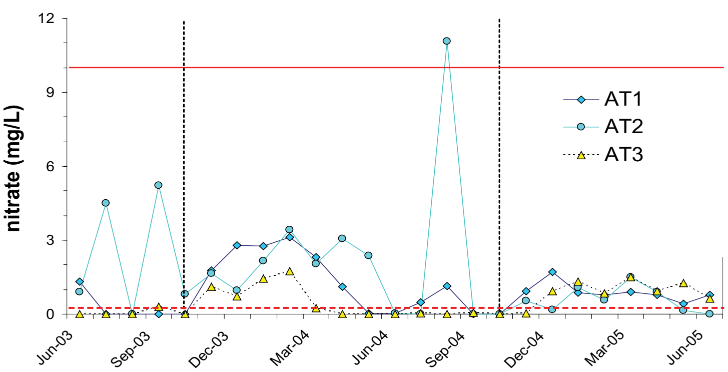


Figure 27. Nitrate concentrations on Atascadero Creek from June 2003 to June 2004. The vertical lines mark the beginning of the water-year. Atascadero provides an interesting look what happens with nitrate over the course of a year. AT3 (Puente Dr.) represents the normal and expected variation in nitrate: a slow rise during the winter to peak values at the end of the rainy season (caused by an increasing amounts of high nitrate soil and groundwaters entering the river as the rainy season progresses), followed by a slow decrease (as plants and algae remove nutrients) throughout the growing season.

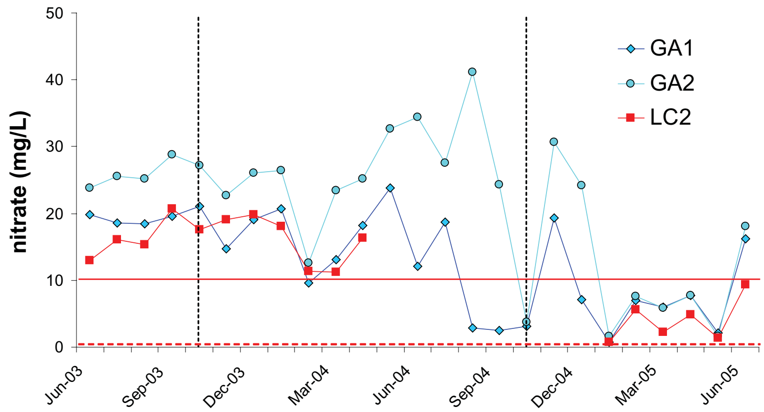
Notice that concentrations increased with downstream flow in 2004, and that higher concentrations continued later into the summer: from AT3 (at Puente Ave.) to AT2 (at Patterson Ave.), and then to AT1 at the tidal limit. This is highly unusual and indicates that additional nitrate was coming into the creek below AT3. Typically, as water flows downstream, nutrients are removed by biological activity (uptake by plants, algae and bacteria). Just upstream of AT3 are a number of horse corrals, and there is a golf course between AT3 and AT2. The horse corrals are probably responsible for the pulses of high nitrate seen at AT2, while golf course runoff from watering greens contributes higher overall nitrate. The rock and concrete weir at the tidal limit (AT1) turns the creek above this point into a long, linear lake extending up to Patterson. Nitrate probably leaks into this section from plant nurseries on the bluff above, but biological uptake in this section reduced nitrate concentrations to near zero in mid-summer. After the heavy rains of 2005, this pattern is not as evident. Heavy flushing during storms may have reduced overall concentrations and numerous late-season storms may have delayed algal growth, delaying the nitrate reduction usually seen in late spring.

High nitrate levels in Glen Annie Creek (center of photo) can be partially attributed to Glen Annie Golf Club (foreground) and irrigated orchards (background). This photo was taken just upstream of Goleta Stream Team's GA2 sampling site.

The significant difference between concentration and amount must be highlighted: concentrations indicate relative abundance, they do not provide a measure of the total amount of available nitrate or phosphate. Often the amount is far more important. The amount (also called flux or export) is the product of both concentration and flow: high concentrations provide little nitrate if flows are very low. When the amount is small, as it is in sections of Atascadero during the summer, biological uptake can quickly reduce nitrate concentrations to near-zero.

The Atascadero system, with the longest continuous reach of year-round water and the greatest number of Stream Team sampling locations, is particularly interesting. Its nitrate variations are described, in some detail, in Figure 27. Similarly, variations in the excessive nitrate concentrations of Glen Annie and Los Carneros creeks are addressed in Figure 28. The mean nitrate concentrations found at each sampling site are summarized in Figure 29 (upper panel).

Figure 28. Nitrate concentrations on Glen Annie and Los Carneros creeks from June 2003 to June 2005. The vertical lines mark the beginning of the water-year. These streams, with high nitrate from agricultural irrigation and Glen Annie Golf Course runoff, provide a contrasting picture to Atascadero Creek.



The Public Health maximum of 10 mg/L is almost always exceeded and there is little biological uptake of nitrate in the summer because the streams see little direct sunlight, being well shaded by riparian vegetation (which limits the growth of plants and algae). Between GA2 (at Cathedral Oaks) and GA1 (Hollister Ave.) there is a steady decrease in nitrate from biological activity (algae and aquatic plants may be limited by poor light, but bacteria are not), indicating that very little new nitrate enters the creek in this section.

Notice that concentrations at GA2 are at their highest just before the beginning of winter rains, and that concentrations decrease in winter. Simply put, winter rains increase concentrations in creeks with low nitrate (like Atascadero), but decrease concentrations where nitrate is high. These are very high nitrate concentrations. Only in Franklin Creek in Carpinteria, which receives high concentrations from greenhouse runoff, do we see higher nitrate.

In 2005, the late-winter decrease has lasted longer due to sustained, lower nitrate runoff from upper parts of the watershed. However, by June 2005, the normal pattern of high agricultural concentrations is being re-established.

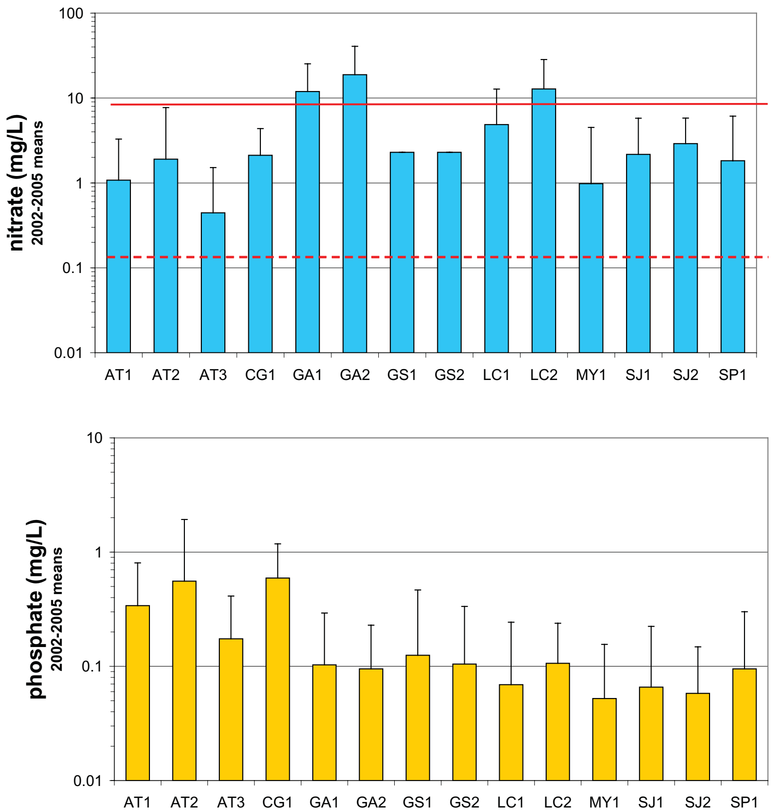


Figure 29. Upper panel: Average nitrate concentrations, June 2002 to June 2005. The horizontal line mark marks the EPA's proposed limit for maximum nitrate in this region: 0.16 mg/L. Lower panel: Average phosphate concentrations, June 2002 to June 2005. The horizontal line marks the EPA's proposed limit for maximum phosphorus in this region: 0.030 mg/L. Phosphate typically makes up more than 90% of the total phosphorus in the stream. The "error bars" represent twice the standard deviation of the samples at each site – 95% of the measured values will typically be below this limit.

Phosphate

As with nitrate, the question arises: how much phosphorus is too much phosphorus? The EPA has recommended maximum levels of phosphorus concentration for streams in this region (Ecoregion III): an overall recommendation of 0.022 mg/L, and 0.030 mg/L for Sub-region 6 (US-EPA, 2000). In this report, the 0.030 mg/L benchmark is used. All the streams in the region have high phosphate concentrations because phosphorus content is high in the marine deposits that make up a large part of the underlying geologic strata (Dillon, 1975; Grobler and Silberbauer, 1985; Schlesinger,1997); this is partially accounted for in the higher EPA limit for Sub-region 6.

Figure 29 (lower panel) summarizes the Goleta Stream Team results, showing average phosphate concentrations at each location. All sites have mean phosphate concentrations above the 0.030 mg/L phosphorus limit. The Atascadero locations have noticeably higher phosphate concentrations than were found in the other creeks. Note that Figure 29 underestimates the true phosphorus situation – phosphate is only part of the total phosphorus concentration in Goleta creeks, while organic phosphorus makes up the remainder. On average, phosphate contributed approximately 90% of the total phosphorus in Channelkeeper's samples.

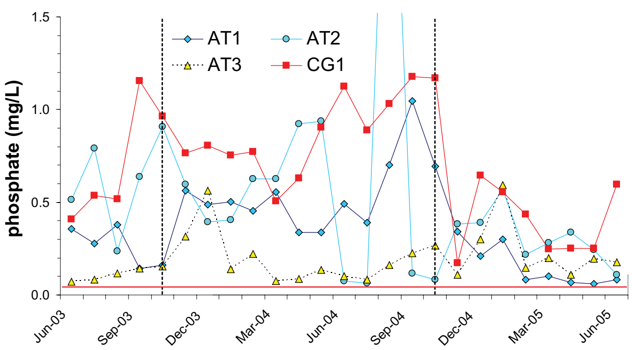


Figure 30. Phosphate concentrations in the Atascadero drainage from June 2003 to June 2005. The vertical lines mark the beginning of the water-year. There appears to be little recognizable pattern to phosphate concentrations. On occasion there is an increase in phosphate around the time of storms (as in December 2003 at AT3, or during the big January 2005 storm), but generally, concentrations are relatively consistent. These concentrations are, however, extraordinarily high. On average, about 5 to10 times higher than in Glen Annie and Los Carneros creeks, and about 200 to 300 times the recommended EPA maximum for stream in this region (0.030 mg/L, the solid horizontal line). This is the opposite of the situation with nitrate (where concentrations are very much higher in Glen Annie and Los Carneros creeks due to agricultural runoff). There are a number of possible phosphate sources along Atascadero. Homeowners are usually far more wasteful of fertilizer than ranchers, and may perhaps be using mixtures high in phosphorus. Animal waste from horse ranches along the creek, and neighborhood dogs may also add to the problem. Notice phosphate concentrations at CG1 and AT2, immediately below horse corrals, are considerably higher than at AT3 or AT1 further downstream. Corrals just above AT2 are also the probable cause of episodically high concentrations at this location. Phosphate usually decreases downstream of the CG1 and AT2 "hot spots" as plants, algae, bacteria and chemical transformations reduce concentrations. Extensive flushing from the many large storms of 2005 are the probable reason for lower concentrations this past winter compared with 2004.

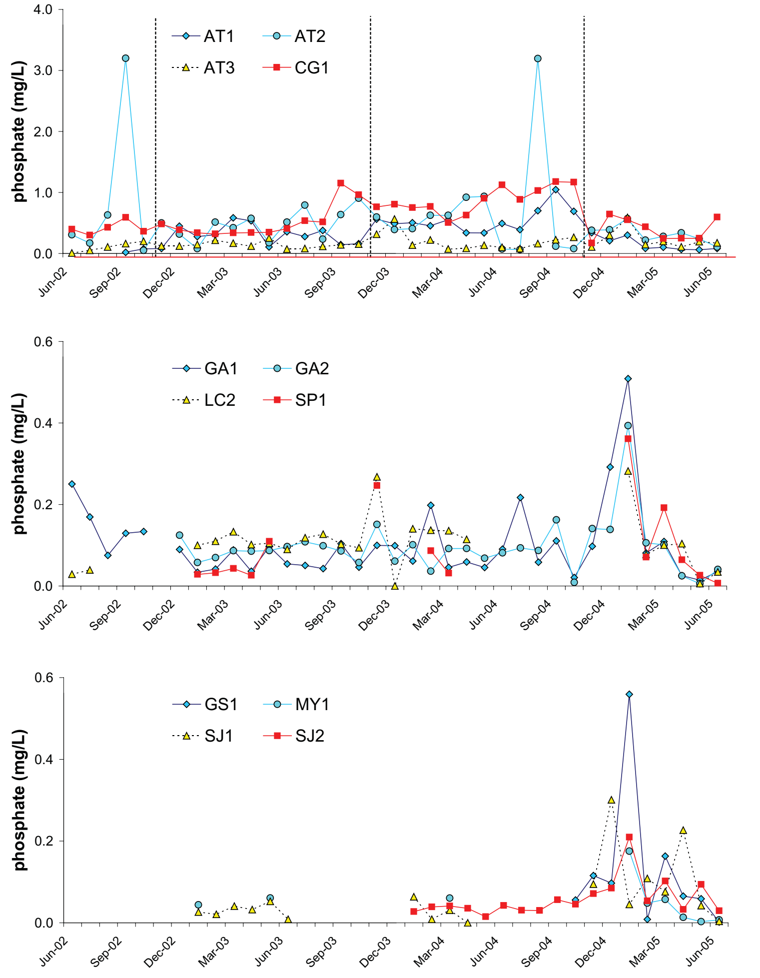


Figure 31. Phosphate concentrations, June 2002 to June 2005. Dashed vertical lines mark the start of each water-year. The horizontal line marks the EPA proposed target for maximum phosphorus in this region: 0.030 mg/L. The graphs show phosphate, which typically makes up more than 80% of the total phosphorus in the stream. Note that the graphs use different vertical scales.

Patterns of phosphate variation in the Atascadero drainage, paralleling the nitrate discussion, are addressed in Figure 30. The amount of phosphate observed at these locations is extraordinary. At the Glen Annie and Los Carneros sampling sites there is a noticeable association between increased phosphate and the beginning of the rainy season (e.g., November 2003, Figure 31). Initial storms mobilize much of the phosphate accumulated on impervious surfaces and in

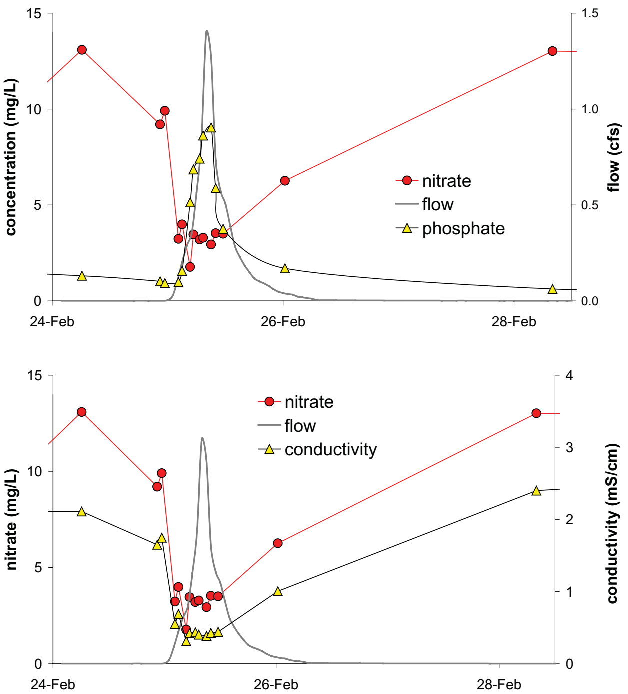


Figure 32. The biggest storm of 2004 occurred on February 25. Peak flow was almost 1,000 cubic feet per second (cfs) on Glen Annie Creek at Hollister Avenue (GA1); flow is usually less than 1 cfs when Channelkeeper samples this creek. UCSB sampled nutrients during the storm and measured conductivity on the collected samples. The upper panel shows the variation in nitrate and phosphate; a pictorial representation of the storm hydrograph (the variation in flow during the storm) is shown in the background. Note that nitrate decreased while phosphate increased. This is typical: storm runoff dilutes high background concentrations of nitrate while the movement of sediment containing phosphorus into the stream increases phosphate concentrations. The lower panel shows how conductivity mimics the changes in nitrate. Rain has very low conductivity and very low nitrate concentrations, compared with Glen Annie baseflow. The dilution of normal creek water by rainfall and rapid runoff has the same impact on both.

riparian areas over the dry season and transport it to streams (Hager, 2001; MBCWMN, 2002). Early storms also move large amounts of sediment and accumulated debris in what were initially dry or near-stagnant creeks, which also increases phosphate concentrations. The effects of these storms usually remain evident for days afterwards, which is why these increases are seen in the data.

Typically, during the remainder of the winter high phosphate concentrations are only seen during actual storms. Using GA1 as an example, Figure 32 shows what typically happens with concentrations during a storm: phosphate tends to increase, while nitrate decreases (UCSB-LTER). High phosphate is associated with high sediment load during storms. The width and condition of streamside buffer areas, the extent of stream bank armoring and the proximity of un-vegetated, easily erodable soil to the channel or storm drain inlet, as well as the intensity of rainfall, determine how much sediment ends up in the creek, and by how much phosphate concentrations increase.

Large storms typically generate the highest phosphate concentrations observed. This can be seen in concentrations measured on January 9, 2005 (Figure 31). Note that while phosphate measured during this storm in creeks with large and steep catchment areas, agricultural land uses and relatively natural channels creates prominent peaks in Figure 31 (middle and lower panels, e.g., GA1, GA2, LC2 and MY1), concentrations in the Atascadero drainage appear to decrease. Background phosphate concentrations at these sampling locations are so high that stormflow, in spite of increased sediment loading, actually causes a decrease.

Combining Nitrate and Phosphate[12]

Living organisms require both nitrogen (N) and phosphorus (P), therefore it is necessary to consider both nutrients in combination. Absent either nitrogen or phosphorus, a plant or alga needing both could not grow and would begin to die. Oceanic plankton need N and P in a ratio of 16 atoms of nitrogen to one atom of phosphorus.[13] For freshwater organisms, the average ratio is closer to 30:1 (Nordin, 1985; Sterner and Elser, 2002). A stream with a 30:1 N:P ratio contains a balanced amount of both. A ratio of less than 30:1 means that some of the phosphorus goes unused; this case is called “N-limited.” At ratios greater than 30:1, nitrogen is under-utilized, or “P-limited.” 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. Some aquatic plants and algae do not get nitrogen from the water, but have the ability to “fix” nitrogen from the air, or in other words, convert nitrogen gas into ammonia, and then use ammonium for cell metabolism. Ammonium is an important source of nitrogen, normally found only in low concentrations in Goleta streams (typically less than one percent of the nitrate concentration, Table 3). These organisms literally carry their own nitrogen supply, since attached symbiotic bacteria do the heavy lifting. This is a relatively rare ability, and these plants and algae are normally not very competitive in aquatic environments where dissolved nitrogen is abundant. However, when nitrogen becomes limited, these nitrogen-fixing organisms flourish. 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. Figure 33 shows a temporal comparison between nitrate and dissolved organic nitrogen for three sites exemplifying the range of Goleta conditions.

The Goleta Stream Team sampling locations provide examples of both N-limitation and P-limitation. The Atascadero drainage is nitrogen-limited, as illustrated in Figure 34 for AT3, AT2 and CG1. When the nitrate and phosphate concentrations in Figure 34 are close together, the nutrients are roughly in balance; when they are apart, one nutrient is in limited supply, and the nutrient in the lower position is limiting. In the Atascadero drainage, nitrate is always the nutrient in short supply. AT3 provides the best example, as nitrate concentrations at this location often decrease to zero during the growing season (Figures 26 and 27).[14]

Glen Annie is almost always P-limited; given the high nitrate concentrations in agricultural runoff, phosphate is the nutrient in short supply. Other creeks with significant agricultural input are also P-limited (Figure 35). Three phosphorus-limited locations are shown in Figure 36.[15] When nitrate appears above phosphate, the stream is phosphate-limited.

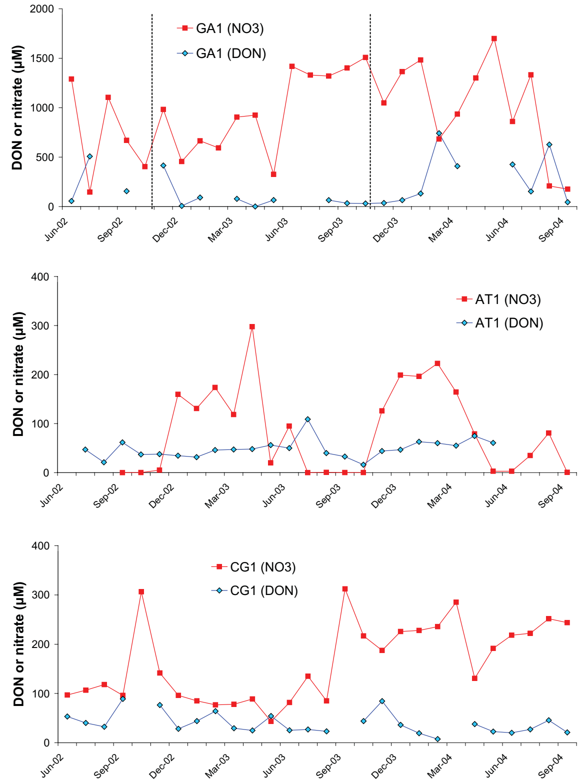


Figure 33. Dissolved organic nitrogen (DON) and nitrate concentrations, June 2002 to September 2004. Dashed vertical lines mark the start of each water-year. When nitrate concentrations are high (GA1 and CG1), DON is typically a small percentage of the total nitrogen in a stream. When nitrate is near zero (late summer at AT1), nitrogen is usually recycled as DON. Relatively pristine streams also have most of their available nitrogen in the form of DON.

It is important to consider flow in the discussion of nutrients. During the decreased flows observed in 2004, N-limitation began earlier and was more severe. Under these conditions, the supply of nitrogen becomes severely limited (to reiterate, 30 times more nitrogen than phosphorus is typically needed) and nitrate concentrations often decrease to zero in summer and early fall (Figure 34, middle panel). At these times, N-fixing plants and algae

Table 3. *Median concentrations (±S.E. of the median) for nutrient species at the Goleta Stream Team sampling sites, June 2002 through September 2004. GS1 and GS2 have been omitted since no total dissolved nitrogen (TDN) or phosphorus (TDP) samples have as yet been analyzed. All concentrations are in micro-moles per liter (µM). DON and DOP are abbreviations for dissolved organic nitrogen and dissolved organic phosphorus, respectively.*

	uM	uM	uM	uM	uM	uM	uM
site	NH4	NO3	PO4	DON	DOP	TDN	TDP
AT1	1.3±0.6	79.8±22.8	12.4±1.8	47.1±5.0	1.5±0.5	143.0±22.2	13.4±2.0
AT2	0.8±0.6	117.3±43.8	17.6±5.1	40.6±4.6	0.8±0.4	166.1±37.6	16.4±2.7
AT3	0.4±0.1	3.1±8.2	4.4±0.8	32.3±12.3	1.2±0.9	40.5±16.8	4.6±1.0
CG1	1.9±1.1	138.2±18.8	17.0±2.2	32.5±5.3	1.4±0.6	187.1±15.8	18.7±1.9
GA1	0.9±0.4	958.8±102.3	2.9±0.6	72.1±53.5	1.1±0.2	1287±95.7	2.5±0.6
GA2	0.5±0.8	1740.7±186.5	2.8±0.2	66.6±119.0	0.8±0.5	1853.1±168.3	3.3±0.5
LC1	0.9±0.6	408.6±122.3	0.9±0.5	52.3±11.4	1.0±0.4	478.1±122.4	1.7±0.6
LC2	0.2±0.2	1119.7±139.4	3.5±0.5	54.8±64.3	1.0±0.3	1200.9±140.1	3.7±0.6
SJ1	0.0±0.3	77.2±22.4	0.9±0.3	12.4±5.6	0.5±1.1	87.1±20.4	1.3±0.6
SJ2	0.5±0.4	191.5±33.3	1.2±0.2	15.8±7.1	1.8±0.4	208±38.6	1.1±0.6
SP1	0.1±1.1	18.3±9.9	1.1±1.0	23.9±8.3	0.7±0.2	31.8±16.2	1.8±1.1

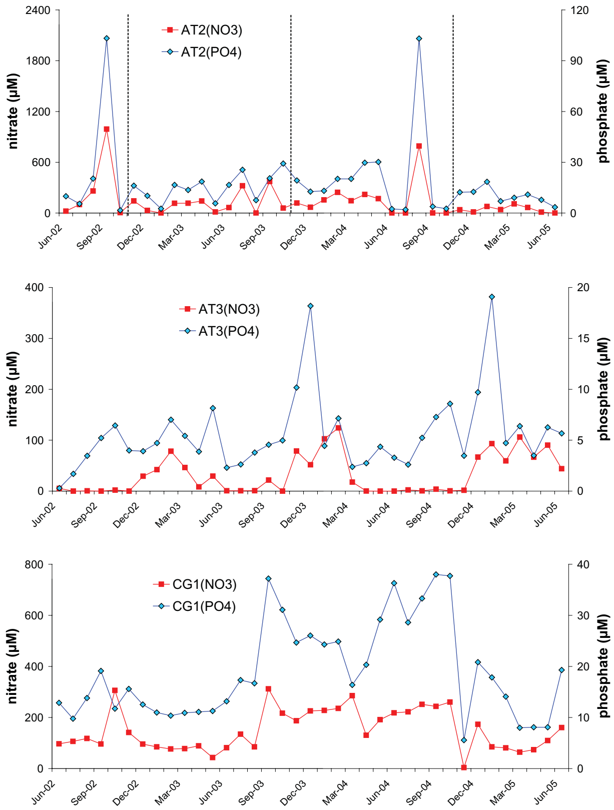


Figure 34. Nitrate and phosphate for three Atascadero Creek locations, June 2002 to June 2005. Dashed vertical lines mark the start of each water-year. Concentrations are given in micro-moles/L (µM) and the nitrate scale is 20 times the magnitude of the phosphate scale. This is the approximate uptake ratio of terrestrial aquatic organisms, and the nutrient that appears in the lower position on the graph is "limited," e.g., living organisms in the stream are more likely to run out of nitrogen than out of phosphorus. Sites with a lot of algae (e.g., AT3) often do. Urban stream are typically phosphorus-limited.

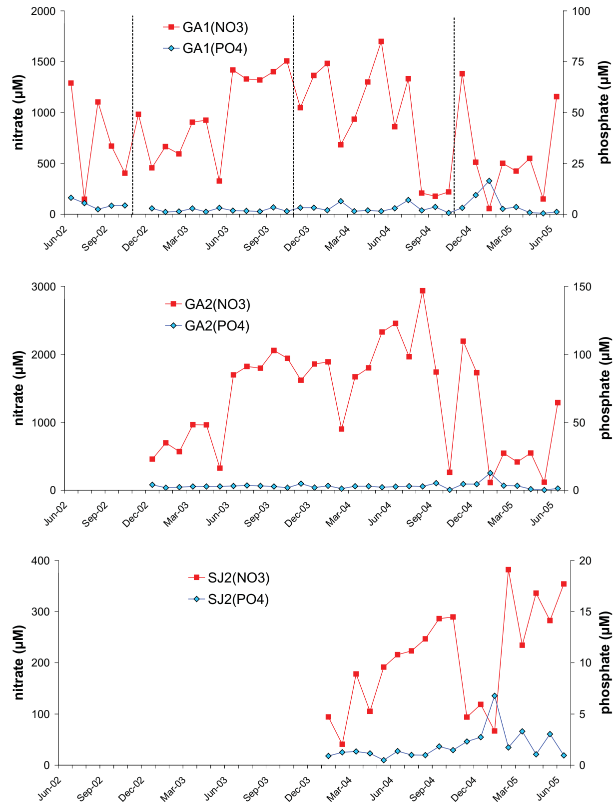


Figure 36. Nitrate and phosphate for three agricultural locations (Glen Annie and San Jose creeks), June 2002 to June 2005. Dashed vertical lines mark the start of each water-year. Concentrations are given in micro-moles/L (µM) and the nitrate scale is 20-times the magnitude of the phosphate scale, approximately the uptake ratio of terrestrial aquatic organisms. The limiting nutrient" is the one in the lower position on the graph. Glen Annie and most agricultural streams are "phosphorus limited," e.g., living organisms are more likely to run out of phosphorus than out of nitrogen. These sampling locations usually don't, because shade limits algal and plant growth.

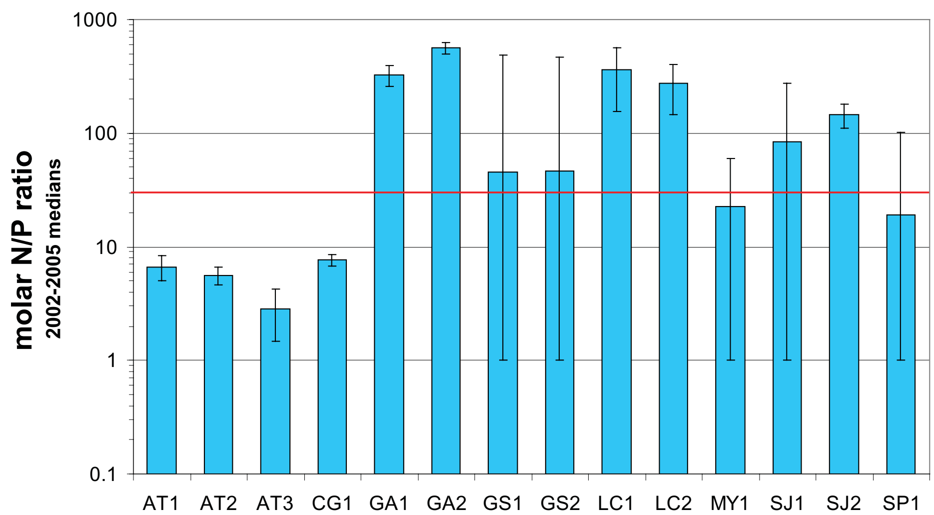


Figure 35. Median nitrate to phosphate ratios for the Goleta Stream Team sampling sites: June 2002 to June 2005. Error bars indicate the standard error of the median. Life requires both nitrogen and phosphorus, but in different amounts. Plankton, on which the oceanic food chain is based, use nitrogen 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 indicated by the red horizontal line 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% of the total nitrogen and phosphate 90% of the total phosphate). The Goleta streams divide into two very distinct classes: (1) urban streams where the ratio is below 30:1, and (2) agricultural streams with ratios far above 30:1. The urban streams (Atascadero, San Pedro) are "nitrogen limited," meaning that while phosphorus is plentiful, nitrogen is often exhausted. The agricultural creeks (Glen Annie, Los Carneros and San Jose, streams that collect agricultural runoff from areas above the sampling points) are "phosphorus limited"; more than sufficient nitrogen but phosphorus is typically in short supply. This has implications for the Goleta Slough. Limited samples from the slough (taken from the bicycle bridge to Goleta Beach) indicate a rapidly changing and abrupt environment (note the extreme GS1 and GS2 standard errors) that will be discussed in detail later.

become dominant and can dramatically change what is observed in the creeks. Possible impacts of these changes on the food chain remain unexamined.

The export of nutrients from the mouth of the Goleta Slough to the Santa Barbara Channel is probably of little importance. The mixing of relatively small volumes of creek water with the vast amounts of saltwater circulating in the channel likely precludes a meaningful impact from terrestrial nutrients.16 However, variations in nutrient export undoubtedly have noticeable and severe effects on the Goleta Slough itself. These variations and the changes observed during the Goleta Stream Team sampling program are discussed in the Goleta Slough Results section.

Bacteria[17]

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 (disease-causing) bacteria, viruses, and protozoans that also live in human and animal digestive systems. Their presence in streams indicates that pathogenic micro-organisms might also be present, and that swimming and eating shellfish therein might pose a health risk. Since it is difficult, time-consuming, and expensive to test directly for the presence of a large variety of pathogens, water is usually tested for coliforms and fecal streptococci instead. Typically, a single sample is collected from each location (along with occasional duplicates for quality control), brought back to the Channelkeeper lab, and analyzed within six hours for three types of indicator bacteria: total coliform, E. Coli and enterococci.

Total Coliform

Total coliforms are a large and widespread group of bacteria. Coliforms can occur in human feces but are also found in animal manure, soil, vegetation, submerged wood, and in other places outside the human body. Therefore, the usefulness of total coliforms as an indicator of fecal contamination depends on the extent to which the bacteria found are fecal and human in origin. For recreational waters, total coliforms are no longer recommended by the EPA as an indicator, but they are still the standard test for drinking water because their presence indicates contamination of a water supply by some outside source. California still requires a total coliform test for recreational waters because the ratio of fecal to total coliforms (number of fecal coliforms divided by the total number of coliforms) remains a good indicator for swimming-related illnesses.

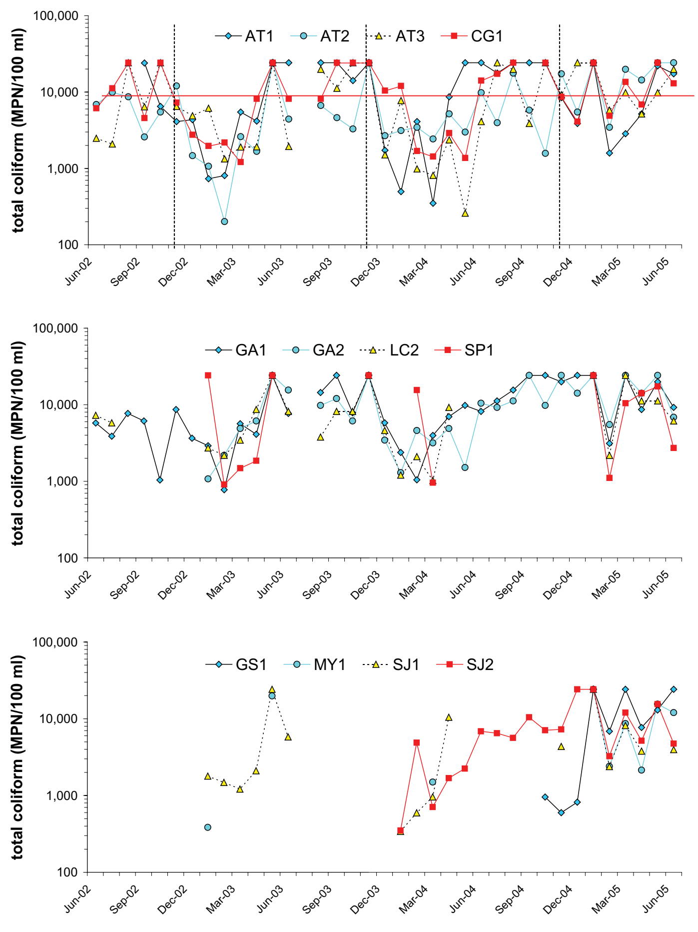


Figure 37. Total coliform concentrations, June 2002 to June 2005. Dashed vertical lines mark the start of each water-year. The horizontal line marks the Public Health single sample freshwater-beach limit of 10,000 MPN/100 ml. The dilution typically used during the test procedure cannot determine concentrations above 24,192 MPN/100 ml and concentrations greater than 24,192 have been assigned this number (note the "flat" top to data in the upper panel).

E. coli

E. coli is a species of fecal coliform bacteria that is specific to fecal material from humans and other warm-blooded animals. EPA recommends E. coli as the best indicator of health risk from water contact in freshwater; California regulations still require the broader fecal coliform test.

Enterococcus

Enterococci are a more human-specific subgroup of fecal streptococci bacteria. Enterococci are distinguished by their ability to survive in salt water, and in this respect they mimic many pathogens more closely than the other indicators. The EPA recommends enterococci as the best indicator of health risk in saltwater used for recreation, and as a useful indicator in freshwater as well.

Bacteria levels are reported as the most probable number (MPN) of bacteria in 100 milliliters (100 ml, about 4 ounces) of water; Channelkeeper uses a statistical test instead of directly counting bacteria, so the actual reported number remains a statistical estimate. There are two California Public Health standards for each test: a single sample limit and a limit for an average of five or more samples collected over a period of either five weeks or a month (called the "geomean").[18]

Figures 37, 38 and 39 show the monthly variation in total coliform, E. coli and enterococci, respectively. Concentrations dramatically increase during storms and remain elevated for three to four days afterwards. This is most easily seen in the data for May and November 2003, and January 2005, when sampling occurred during storm events. The most obvious pattern seen is for total coliform (Figure 37), but also seems to hold for the other two indicators. Concentrations increase from a minimum in May or June, reaching a maximum at or soon after the start of winter rains, sometime between

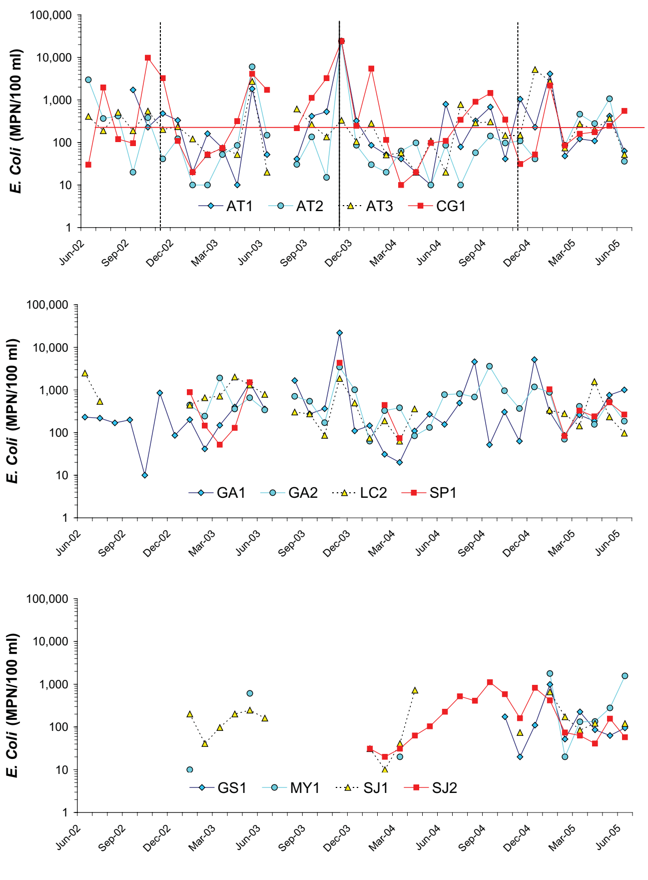


Figure 38. E. Coli concentrations, June 2002 to June 2005. Dashed vertical lines mark the start of each water-year. The horizontal line marks the Public Health single sample freshwater-beach limit of 235 MPN/100 ml. The dilution typically used during the test procedure cannot determine concentrations above 24,192 MPN/100 ml and concentrations greater than 24,192 have been assigned this number (during stormflow in November 2003).

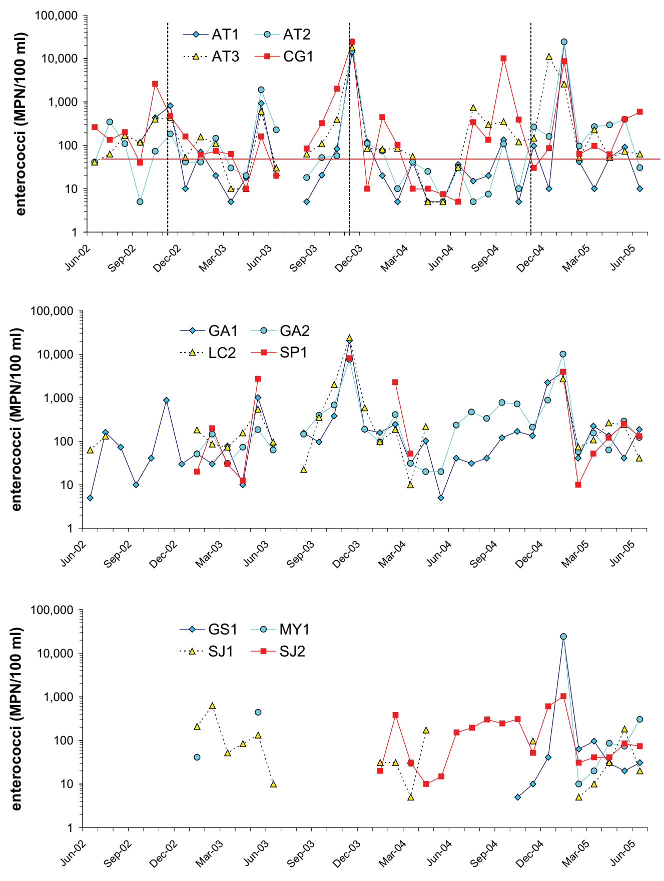


Figure 39. Enterococci concentrations, June 2002 to June 2005. Dashed vertical lines mark the start of each water-year. The horizontal line marks the Public Health single sample freshwater-beach limit of 61 MPN/100 ml. The dilution typically used during the test procedure cannot determine concentrations above 24,192 MPN/100 ml and concentrations greater than 24,192 have been assigned this number (during stormflow on November 2003).

September and December. Concentrations then begin a gradual decrease to a late spring or early summer minimum. Presumably a winter decrease could be expected, caused by higher and colder wet-weather flows after the first flushing storms of the season wash bacteria from impervious surfaces. Periodic flushing, colder water temperatures and faster flows may reduce concentrations throughout the wet season and keep them low until spring.

It is somewhat harder to envision why bacteria levels should increase as the dry season progresses. While warmer water temperatures are probably more conducive to the survival of bacteria, the primary mechanism that removes indicator bacteria from open waters appears to be predation by zooplankton, rather than adverse environmental conditions (Rassoulzadegan and Sheldon, 1986). However, research has shown that coliforms and enterococci can survive and grow in natural waters (Francy et al., 2000;

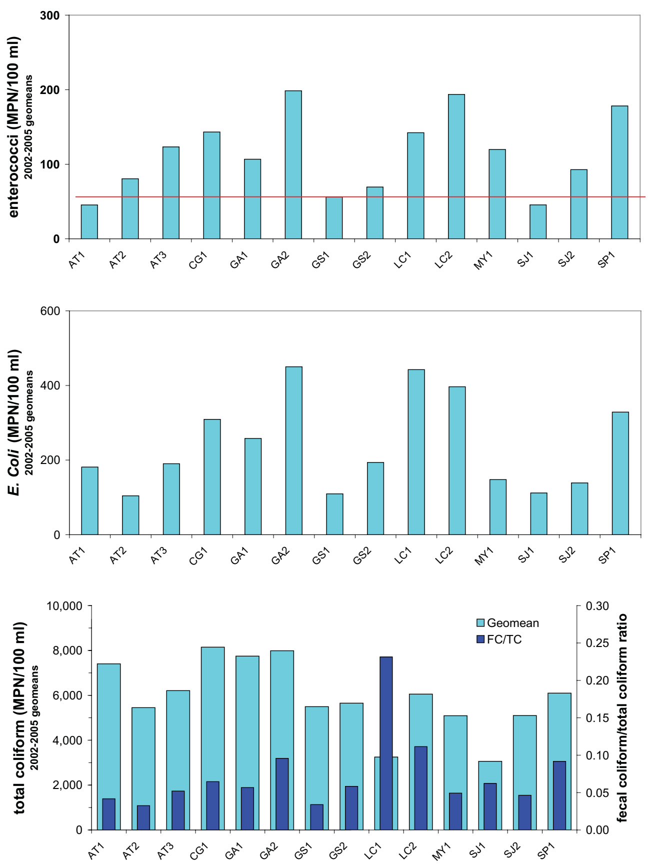


Figure 40. Average enterococci, E. Coli and total coliform concentrations, June 2002 to June 2005. Solid horizontal lines mark the EPA's recommended freshwater beach Public Health limits for maximum enterococcus (61 MPN/100 ml) and E. Coli (235 MPN/100 ml), and the California limit for total coliform (10,000 MPN/100 ml); the total coliform limit decreases to 1,000 (dashed line) if the fecal coliform/total coliform ratio exceeds 0.1.

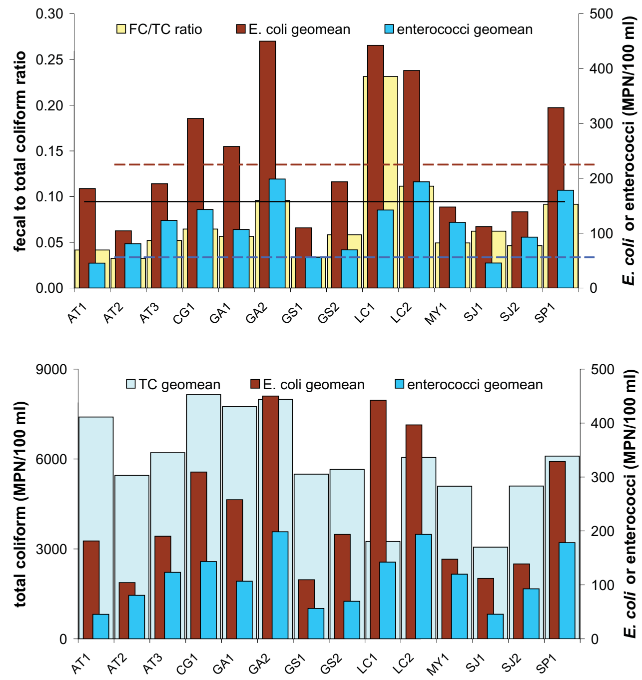


Figure 41. Upper panel: The average fecal to total coliform ratio with E. coli and enterococci concentrations, June 2002 to June 2005 geomeans. Dashed horizontal lines mark the EPA's recommended freshwater beach Public Health limits for maximum enterococcus (61 MPN/100 ml) and E. Coli (235 MPN/100 ml). 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: June 2002 to June 2005.

Nasser and Oman, 1999), and can reproduce in plants and soil (Solomon et al., 2002; Hardina and Fujioka, 1991; Marino and Gannon, 1991).[19] It is therefore possible that these bacteria could not only be surviving, but also reproducing in the streamside environment during the warm temperatures of the Santa Barbara summer. Another explanation may be that bacteria become more concentrated as flows decrease throughout the dry season.

Since Goleta Stream Team only samples once a month, using the "average geomean" standards would be inappropriate. However, the geomean concept of reducing the importance of occasional very high or very low samples is a useful tool. Accordingly, geomean values of all samples taken from June 2002 to June 2005 for each of the three types of bacteria were calculated and the results shown in Figure 40. When it comes to discerning which locations generally have the highest numbers of bacteria, there is relatively good agreement between all three tests. However, in terms of determining which sites 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 (Figures 40 and 41).

All three tests agree that LC1 and LC2 are highly polluted and do not meet any of the Public Health standards. CG1, GA1, GA2 and SP1 fail the E. coli and enterococci standards, but have acceptable total coliform numbers. AT2 and AT3, GS2, MY1, and SJ2 fail the enterococci standard but not the E. coli and total coliform requirements. Only AT1, GS1 and SJ1 usually meet all standards. This is quite typical; studies generally show that while there is usually agreement between the three tests at either highly polluted or pristine sites, they can appreciably disagree on sites that lie in the middle (Kinzelman, 2003; Nobel et al., 2003).

Goleta Slough Results

Since evaluating potential impacts on the Goleta Slough from surrounding watersheds is one of the major purposes of the Goleta Stream Team program, this section separately examines data from the limited sampling at the GS1 and GS2 sites. The object is to analyze sampling results for this important location as a totality, and not item by item as was done in earlier parts 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 river flow and blockage at the slough mouth, lagoon water may be alternately brackish (low salinity ranging from 5-30 parts per thousand or ppt, approximately 4-46 mS/cm) or hyper-saline (salinity greater than 40 ppt or 60 mS/cm). Finally, the slough is periodically flushed with freshwater during winter storms. On top of this extreme seasonal variation, since stream flow heavily influences slough conditions, the year to year changes due to differences in rainfall are also considerable.

Flows from Glen Annie and Los Carneros creeks exert significant influence on slough conditions. During 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 closed for longer periods of time, while inflows of freshwater and nutrients appreciably decrease. The difference between dry- and wet-year nitrogen export from Glen Annie and Los Carneros creeks to the slough is appreciable, since both streams combine very high nitrate concentrations with drastic changes in flow (USCB-LTER).

Volunteers sample at Goleta Slough by lowering a bucket from the bicycle bridge.

Sampling of the slough at GS1 and GS2 (from the Goleta Beach bicycle bridge) began in October 2004, and data collected since are summarized in Figure 42 (averages of monthly GS1 and GS2 values). In the upper panel are the standard measurements made during Stream Team surveys. Conductivity values indicate which water source was dominant: tidal inflows from October through December (> 43 mS/cm), freshwater stormflows on January 9 (0.8 mS/cm), and mildly brackish water indicating mainly freshwater sources following the January storms (between 3-5 mS/cm). Lower values after April (< 3 mS/cm, approximately the same as conductivity measured at LC2 and GA1) indicate either the formation of a complete sand barrier at the outlet or the highly restricted passage of salt water into the slough.

pH has remained relatively consistent, between 7.5-7.9 during the period of tidal and stormflow dominance, and greater than 8.1 from April through June 2005. The April pH measurement of 8.2 was the highest recorded and indicates a substantial algal bloom during that month – dissolved oxygen increased to 18.4 mg/L (153% of saturation), in contrast with 8.2 and 7.8 mg/L during March and May, respectively. With tidal and creek inflows appreciably decreased by June, stagnant conditions have begun to develop. Daytime DO in June was down to 5.1 mg/L (69% of saturation).

The June 2005 decrease in dissolved oxygen is worrisome. Compared with May, pH remained high and dissolved inorganic nitrogen (nitrate plus ammonium) levels decreased by 40%, seemingly indicating ongoing photosynthetic productivity. Night-time DO decreases have not yet been measured, but given these indications, they could be appreciable.

Nutrient concentrations also reflect changes in the source of slough water during the sampling period. Tidal inflows from October through December 2004 were low in nitrate, while creek inflows provided high nitrate and low phosphate freshwater during the months that followed (Figure 42, middle panel). The variation in nitrate concentration during this change-over was extreme, from less than one to greater than 400 µM, a range of three orders of magnitude.

However, the true measure of nutrient availability is the flux, or amount of nitrogen or phosphate introduced into the slough, e.g., the product of the quantity of inflow water and its nutrient concentration. As stated previously, for creek inflows this is simply flow multiplied by concentration. At present, the flux from Glen Annie and Los Carneros creeks remains unknown.[20] However, since high nitrate concentrations are combined with high creek inflows during the rainy season, the monthly flux changes will be even more extreme than the variation in concentration.

The molar nitrate to phosphate ratio (N/P ratio) reflects the relative availability of both nutrients in combination, e.g., which one is liable to run out before the other and thus limit growth. Using the same 20:1 N/P approximation as before, the Goleta Slough was nitrogen-limited when dominated by tidal inflows (average N/P of 1.5 from October through December) and phosphorus-limited following the January storm (average N/P > 800). Storm inflows from Goleta are roughly in balance as normal stream nitrate concentrations decrease due to dilution and phosphate concentrations greatly increase due to high sediment levels: the N/P ratio on January 9, 2005 was 4:1, and the influence of recent stormflow was also reflected in decreased N/P ratios in March and May (samples for those months were collected two and three days, respectively, after storms; see Figure 42).

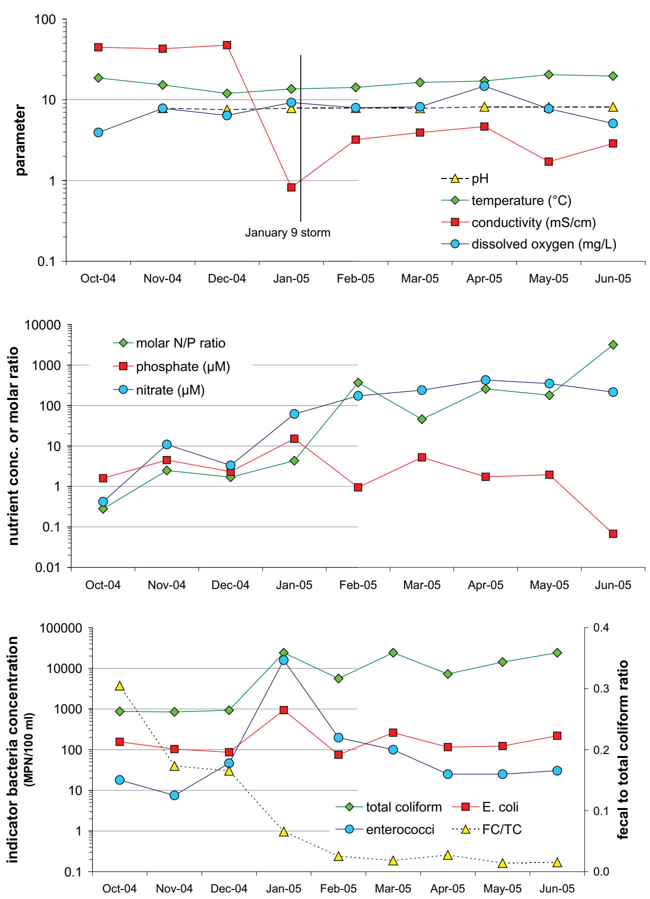


Figure 42. Monitored Goleta Slough parameters (upper panel), nutrient concentrations (middle) and indicator bacteria values (lower), October 2004 to June 2005 (averaged GS1 and GS2 measurements and concentratons). The vertical line indicates values during the large January 9 rainfall (3.1 inches); March and May sampling took place two and three days, respectively, after smaller storms (0.5 and 0.7 inches).

Ammonium concentrations were very high in November-December 2004 (13 and 11 μM, respectively). Throughout the period of tidal dominance (October through December), ammonium concentrations exceeded those of nitrate. Presumably, this highly unusual situation was 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 2004 supports this assumption, as anaerobic bottom sediments are high in both nutrients.

The major storm of January 9, 2005 (3.1 inches of rain) is marked on Figure 42. During large storms, resident slough water is totally replaced by freshwater storm flows, and the measured parameters reflect this change in chemistry. In comparison with December 2004 data, January 2005 storm samples showed a dramatic decrease in conductivity (48-0.8 mS/cm), increased nitrate (3-62 μM, or 0.05-0.87 mg-N/L) and phosphate (2-15 μM, or 0.07-0.47 mg-P/L) concentrations, and reduced ammonium (11 to 2 μM).

The January storm also caused a dramatic rise in concentrations of indicator bacteria in the slough (Figure 42, lower panel). Enterococci numbers rose to 16,000 MPN/100 ml (the freshwater beach limit is 61), E. coli to 900 (the beach limit is 235), and total coliform concentrations exceeded 24,000 (the maximum concentration determinable by our tests; the beach limit is 10,000). There was an unusual reversal in the relative numbers of E. coli and enterococci during the storm, one that appears to have continued into February. Typically, E. coli concentrations are higher than those for enterococci as indicated by their respective Public Health limits: 235 and 61, respectively. This is what Channelkeeper data usually show (Figure 41), as did samples from the slough during every month except January and February (Figure 42, lower panel).

What is also notable is that from October to December 2004 (under tidal influence), the fecal to total coliform ratio was high (an average of 0.2). A ratio above 0.1 lowers allowable total coliform concentrations to below 1,000. However, in spite of a lower limit, these waters would have been judged safe for swimming during this time, as all indicator bacteria tests were within acceptable limits. From March into June, when freshwater inflows dominated the slough system, E. coli and enterococci concentrations remained below beach limits. However, total coliform numbers were mostly above the allowable level (April was the only exception). This is a fairly rare situation. In over four years of Channelkeeper Stream Team sampling, there have been few occasions when total coliform numbers approached or exceeded 24,000 outside of storm periods, and these occasions are almost never associated with acceptable E. coli and enterococcus concentrations. It is possible that these increases in both total coliform and enterococcus numbers were due to some sort of contamination, or it may be possible that the bacteria were reproducing in the slough itself.

Unfortunately, the changes that these physical and chemical variations produce in the lagoon and marsh remain unknown. As mentioned earlier, Goleta Slough is listed on the State's 303(d) list of impaired water bodies for several pollutants, including pathogens and sediment. Expanding monitoring efforts to include additional sites in the slough and additional pollutants such as metals and priority organics would help in the further evaluation of these, and other, water quality impairments and their effects on the slough.

Summary of Results: Problem Areas

In this section, the sampling results discussed previously are reviewed to identify overall problem areas and potential causes. Three categories of data are examined: physical parameters, biological parameters, and Public Health parameters.

Physical Parameters

Conductivity, water temperature, pH, and turbidity are grouped into the physical parameters category. Table 4 summarizes problem locations identified by abnormal values found in Goleta Stream Team sampling results.

Table 4. *Physical parameters. Numbers in the table are calculated criteria values that identify specific problems at the Goleta Stream Team sampling sites. Column headings show the parameters, measurement units and criteria used to flag problem areas. The specific criteria were: (1) median conductivity > 2,000 µS/cm; (2) 10% of monthly water temperatures ≥ 26.4°C; (3) 10% of monthly pH values > 8.3; and (4) median non-storm turbidity > 1.9 NTU.*

	conductivity	temperature	pH	turbidity
	µS/cm	%	%	NTU
site	median	10% ≥ 26.4 ºC	10% ≥ 8.3	median
AT1	2,550			2.52
AT2	2,448			2.50
AT3		21.6%	59.5%	
CG1				4.53
GA1	2,590			
GA2	2,395			
GS1				
GS2				
LC1	2,505	14.3%	57.1%	
LC2	2,815			
MY1			25.0%	
SJ1			18.6%	
SJ2				
SP1			35.7%	

Conductivity

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 sources: agricultural runoff in Glen Annie and Los Carneros creeks, urban irrigation runoff and nuisance flows in Atascadero Creek, high evaporation at AT1, AT2 and LC1, and concrete canals above LC1 and AT2. The criterion used to identify excessive conductivity was a median value greater than 2,000 µS/cm (25% above the maximum limit for domestic water supplies).

Temperature

The criterion for water temperature was a statistical test; if 10 % of the monthly values were equal to or exceeded 26.4°C, it was judged excessive (26.4°C is 10% higher than the maximum temperature benchmark of 24°C used earlier). Excessive temperatures are caused by un-shaded, shallow trickling flows, e.g., the absence of riparian vegetation. The open concrete canal sites, AT3 and LC1, have excessive temperatures. Had it not been dry most of the time, SJ1, with an identical environment, would also have been listed.

pH

A similar statistical criterion was also used for pH: excessive pH was identified if 10% of the monthly values exceeded 8.3.[21] Excess pH in Goleta is caused by algal blooms, or possibly by dissolution of cement in concrete channels. All problem locations share both characteristics, except for MY1. High pH in Maria Ygnacio Creek 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 pH from limestone areas in the upper catchment.

Turbidity

Excessive turbidity was identified as non-storm median values exceeding the suggested EPA limit of 1.9 NTU. The sites exceeding this limit 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). GS1, GS2, LC1 and MY1 also have excessive turbidity according to this criterion. However, they have been removed from the list because of justifiable physical explanations (such as tidal inflows at Goleta Slough) or limited sampling focused mainly during or after storm periods (LC1 and MY1).

Biological Parameters

Biological problem areas were identified by examining nitrate, phosphate, minimum dissolved oxygen, and excessive dissolved oxygen saturation. Excessive biological productivity or eutrophication is the major biological problem identified by Goleta Stream Team sampling. Excessive nutrient concentrations are the major causal factors, and both minimum DO values and excessive DO saturation pinpoint the deleterious effects. Problem locations are summarized in Table 5.

Table 5. *Biological parameters. Numbers in the table are calculated criteria values that identify specific problems at the Goleta Stream Team sampling sites. Column headings show the parameters, measurement units, and the criteria used to flag problem areas. The specific criteria were: (1) median nitrate > 0.52 mg-N/L; (2) median phosphate > 0.03 mg-P/L; (3) greater than 5% of monthly DO < 5 mg/L and a minimum DO ≥ 4.0; and (4) 10% of the monthly values > 120% saturation. Particularly egregious results are shown in bold.*

	nitrate	phosphate	minimum DO	% DO sat.
	mg-N/L	mg-P/L	% (mg/L)	percent
site	median	median	5% < 5 (min)	10% < 120%
AT1	0.83	0.34		34.3%
AT2	0.96	0.39	8.1% (4.0)	
AT3		0.15		86.5%
CG1	1.83	0.52	10.8% (3.5)	13.5%
GA1	12.67	0.08		
GA2	23.38	0.09		
GS1	2.41	0.07	11.1% (3.9)	11.1%
GS2	2.44	0.05	11.1% (3.9)	11.1%
LC1	5.49			75.0%
LC2	13.07	0.10		
MY1		0.05		
SJ1	1.43	0.04		17.6%
SJ2	3.07	0.04		
SP1	0.62	0.05		35.7%

Nutrients

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 slightly less conservative since they evaluate only the nitrate and phosphate fractions of these elements.

Almost all sampling locations showed excessive nutrients. To distinguish particular problem situations, concentrations far above the norm are shown in bold ("far above the norm" being defined as ten times the EPA limit). Agricultural runoff is the major cause of high nitrate, and the worst problems are in Glen Annie and Los Carneros creeks. This, in turn, causes problems within the slough itself. Although not as egregious, agriculture is also the primary source of high nitrate levels 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," e.g., runoff from the fertilization and over-watering of lawns, landscaping, parks and golf courses. There are other sources contributing to the overall nitrate 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 noticed during storms and the rainy season, whereas the majority of Goleta Stream Team sampling takes place during the dry season, when urban nuisance flows and agricultural runoff dominate.

The main cause of high nitrate levels in San Jose Creek is agricultural runoff. This photo was taken near Goleta Stream Team's SJ2 sampling site.

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 (fertilizers, pesticides, etc.), the main probable cause is animal waste from domestic pets and horses. High phosphate concentrations at CG1 and AT2 can be directly related to the presence of horse corrals and stables adjacent to the creek.

Given the prevalence of high nutrient concentrations, it is worthwhile to examine the few sampling locations that do not appear to have nitrate or phosphate problems (note that no location has acceptable concentrations of both nitrate and phosphate). MY1 has acceptable nitrate because sampling is usually restricted to during and after sizable storms, when the majority of flow is coming from relatively low nitrate upper-catchment elevations; the remainder of the time the creek is dry. Excessive algal growth above and around AT3 often reduces nitrate concentrations to near-zero; low flows with high phosphate and plentiful algae ensure nitrogen limitation and exhaustion. Low phosphate at LC1 results from a combination of causes - low flows with high nitrate producing a reduction in phosphate concentrations, along with limited sampling due to the absence of summer flow.

Dissolved oxygen

Actual rather than potential algal problems can be identified by dangerously low levels of dissolved oxygen and excessive oxygen saturation. Two criteria were used to identify low DO: minimum concentrations equal to or below 4 mg/L, and greater than 5% of the monthly DO values lower than 5 mg/L. The criterion for percent saturation was greater than 10% of the monthly values exceeding 120% saturation. Locations where more than

20% of the monthly oxygen saturation exceeded 120% are identified in bold. Not surprisingly, two of these sites, AT3 and LC1, are located in concrete channels and are prone to over-growth of algae. While the third site, AT1, is a more natural stream channel, the lake-like environment here is conducive to heavy algal growth in the summer when flows are slower and the water warmer.

The DO criteria are somewhat contradictory, as excessive percent saturation values are only likely to be found during daylight, while minimum DO concentrations generally occur at night. Since all Goleta Stream Team sampling currently takes place in 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 have been identified by each of the two parameters. Although nitrate concentrations at AT3 are low, high percent DO saturation identifies this location as having the most critical algal problem in the area.

Public Health Parameters

In this section, indicator bacteria concentrations and the fecal to total coliform ratio (FC/TC) were used to evaluate threats to public health. While many problem locations are not common sites for human recreation, it is clear that bacterial contamination is a problem at many Goleta Stream Team sampling sites. Results are summarized in Table 6.

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

	E. Coli	enteroccoi	FC/TC	total coliform
	MPN/100 ml	MPN/100 ml	radio	MPN/100 ml
site	geomean	geomean	geomean	geomean
AT1				
AT2		81		
AT3		123		
CG1	309	143		
GA1	258	107		
GA2	450	199	0.10	7988
GS1				
GS2		70		
LC1	442	142	0.23	3250
LC2	397	194	0.11	6053
MY1		120		
SJ1				
SJ2		93		
SP1	329	178		

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 public beaches. 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 Public Health standards for swimming, no locations present a true hazard for occasional recreational users, the most likely form of public contact with these waters. E. coli is judged by the EPA as the best freshwater indicator of a public health threat, and no site consistently had concentrations exceeding the "infrequent use" standard. However, it cannot be disputed that many sites do have problems with bacterial contamination, regardless of the uncertain impact on public health.

Some of the possible reasons for high enterococci counts were discussed in earlier sections of the report. Perhaps most worrisome is the very high FC/TC ratio at LC1. The cause of this contamination is not immediately apparent, as nearby upstream land uses consist of light industrial businesses, parking lots, and Highway 101. Fortunately, this location is fenced to prohibit public access and is an unlikely site for human recreation.

Based on the twelve criteria identified above, all of the Goleta Stream Team sites show at least some water quality problems. The sites with the fewest impairments were SP1, MY1, and GS1, each exceeding only three of the twelve criteria. However, it must be noted that two of these sites, SP1 and MY1, are frequently dry and therefore had smaller data sets than many of the other sites. The site which exceeded the most criteria was LC1 with nine, followed closely by LC2 with eight, and CG1 and GA2, both with seven. Based on this information, it is fairly safe to conclude that Los Carneros Creek has the most water quality impairments of all the creeks in the Goleta Stream Team sampling program.

The criterion that was most frequently exceeded was that for phosphate; 13 out of 14 sites had median phosphate levels above the .030 mg/L standard. Interestingly, the only exception was LC1, which was the site with the most problems overall. The next criterion to be exceeded the most was that for nitrate, with median values at 12 out of 14 sites exceeding the standard, followed closely by enterococcus, which was exceeded at 11 out of 14 sites. The criterion that was exceeded least was that for temperature, which was exceeded only twice, at AT3 and LC1 (both open, concrete channels). Based on this information, it is clear that nutrient pollution is the largest water quality problem identified by Goleta Stream Team sampling.

RECOMMENDED ACTIONS

The findings from the first three years of Channelkeeper's Goleta Stream Team water quality monitoring efforts highlight the need for action to address the impairments identified. Although three years of data are not necessarily conclusive, there are several reasons to implement proactive measures now to reduce pollution in this valuable watershed.

The Goleta Slough is listed as an impaired waterbody on the State's 303(d) List of Water Quality Limited Segments due to its contamination by pathogens, heavy metals, priority organics and sedimentation. Moreover, the surrounding area is poised to undergo significant land use changes in the near future, which may further impair water quality in the watershed. The new City of Goleta is currently formulating comprehensive plans for future land use and development, and the Santa Barbara Airport (located in the Goleta Slough) is set to undergo major construction to expand the runway and other airport facilities as part of its Aviation Facilities Plan.

The Central Coast Regional Water Quality Control Board (RWQCB) is required to develop Total Maximum Daily Loads (TMDLs) for pollutants of concern in impaired waterbodies, and development of TMDLs for Goleta Slough is scheduled to begin soon. Further, Santa Barbara County and the Cities of Goleta and Santa Barbara will soon be implementing Storm Water Management Programs (required pursuant to the State General Permit for Small Municipal Separate Storm Sewer Systems), and must demonstrate that the strategies therein are effectively reducing pollution in stormwater and runoff. However, due to resource limitations, the slough is not regularly monitored by any entity other than Channelkeeper, so water quality data to facilitate these efforts is sorely needed.

Continue and expand monitoring: Channelkeeper's data can continue to serve as an important resource for municipalities, regulatory agencies and other stakeholders to evaluate the need for and effectiveness of water quality protection and restoration efforts. It will also provide a useful baseline for the new City of Goleta as it plans for future land use and development, and for the Santa Barbara Airport as it undertakes its expansion plans. Therefore, Channelkeeper's Goleta Stream Team program should be continued, and should further be expanded to include more sampling sites in the slough itself and to conduct dry and wet season sampling for the full suite of pollutants, particularly metals, herbicides and pesticides known to occur in the watershed.

Conduct creek walks: The Goleta Stream Team data would be even more useful if it were supplemented by additional efforts to pinpoint sources of the nutrient and bacterial pollution identified through Channelkeeper's sampling program. This could be achieved by conducting creek walks to identify discharge points and discrete sources of runoff that may be contributing polluted water to the creeks or slough, testing the discharged water for pollutants, then consulting the County's land use and storm sewer maps to pinpoint potential sources contributing to the pollution.

Educate property owners and enforce ordinances: Once specific sources are identified, Channelkeeper and/or other environmental groups in cooperation with regulatory agencies should reach out to owners of properties from which discharges may be originating. The focus of the outreach efforts would be to educate business or property owners on the potential problems posed by their particular discharges and present solutions and best management practices (BMPs) that different types of business or property owners can implement to prevent pollution in the future. The County of Santa Barbara has already developed brochures targeting dog and horse owners, creekside residents, gardeners, restaurants, automotive service businesses, construction contractors and mobile cleaners; these could be distributed to business owners or residents that own property from which discharges may be originating. This outreach and education should be followed by targeted inspections and monitoring by relevant RWQCB, County or City (Goleta or Santa Barbara, depending on location) agency staff responsible for enforcement of existing water quality protection regulations and ordinances. If such monitoring efforts or inspections identify ongoing pollution problems from particular sources, the appropriate agencies should follow up with enforcement action, such as issuing fines or cease and desist orders, to ensure that illegal discharges cease. In the Goleta Slough watershed, these education and enforcement efforts should target agricultural operations, large horse facilities, and golf courses, all of which Channelkeeper believes contribute significant amounts of nutrients into many of the creeks monitored by Goleta Stream Team.

Inventory agricultural operations and encourage enrollment in the RWQCB's agricultural waiver program: As Goleta Stream Team data and numerous other water quality monitoring efforts have shown, waterbodies in agricultural areas, including the Goleta Slough watershed and elsewhere, often contain highly contaminated runoff. In recognition of this problem, the RWQCB adopted a regulatory program for irrigated agricultural operations on the Central Coast, which requires farmers to develop farm water quality management plans that address, at a minimum, irrigation management, nutrient management, pesticide management and erosion control; begin implementing best management practices identified in their plans; conduct monitoring to ensure compliance; and complete 15 hours of farm water quality education within three years. An inventory of all sizeable agricultural operations in the Goleta area should be conducted to determine how many have enrolled in this program, and any that have not should be encouraged to do so.

Increase monitoring and consider treatment of golf course discharges: As noted above, Glen Annie, Hidden Oaks and Twin Lakes Golf Courses are located upstream of sampling sites (GA2, AT2, and SP1, respectively) where Goleta Stream Team has identified significant nutrient pollution problems. Relevant local agencies and/or environmental groups may want to conduct additional monitoring at golf course discharge points to ensure compliance with water quality standards and discharge ordinances. The City of Santa Barbara is building a stormwater detention basin at the Santa Barbara Golf Club to naturally treat runoff from the golf course before it enters Las Positas Creek; similar systems may well be needed at Glen Annie, Hidden Oaks and Twin Lakes Golf Courses, and these options should be considered by relevant County or City officials in cooperation with the golf course owners or operators.

Implement stormwater treatment controls: There are a variety of treatment technologies and methods available for reducing bacteria in creeks and storm drain systems, including active treatment systems, such as ultraviolet (UV) light and ozone treatment systems, and stormwater treatment BMPs, such as vegetated swales, infiltration basins, constructed wetlands, and permeable pavement, to name just a few. Both the County and City of Santa Barbara have already installed many such systems, such as bioswales at Bohnett Park and a UV treatment system at Escondido Pass. Other priority sites that would benefit from treatment controls have also been identified; local municipalities should continue to allocate and seek additional funding to implement more of these types of stormwater treatment controls in priority areas throughout the Goleta Slough watershed.

Encourage installation of low-impact development BMPs: In an effort to reduce the mobilization of pollutants in runoff, urban planners are increasingly looking to the use of structural BMPs such as infiltration practices. One example is the use of porous pavement as opposed to impervious asphalt or concrete. Regulatory agencies should seek to encourage the installation of such BMPs by developing and providing incentives, such as facilitated permitting or cash stipends or rebates, to property owners.

In conclusion, while there are many water quality problems throughout the Goleta Slough watershed, there are also many opportunities to address them. Santa Barbara Channelkeeper is committed to improving water quality throughout the South Coast area, and looks forward to working together with government agencies, environmental groups, and the public to achieve this goal.

ENDNOTES

1. The sections on the South Coast were adapted from Veirs et al. (1998), USACE (2002), USBR (2002), Questa (2003) and USDA-FS (2004). A reference list is included at the end of the report; when available, references with web addresses were chosen so documents can be easily accessed for ad ditional information. In addition to general references, specific citations were used when warranted.
2. Climate data for the Santa Barbara region are available from a number of internet sources: DRI-WRCC, CDEC, CCDA and JISAO. Data is also available from the County of Santa Barbara (CSB-PWD). The discussions that follow reference the "water-year" instead of using a calendar year; the water-year begins on October 1 and ends the following September 30, e.g., water-year 1998 began on Oc tober 1, 1997 and ended on September 30, 1998. Hydrologists and agencies concerned with water in California use a water-year to present and analyze data because it better fits the seasonal progression of annual precipitation: rainy to dry, snowfall to snowmelt.
3. This section used SBC-DPD (1998, 2002) and Nelson as references.
4. This creek is known by two names: Glen Annie and Tecolotito. Throughout this report the name Glen Annie will be used.
5. Perhaps the best way to view the Atascadero sampling scheme is that at CG1, urban runoff from the rela tively small area between upper State Street and Foothill Road is sampled. At AT3 we observe the change in water quality when runoff from the more commercial uses around Modoc and Hollister are added. Next, additional impacts are measured at AT2 when agricultural and golf course runoff are included, 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 (AT1) during the dry season.
6. Such as Cladophora, Rhizoclonium, Enteromorpha and Spirogyra.
7. US-EPA (1997), Deas and Orlob (1999) and Heal the Bay (2003) were used in the preparation of the sec tions on water quality parameters.
8. It is often simpler to think of mg/L as "parts per million," since a liter of water weighs a million milli grams, 1 mg/L is the same as one part of dissolved oxygen in a million parts of water.
9. The meter makes this calculation based on measured temperature and an entered value of sampling site elevation.
10. A percent saturation above 100 simply indicates that water is not at equilibrium but in the process of releasing oxygen into the atmosphere, just like a glass of recently poured soda sheds an over-satura tion of carbon dioxide as streams of bubbles.
11. Three sets of data were combined to make the pH charts: field measurements up until July 2003, labora tory measurements made from collected samples from July 2003 to March 2005, and finally, field measure ments again from April 2005. pH is a difficult measurement to make, even in the laboratory, and the portable meters initially used by Stream Team proved unreliable. Newer, higher quality meters are now available and have been used since April 2005. During the intervening period, laboratory measurements were made with a meter borrowed from the UCSB-LTER program; these measurements were made in conjunction with field measurements using the old meters, but only the laboratory data is used in Figure 19.
12. Given that the suggested EPA eutrophication limits are typically measured as total nitrogen and total phosphorus, some explanation as to why we used phosphate instead of phosphorus, and nitrate instead of total nitrogen in the previous discussions is warranted. The UCSB-LTER project analyzes the nutri ent samples collected by Goleta Stream Team for Channelkeeper. Nitrate and phosphate (and ammo nium) are analyzed as soon as possible (typically within a few days; see methodology appendix), but total nitrogen and total phosphorus are analyzed months or even a year later (samples undergo initial

processing as soon as possible, but are then stored in a preserved condition – no 2005 samples have yet been analyzed for total dissolved nitrogen or phosphorus). Therefore, nitrate and phosphate results are used in this report because these results are available sooner. Nitrate and phosphate results are generally available two months after the sampling date, and total nitrogen and phosphorus 5-10 months thereafter. Error and imprecision are part of all laboratory analysis; a result is never simply a number but a number plus or minus some error. Total nitrogen and total phosphorus are analyzed to determine the concentrations of organic nitrogen and organic phosphorus in a sample. The inorganic concentration is simply subtracted from the total – phosphate from total phosphorus, inorganic nitrogen (nitrate + ammonium) from total nitrogen – what remains is the organic fraction. Sometimes the analysis error or the precision of the result is such that the inorganic concentration is higher than the total concentration, e.g., a larger number has to be sub tracted from a smaller. For example, the total phosphorus concentration may end up being lower than the phosphate in a sample. Obviously, this kind of result cannot be true; it represents either imprecision or error. It happens about 4% of the time with nitrogen (an acceptable rate, particularly when concentrations are high), but 50% of the time with phosphorus. The phosphorus results present a real problem, one that the UCSB laboratory has not been able to solve. Something in our local stream water removes phosphorus from solution during the test procedure, and since the total phosphorus results are undependable, phosphate is used instead. This is not an important distinction. Phosphate makes up a large majority of total phosphorus in Goleta samples, and nitrate is the dominant nitrogen fraction at most locations. Analysis of filtered vs. un filtered samples to determine nutrient composition is another difference without a distinction. Tests on filtered and unfiltered samples at most of the Goleta Stream Team sites show no statistical difference be tween these two types of samples. Except for those rare rainy days, Goleta creek water is relatively sedi ment free (Figures 24 and 25). Summarized results of the overall nutrient analysis (through September 2004) are presented in Table 3, and Figure 32 shows a temporal comparison between nitrate and dissolved organic nitrogen for three sites exemplifying the range of Goleta conditions. The variation of nutrient concentrations and other constituents during storms is not part of the Channelkeeper sampling program, nor is it discussed in any detail in this report. However, it remains an important topic since the vast majority of the annual load of pollutants flushed into the neighboring ocean occurs during these events. Figure 31, showing variations in concentration during the major storm of 2004 (data from UCSB-LTER), was included to give some idea of what does happen.

13. This ratio, 16:1, is named after its discoverer, the "Redfield ratio" (Sterner and Elser, 2002).
14. The vertical nitrate and phosphate scales in Figure 33 were set in a proportion of 20:1; e.g., a concentration of 100 µM on the nitrate scale is located directly across from 5 µM on the phosphate scale, 400 opposite 20, etc. The unit is micro-moles per liter (µM – "M" is the symbol for moles per liter). Redfield ratios are pro portions between atoms. Previously, nutrient concentrations were shown as mg/L, a unit based on the weight of nitrogen or phosphorus in water. The µmole, a measure of the number of atoms, is more useful 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 31 µM.
15. In this figure, the vertical nitrate and phosphate scales are similarily set in proportions of 20:1, 3,000 µM of nitrate opposite 150 µM of phosphate, etc.
16. A possible exception may be greatly increased export during El Niño years when the upwelling and circula tory processes that normally provide a large supply of nitrogen to the Channel are greatly diminished in warmer ocean waters.
17. The following documents were used as references in the preparation of the bacteria section: US-EPA, 2002 and 2004; SWRCB, 2003 and 2004; RWQCB-LA, 2001. There are significant differences between EPA guidelines for indicator bacteria and current California State regulations, as well as variations among the dif ferent Regional Water Quality Control Boards and counties within the state. The regulatory situation is in the process of changing as some of these differences are resolved, and the following narrative should be considered a reasonable overview only.

18. To calculate the geomean, bacteria counts are converted into logarithms, averaged, and then the average log value is converted back into a regular number; the geomean reduces the influence of very high or low numbers which might unfairly represent aberrant samples. For freshwater recreational use, total coli form must not exceed 10,000 MPN per 100 ml in a single sample, and the average must not exceed 1,000. For E. coli, the "average" limit is 126 bacteria/100 ml of water, and the single sample limit varies from 235-500 depending on intensity of use (235 for beach areas, 500 for occasional recreational use). For enterococcus, the limit for the average of five or more samples is 33 MPN/100 ml, and the single sample limit can vary from 61-151, again depending on frequency of water use. The total coliform av erage and single sample limits of 1,000 and 10,000, respectively, are only valid as long as the fecal/total coliform ratio is less than 0.1 (in other words, if less than 10% of the coliforms are of fecal origin). If the ratio rises above 0.1, the single sample limit is lowered to 1,000. Although Channelkeeper does not actually test for fecal coliform, the E. coli values have been multiplied by 1.7 to estimate fecal coli form concentrations. This assumes that a sample tested for fecal coliform would have approximately 60% E. coli; this equivalency is the value assumed by most regulatory standards and is a conservative estimate; see also Cude, 2005.
19. It was found that river-bank soil was the principal source of dry weather E. coli in a Florida stream, and that E. coli exhibited a competitive advantage over predators as soils dried (Solo-Gabriele et al., 2000).
20. However, UCSB-LTER sampled nutrient concentrations and recorded flows in 2004 and 2005, so this data should be available soon.
21. 8.3 is the Central Coast Regional Water Quality Control Board's upper limit for water contact recre ation.

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APPENDIX

Methodology

Methodology

All Stream Team sampling and laboratory analysis is conducted in compliance with a Quality Assurance Project Plan approved by the State Water Resources Control Board. The following summarizes all Stream Team testing procedures.

Water sampling and chemical analyses

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

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

Detection limits were 0.3 µmol L^{-1} for NH_4^+ and PO_4^{3-} and 0.5 µmol L^{-1} for NO_3^-; accuracy was + 5%. Total dissolved nitrogen (TDN) was determined after persulfate digestion (Valderrama, 1980) followed by measurement of nitrate. The basic persulfate reagent was added immediately after filtration to a separate aliquot and the digestion done within one week The detection limit was 0.5 µmol L^{-1} and accuracy was + 10%. Dissolved organic nitrogen (DON) was computed as the difference between TDN and dissolved inorganic nitrogen (DIN equals nitrate plus ammonium).

The goal was to analyze inorganic nutrient samples and begin the digestion of total dissolved nitrogen samples within 48 hours of collection, and we were able to meet this goal for most of the samples collected. However, during winter storm periods, when high sediment concentrations prevented filtration in the field and the UCSB-LTER laboratory was inundated with samples, the 48-hour limit was often exceeded by one to five days. To evaluate the effect of delay, three types of samples were collected from six streams with widely varying nutrient chemistry: (1) samples filtered in the field and analyzed in duplicate within 12 hours; (2) samples filtered in the laboratory on the day of collection, stored at 4°C, and repeatedly re-analyzed after delays of 1 to 14 days; and (3) an unfiltered sample, stored at 4°C, sub-samples of which were repeatedly filtered and analyzed after similar delays. Numerous duplicate and deionized water samples provided quality assessment and control. The average error (the combined error of processing, delay, instrument calibration and analysis) for nitrate was 5-10% (the higher percentage error in the second week of delay), 10% for phosphate, and 20% for ammonium. Samples filtered within two days showed almost no variation in nitrate and phosphate from initial values, while ammonium was usually within 10%. Delays greater than two days did sometimes cause significant increases in ammonium concentrations.

Bacteriological analysis

Water samples for bacteria analysis were 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 were placed in coolers, transported on ice, and analyzed within six hours of collection.

Each sample was analyzed for three indicator bacteria: total coliform, E. coli, and enterococcus using IDEXX Colilert® and Enterolert® methodologies (ASTM #D6503-99). Both methods are approved by the Environmental Protection Agency (EPA, 2003a). The sample, diluted with distilled, bacteria-free water (typically using a dilution of 10:1), was 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 was 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 can be evaluated by examining the differences between duplicate field samples. Two duplicates (consecutive samples taken at the same location) were collected on each sampling day. A measure of reproducibility is the difference proportion, the absolute value of the difference between two samples divided by the average value, or

difference proportion = (2 êN1 – N2 ê)/ (N1 + N2)

where N1 and N2 are the concentrations of the first and second samples (Kayhanian et al., 2005). The mean and median difference proportions for the bacteria analyses are shown in Table A1.

Table A1. *Average and median difference proportions (expressed as a percentage ± the standard deviation) of duplicated samples collected in Channelkeeper sampling programs: 2001-2005.*

	number of duplicates	average concentration	average difference proportion	median difference proportion
		MPN/ 100ml	%	%
E. Coli	124	460	43.3 ± 38.9	34.9 ± 48.6
enterococci	126	45	55.7 ± 50.9	42.3 ± 63.6
total coliform	116	4670	37.2 ± 34.7	27.0 ± 43.4

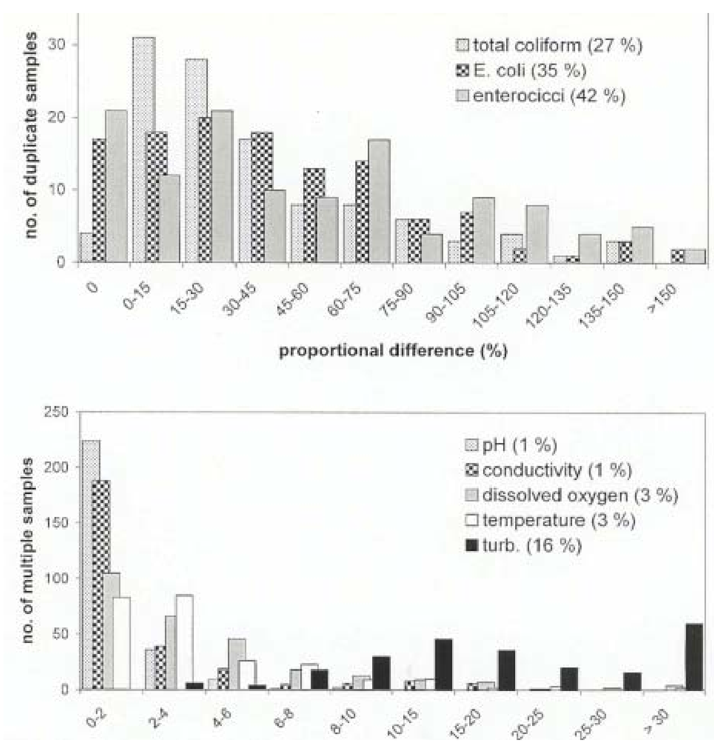

Figure A1 gives the histogram showing the distribution of the difference proportion results. Considering that bacterial concentrations in stream flow vary both spatially and temporally and can range over more than three orders of magnitude (less than 10 to greater than 24,192 MPN/100 ml), these results are satisfactory.

Figure A1. As part of the QA/QC procedure, duplicate bacteriological samples were taken by each team at a randomly selected site during sampling. The proportional difference, expressed as a percent, is the difference between the two sample concentrations divided by the average. The upper panel shows the histogram of proportional differences for bacteria samples taken by Channelkeeper sampling teams from 2001-2005. The median proportional difference is shown in parentheses in the legend. Similarly, the lower panel shows the proportional differences for all multiple parameter measurements (the difference between maximum and minimum values divided by the average) taken between June 2004 and July 2005.

In-field measurements

Portable, hand-held meters were used to take field measurements for dissolved oxygen, pH, conductivity, water temperature and turbidity. Measurements were typically taken near the center of flow, below the surface in the upper half of the water column. The objective was to obtain measurements characteristic of the bulk of stream flow and not a spectrum of variation at the testing location. All instruments were calibrated according to manual instructions using certified laboratory standards on the day prior to sampling. Table A2 shows the type and accuracy of each meter used.

Table A2. *Meters and accuracy.*

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 pH Testr2 (prior to April 2005)	± 0.1 pH
Oakton ph/mV/Temperature Meter (April 2005)	± 0.01 pH

At each site, three readings were taken in three different areas of the creek 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 that is entered into the database.

After sampling, all results are checked for quality control purposes. Any suspicious results are re-tested within six hours at the lab using a 500 ml sample collected at each location and transported on ice. Suspicious 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 (e.g., milli vs. micro, or ppt vs. ppm). The "backup" samples were also used in cases of on-site equipment failure or suspected meter malfunctions.

The difference proportion used to evaluate duplicate bacteria samples can also be used to examine the repeatability of multiple measurements. In this case, the difference between maximum and minimum measurements is expressed as a percentage of the average of all measurements (typically either three, in the case of dissolved oxygen, conductivity and pH, or six for turbidity and water temperature). The median difference proportions for each parameter for all measurements made by both the Ventura and Goleta Stream Teams from June 2004 through July 2005 are shown in Table A3, and a histogram of these results is exhibited in Figure A1 (lower panel).

The repeatability of measurements is usually very good. With the exception of turbidity, a majority of the multiple measurements are within a few percentage points of each other. Turbidity measurements are afflicted by problems similar to those that effect bacteria concentrations: a spatially and temporally varying dispersion in stream flow. In addition, turbidity can vary with stream velocity, and its measurement is particularly susceptible to errors in collection and measurement, e.g., disturbing bottom sediment while collecting samples and/or failure to properly clean sample vials. This occasionally accounts for proportional errors greater than 100%.

Table A3. *Median difference proportions (expressed as a percentage) and standard deviations of multiple parameter measurements collected in Channelkeeper sampling programs, June 2004 to July 2005.*

parameter	n	unit	median value	max. value	min. value	median standard deviation	median difference proportion
VENTURA							
dissolved oxygen	142	mg/L	8.86	17.43	4.05	0.09	2.1%
% saturation	142	%	94.1	196.5	53.8	1.09	2.1%
pH	142	units	8.15	9.03	6.95	0.04	1.0%
conductivity	142	µS/cm	1,091	2,747	335	3.8	0.8%
temperature	126	° C	16.9	24.6	6.2	0.15	2.1%
GOLETA							
dissolved oxygen	129	mg/L	9.33	19.76	3.41	0.15	3.4%
% saturation	125	%	94.4	32.8	98.2		3.3%
pH	130	units	8.17	8.90	7.10	1.65	0.7%
conductivity	142	µS/cm	1,923	47,600	164	0.03	1.8%
temperature	117	° C	16.9	27.1	7.2	23.1	3.1%
turbidity	118	NTU	3.96	309.5	0.13	0.30	16.4%

Periodically, Channelkeeper conducts quality control exercises to determine the between-sampler error. Three to four volunteers will each make the typical series of three or six measurements, exchanging meters until all have individually completed the total series of tests performed at a site on a sampling day. These exercises are performed on regular sampling days, each team doing the series of measurement at one pre-selected location during the normal course of activities.

Examples of these results are shown in Table A4. A one-way ANOVA analysis is used to determine whether or not there is a significant difference ($p < 0.05$) between samplers for a given parameter. The results indicate that it often does matter who makes the measurements: over half the results show a statistically significant difference between samplers. However, for pH, water temperature and conductivity, the difference is relatively meaningless: the difference proportion for these parameters is about 1%, approximately the same difference found between the individual measurements of a single sampler (Table A3). Quite often for these parameters a sampler records the same, or almost the same, reading on each successive measurement. The extremely small variance of the measurements can make small differences between samplers statistically significant – statistically significant but meaningless in practice.

Differences between samplers are almost always significant with dissolved oxygen. Oxygen, as a gas dissolved in water, can vary spatially and temporally, and where a measurement is made (e.g., in turbulent vs. quiescent flow) as well as the experience and care of the sampler (since the meter's probe has to be kept in motion and readings usually fluctuate around a central value) play a role. However, here too the significant difference is without practical value. The range of proportional difference between samplers was between 1-7%, comparable with a median difference of 2-3% between individual measurements made by the same sampler and a 2-3% meter error.

Table A4. *Difference proportions (expressed as a percentage) between average parameter measurements (the average of three to six measurements by each sampler) collected by three to four samplers at the same locations on the given dates, e.g., a measurement of between-sampler error. Results shown in bold italics indicate a significant difference between sampler measurements ($p < 0.05$, one-way ANOVA).*

date	pH	turbidity	conductivity	water temperature	dissolved oxygen
November 2, 2002	2.4%	254.5%	1.1%		
November 2, 2002	1.8%	209.5%	0.2%		
November 2, 2002	1.3%	187.5%			5.4%
June 23, 2004		45.0%		1.0%	6.1%
June 23, 2004		126.8%		0.4%	2.0%
June 23, 2004		2.4%		0.0%	1.6%
July 10, 2004	0.4%	26.5%	0.6%	3.4%	0.9%
July 10, 2004	0.9%	3.4%	0.8%	1.3%	3.2%
September 10, 2005	0.2%	41.6%	0.5%	0.8%	7.0%
median	1.1%	45.0%	0.6%	0.9%	3.2%

Turbidity measurements show a much wider variation for reasons expressed earlier. Differences between samplers are noticeably higher than the differences between measurements done by a single sampler (median difference proportions of 16 and 45%, respectively – Tables A3 and A4). Given the nature of the test procedure, this appears to be unavoidable. However, since turbidity measurements are typically low (60% of the Goleta measurements over the past year were below 5 NTU) even a large error is manageable.

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John Simonitch
Krista Simundson
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Katia Stejko
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Das Williams
Gary Wyatt
Kylah Wyatt

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