The State of the Ventura River

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

Al Leydecker

Introduction

The Ventura River and tributary streams transport pollutants such as bacteria and excess nutrients downstream to the estuary and ocean, and the purpose of Santa Barbara Channelkeeper's Stream Team program is to provide comprehensive and long-term monitoring of conditions in this ecologically important watershed. Ventura Stream Team began early in 2001 as a partnership program of Santa Barbara Channelkeeper and the Ventura Chapter of the Surfrider Foundation. The program has three goals: (1) establish a baseline of information about stream conditions in the watershed; (2) establish a trained volunteer monitoring base; and (3) locate previously unidentified point sources of pollution.

Stream Team conducts monthly on-site testing of the Ventura and major tributaries at designated locations. Near the beginning of each month, teams of volunteers measure physical and chemical parameters in the field using portable, hand-held instruments. Data collected includes on-site measurements of dissolved oxygen, turbidity, conductivity, *p*H, temperature and flow. 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 through the cooperation of the Santa Barbara Channel – Long Term Ecological Research Project (SBC-LTER) at the University of California, Santa Barbara. The parameters measured are ammonium, nitrite plus nitrate, orthophosphate, total dissolved nitrogen and total dissolved phosphorus. Characteristics such as vegetation and observed aquatic life are also recorded. Occasionally, tests for other ions and contaminants are conducted. As part of every sampling event, instruments and meters are checked and calibrated against factory standards before taking them out into the field. Additional quality control checks are periodically performed in the field and as part of every bacteriological and chemical analysis.

In February 2006, a comprehensive report and analysis of the data collected during the first five years of the program was prepared and circulated to interested individuals, environmental organizations and government agencies. This report is available in PDF format on the Stream Team website (http://www.stream-team.org/Ventura/main.html), as are numerous other special reports on Ventura River conditions. The data collected as a result of Stream Team activities are also available here. The purpose of this report is to supplement the original document, *Ventura Stream Team: 2001-2005*, and bring it up to date with a summary and analysis of an additional year of data. Since this document is meant to supplement and not replace the original report, it does not contain the introductory sections describing the environmental setting, hydrology and detailed sampling site descriptions. The reader is referred to the original document for that information.

Sampling Locations

The Ventura sampling sites represent four distinct reaches or sub-watersheds: four on the lower Ventura River, two on Canada Larga, four on San Antonio Creek and its tributaries, and five upper Ventura/Matilija locations. Sampling is typically accomplished by three teams: one on the lower Ventura and Canada Larga, another on San Antonio Creek, and the third monitoring the upper Ventura/Matilija. A map of the sampling locations is shown in Figure 1.

VR01, the **Ventura River at the Main Street Bridge,** is sampled immediately upstream of the bridge. This site is just above marine influence from the nearby estuary and marks the freshwater boundary.

VR02, the **Ventura River near Stanley Drain,** is located just above the confluence with this large storm drain serving semi-industrial and brownfields areas in northern Ventura.

VR03, the **Ventura River at Shell Road,** is slightly downstream of the Shell Road bridge. The Ojai Sewage Treatment Plant is approximately a mile upstream of this location. VR03 allows us to monitor conditions below the treatment plant and, with two further downstream sampling locations (VR02 and VR01), track the sequential changes that occur as this mixture of normal river water and treated effluent flows to the estuary.

VR04, Lower Canada Larga, is located off Ventura Avenue, just downstream of the Canada Larga bridge. Canada Larga flows through extensive ranch lands before passing through industrial development on its way to the river.

VR05, Upper Canada Larga, is located 3.5 miles up Canada Larga Road, at a small bridge over the creek. The hills and valley bottom around this location provide grazing land for local ranches. The two Canada Larga sites monitor a major Ventura River tributary as land use changes from ranching to industrial.

VR06, the **Ventura River at Foster Park,** is located below the County's Foster Park, slighty downstream of the Casitas Vista Drive bridge. Highly influenced by relatively clean groundwater forced to the surface by a bedrock reef located ¼ mile upstream, VR06 exemplifies natural conditions on the lower river (or, these days, as close to them as we are likely to find) and provides a contrast from which to judge the impacts from the introduction of treated effluent below this point.

VR07, San Antonio Creek at Old Creek Road, monitors a major tributary of the Ventura River and represents the combined drainage from various Ojai Valley land uses.

VR08, Lion Canyon, is sampled just before it enters San Antonio Creek. A sub-watershed of approximately eight square miles, the entire catchment is mostly under single ownership and is used for cattle grazing and dude-ranch activities associated with the Ojai Valley Country Club.

VR09, Stewart/Fox, samples the combined flow out of Stewart and Fox canyons, both of which flow through western Ojai and are partially channelized through the town (this stream is shown on some maps as Pirie Creek).

VR10, Upper San Antonio Creek, adjacent to VR09, combines flow from the upper San Antonio and Thacher drainages in eastern Ojai.

VR11, the **Ventura River at Santa Ana,** is sampled below the Santa Ana Road bridge.

VR12, the **Ventura River at Highway 150** sampling location, is located upstream of the bridge. VR11 and VR12 monitor conditions on the upper Ventura River. The Robles Diversion Dam diverts water to Casitas Lake above these sites; diversions, and the porous sediments that form the river bottom in this reach, typically leave little flow in the channel after the rainy season.

VR13, the **Matilija Creek** sampling location, is approximately one kilometer downstream of Matilija Dam, at an obsolete USGS stream gauging station.

VR14, the **North Fork Matilija Creek** sampling location, is located below a bridge on Highway 33 used as a Ventura County flood gauging station. VR14 represents the most pristine sampling location in the program, the site least affected by anthropomorphic impacts.

VR15, Upper Matilija Creek, is the uppermost sampling location in the watershed. It is approximately 1.5 miles above Matilija Dam, in Matilija Canyon. Sampling above and below Matilija Dam, a candidate for removal and restoration, allows Channelkeeper to monitor the impact of its sediment-filled reservoir.

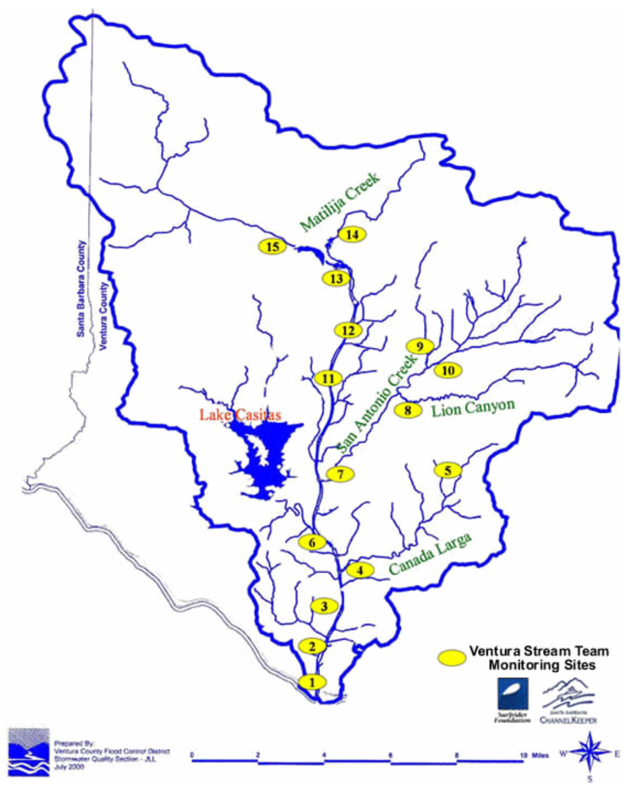


Figure 1. Map with Santa Barbara Channelkeeper's Ventura Stream Team sampling locations.

Since these groupings divide the watershed into reasonable geographic and ecological units, whenever possible we display and discuss the data that follows using a similar format. When the variation of a measured parameter with time is shown or discussed, four sites, VR04, VR05, VR11 and VR12, are omitted. Flow in these locations has become increasingly rare with the passage of time (more on this later); for example, the last three years saw only eleven months of flow at VR04 and VR05, four at VR11 and five at VR12. We do, however, include these sites in the presentation of the overall results for each parameter.

Hydrology

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

Rainfall Variability

The dominant hydrologic characteristic of the Ventura River, and indeed, of all streams in coastal Southern California, is extreme inter-annual variation in rainfall and river runoff. On the Ventura River average annual flows have varied from near zero (1951) to 380 (1995) cubic feet per second (cfs).[1] Since 1878, the average winter rainfall in Los Angeles has been 15 inches (NWS-LA).[2] However, “average” conveys no sense of the extreme variability. Very few years actually have “average” rainfall; most years are drier than average and a relatively few really wet years heavily influence the record (these are usually, but not always, associated with strong El Niño events; Null, 2004; Monteverdi and Null, 1997). If a “wet” year is defined as having rainfall at least 150% above the average (greater than 22 inches in downtown Los Angeles), there have been seventeen “wet” years since 1878, approximately one every seven and a half years. The 1990s were unusual in that three wet years (1993, 1995 and 1998) occurred relatively close together within a single decade.

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) northwards, while the “warm” phase shoves it, and rainfall, southwards – giving the south coast and southern California wetter winters.

Annual flows in the Ventura River, dependent on rainfall, vary in a similar fashion, and one way of showing the long-term pattern is a plot of *cumulative departures from the mean*. The average annual flow in the river is equivalent to five inches of rainfall (measured at Foster Park).[3] The upper panel of Figure 2 plots the cumulative flow excess or deficiency. In other words, a

---

[1] Flows recorded at the USGS gauging station at Foster Park, USGS-NWIS.
[2] The Los Angeles record is the longest in the region. Climate data for the region are available from a number of internet sources: DRI-WRCC, CDEC, CCDA and JISAO.
[3] If we assume that the average rainfall in the watershed is roughly that of Ojai, 21.5 inches, then approximately 20% ends up flowing down the Ventura River. As for the rest, most is evaporated or transpired by plants and trees, and a smaller part recharges the groundwater table or is stored as soil moisture.

continuous accounting of how much each year's flow affected the long-term departure away from maintaining the five inch per year average. The plot shows a pattern of alternately rising and falling trends, where flow was either generally above or generally below average, lasting decades. Increasing trends are generally caused by an increased frequency of big years. The general pattern between 1944 and 1968 was below average flows (a decreasing trend), but from 1968 to 1998 the trend reversed – except during the great California drought of 1987-1992.

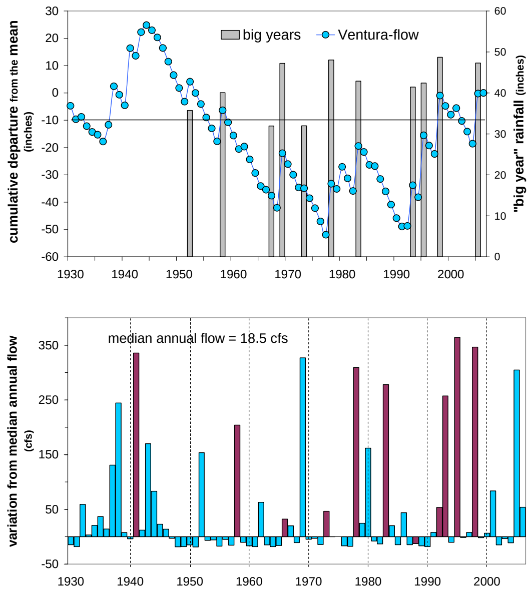


Figure 2. *Upper panel:* The cumulative *flow* excess or deficiency – how much each water-year's flow (measured in inches of runoff at Foster Park) varied from the 4.98 inch overall average. The plot shows the same pattern of rising and falling trends, heavily influenced by wet years, as rainfall. Wet years, in this chart, represent Ojai rainfall above 31.5 inches.
Lower panel: Median annual flow on the Ventura (at Foster Park) is 18.5 cfs, i.e., half the years on the chart had average flows less than this, the other half were greater. The distribution is skewed – "above the median" years tend to be extremely wet. While not a wet year, slightly above-average rainfall in 2006 reinforced increased groundwater inflows from 2005, giving appreciably enhanced flows (annual average = 72 cfs) in summer 2006.

Cycles of Change

The extreme rainfall variability experienced in the Ventura watershed engenders cycles of sediment deposition and removal, algal growth, and the advance and retreat of riparian and aquatic vegetation along the river. In turn, these changes dramatically alter the appearance and biological functioning of the river and riparian zone, and regulate the uptake of nutrients.

Major winter storms, such as occur during severe El Niño years, begin a transformational cycle by completely scouring the channel of vegetation and fine sediment; this occurs, on average, once every seven years (the interval has varied from three to 30 years) (Leydecker et al., 2003). The scoured river channel, with broadened flows, warmer water temperatures, an absence of shade and a nutrient-rich environment (caused by higher nutrient concentrations from enhanced groundwater inputs following a wet winter along with abundant nitrogen and phosphorus from urban and agricultural runoff), becomes dominated by filamentous algae (principally *Cladophora*, *Rhizoclonium*, *Enteromorpha* and *Spirogyra* spp.). Under these conditions, even

Figure 3. View of the Ventura River looking downstream from Shell Bridge (VR03) on October 2, 2004 (upper photo) and on Feburary 2, 2005 (lower).

the undeveloped upper sections of the Ventura River, or the area's pristine streams, provide a hospitable environment for explosive algal growth. Even where nitrate concentrations are low, high phosphorus content from eroding mountain bedrock allow expanded growth of algal species that are able to utilize symbiotic relationships with bacteria to fix atmospheric nitrogen. As long as the storms of succeeding winters continue to be severe enough to keep the channel clean and sediment moving to the ocean, algae both dominate and thrive.

However, sooner or later a low runoff year occurs – mostly sooner, since two out of three years have less than half the average runoff (Figure 2). In the absence of severe winter floods, sediment accumulates in the channel and seedlings, having gained a toe-hold during the previous summer, become more deeply rooted. Exuberant plant growth begins the competitive replacement of algae by aquatic vegetation (Leydecker and Alstatt, 2002). Perennial aquatic plants become established (ludwiga, speedwell, water cress), over-shadowing the water surface and narrowing the channel by further trapping fine sediment. The rapid growth of riparian vegetation provides increased shade to a narrowed waterway and algal growth becomes increasingly confined to open, deeper waters. Where the growth of taller riparian vegetation, like willows and giant reed (*Salix* spp. and *Arundo donax*), appreciably block sunlight, algae may disappear entirely. Over the years these processes increasingly stabilize the channel and elevate the threshold flow of a future scouring storm.

In the five years since 2001, Ventura Stream Team has sampled a wide variety of conditions dictated by the annual variation in rainfall. The last big rainfall event, the previous flood that reset the transformational cycle described above, occurred during the severe El Niño winter of 1998. From 2001 through 2004, Channelkeeper has observed and documented these changes (cf. SBCK(b)). Figure 3 shows the variations in both monthly and annual rainfall that have occurred during the years of the Ventura survey. Prior to 2005, two of the years were slightly above normal (2001 and 2003) and two below normal (2002 and 2004), one of which (2002) could be characterized as a severe drought year.

An Extraordinary Year

The 2005 water-year, characterized by 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 Ojai, 10.4 inches were recorded during the first phase and slightly more, 12.6 inches, in the second. By the end of January, a total of 28.8 inches had fallen since the beginning of the rainy season, compared with the annual average of 20.9 inches. As storms coming out of the Pacific are uplifted over the coastal mountains, even larger amounts of rain are wrung out of them: San Marcos Pass received 18.2 and 24.6 inches, respectively, and amounts even greater than this were recorded in the Ventura River watershed at Old Man Mountain.

As shown in the lower panel of Figure 2, not all high rainfall years are severe El Niño years. At times, some really wet winters are caused by a much shorter weather cycle of 30 to 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 off-shore, 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. However called, it delivered extraordinary amounts of rainfall in the winter of 2005.

The Ventura River reacts rapidly to changes in rainfall. The peak flow on January 11, 2005 is estimated to have been 41,000 cubic feet per second (cfs) – a seventeen foot wall of water at Foster Park. This flood, and the copious rainfall that occasioned it, made 2005 the new transformational year; the year that began the cycle anew (Figure 3).

Another good year

2006 was, again contrary to expectations, another good water-year. Annual rainfall in downtown Ventura was 17.8 inches. This was below the amount of rainfall in 2001 and 2003 (Figure 4), but still 3.9 inches above average. Ojai rainfall (25.3 inches) was also above its annual average of 21.5 (and its median, since 1948, of 18.6 inches). But what made the year exceptional was the extravagantly excessive rainfall in April. In downtown Santa Barbara, 6.31 inches were recorded, 4.6 inches at the Ventura Government Center, 5.4 inches in Ojai. The historical medians (one half the recorded years had April rains below, the other half above, this amount) are 0.72 inches in Santa Barbara, 0.55 inches in Ventura. This was more than eight times the normally expected amount of rain. April 2006 proved to the second wettest April in both Santa Barbara (since 1868) and Ventura (since 1874). The rains continued into May, with 1.2 inches in both Ventura and Ojai compared with long-term averages (since 1948) of 0.23 and 0.45 inches. The bar graph in the upper panel of Figure 3 shows the wet nature of Spring 2006 when compared with previous survey years, and demonstrates that most of the rainfall occurred rather late in the season (more than half the total rainfall fell after February).

The effect on the river of two good water-years in a row, one with exceptionally heavy rainfall and the other with an unusually wet spring, was enhanced groundwater inflows. Wet years, while noted for large amounts of runoff, also replenish groundwater reservoirs, elevating water tables and increasing seepage into rivers and creeks. This can be most directly seen in the unusually high dry-season flows that follow a wet winter, but there is also a carry-over of higher

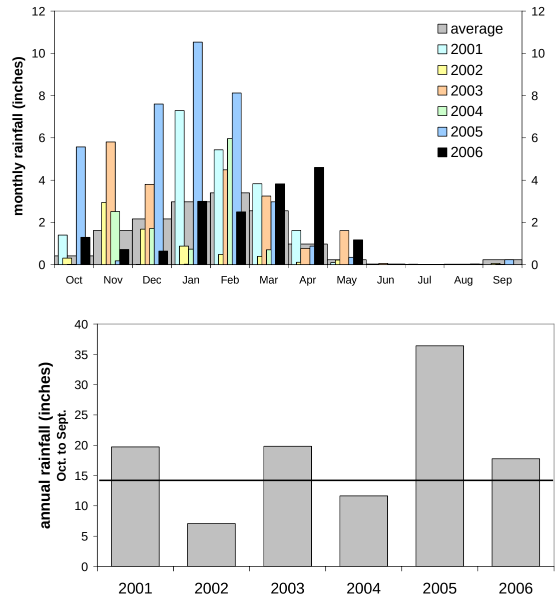


Figure 4. Monthly (upper panel) and yearly (lower panel, for October to September water-years) rainfall for 2006 and previous years of Channelkeeper's Ventura Stream Team surveys (Ventura COOP station, 049285-6, http://www.calclim.dri.edu/ccda/scacoop.html). The heavy line in the lower panel represents the average annual Ventura rainfall of 14 inches. While rainfall in 2006 was not as remarkable as that of 2005, it was an above average year (17.8 inches) with an extremely wet spring (April rainfall was 4.6 inches, the second wettest in since 1874) and far above the median of 0.55 inches (half of Ventura's Aprils have been wetter than this, half drier).

flows into subsequent years. The upper panel of Figure 5 compares June through September flows at Foster Park for each year from 1998 through 2006 and also shows annual rainfall (as well as median dry-season flows and rainfall for comparison). Note that flows were very high during the wet years of 1998 and 2005, but that flows in the years that directly followed were also much higher than might be expected from the amounts of rain that fell. 1999, 2002 and 2004 all had below median amounts of rainfall, yet dry-season flows in 1999 were over twice the median, while those of the other two years were less than half, and while 2004 had appreciably more rain than 2002, flows were quite similar.

What accounts for this is the relatively proximity of a wet year. Wet years recharge the groundwater table, almost all other years deplete it. The recharge that occurs during a wet winter can carry over for quite a number of years. We've attempted to quantify this effect in the lower panel of Figure 5, which shows the ratio between average dry-season flow and rainfall for each year (average dry-season flow divided by the rainfall of the preceding winter). If everything were equal, more rainfall should produce more summer flow and the ratio should be similar from year to year. However, this turned out not to be the case. The bold lines show the trend towards less flow per inch of rain as we move further from a wet year. In contrast with declines shown following the big El Nino year of 1998, and above average rainfall in both 2000 and 2001, 2006 shows a substantial increase in the ratio. In other words, summer flows were far higher than expected, the combined product of 2005 and the wet 2006 spring.

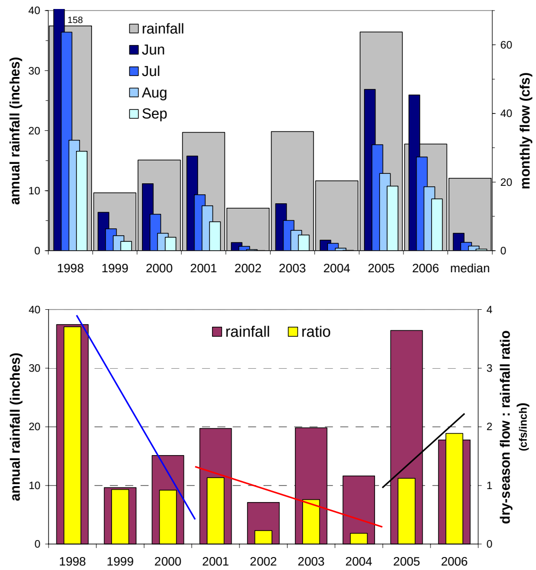


Figure 5. In the upper panel, annual rainfall (in Ventura) is plotted for the severe El Niño year of 1998 and every year since, along with average June, July, August and September flows at Foster Park in cfs for each year (shown on the right-hand axis). The median rainfall and monthly flows are included for comparison. Rainfall is again plotted in the lower panel, but the right-hand scale shows the ratio between average May through September flow and rainfall, i.e., the ratio between average dry-season flow and rainfall. The bold lines show the trend towards less flow per inch of rain as we get further from a large El Niño; it required two years of above-average rainfall (2000 and 2001) to partially recover from low rainfall in 1999. River flow in 2004 was as low as it was in 2000, despite having approximately five times the rainfall. In contrast, 2006 shows an increase in the ratio, more runoff than expected, as the result of a wet spring and two good years in a row enhancing groundwater supplies.

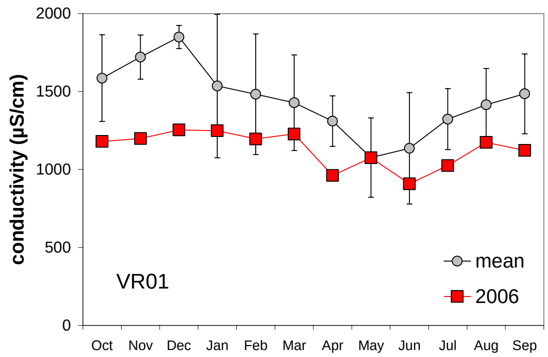
Conductivity[4]

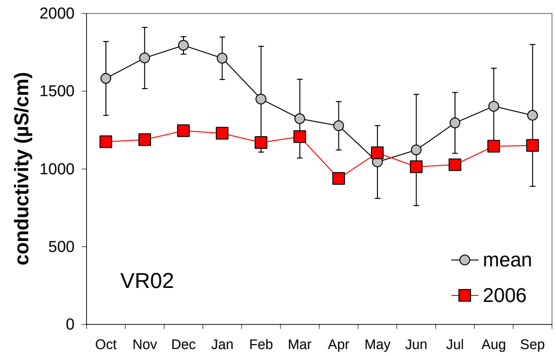
Water, one of the most efficient solvents in the natural world, is able to dissolve a great many solids. Many of these solids when put into solution carry an electrical charge. For example, chloride, nitrate and sulfate carry negative charges, while sodium, magnesium and calcium have a positive charge.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

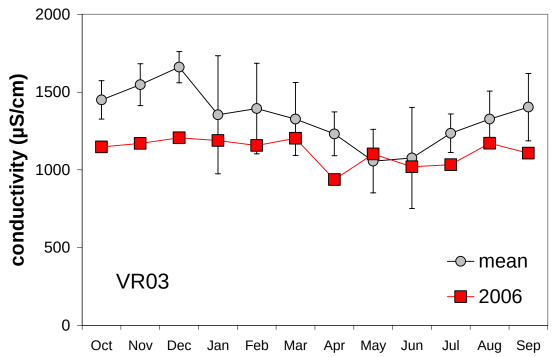
Conductivity is affected by temperature: the warmer the water, the higher its conductivity. For this reason, conductivity is usually reported at a standard temperature: 25 degrees Celsius

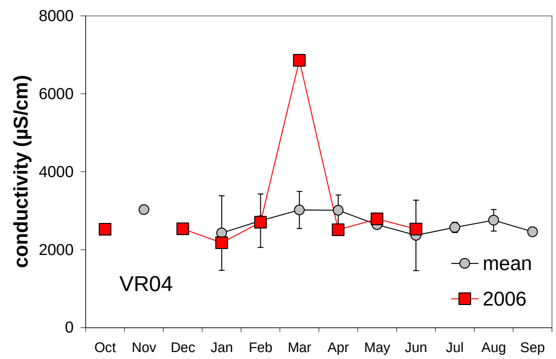
[4] US-EPA (1997), Deas and Orlob (1999) and Heal the Bay (2003) were used as references in the preparation of the following sections on water quality parameters.

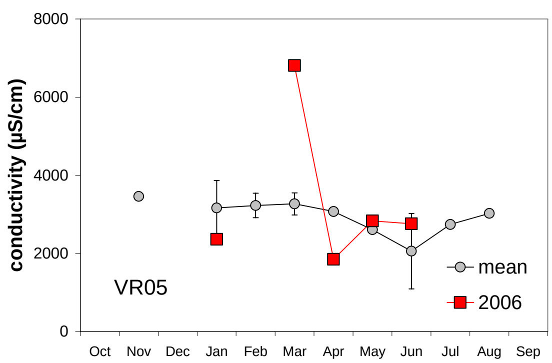
(25°C). Conductivity is measured in micro-siemens per centimeter (µS/cm) or milli-siemens per centimeter (mS/cm). Distilled water has a conductivity in the vicinity of 0.5 to 3 µS/cm and the conductivity of rivers in the United States generally ranges from 50 to 1,500 µS/cm. Drinking water typically has to meet a standard of 1,000 mg/L total dissolved solids and a maximum conductivity of 1,600 µS/cm.

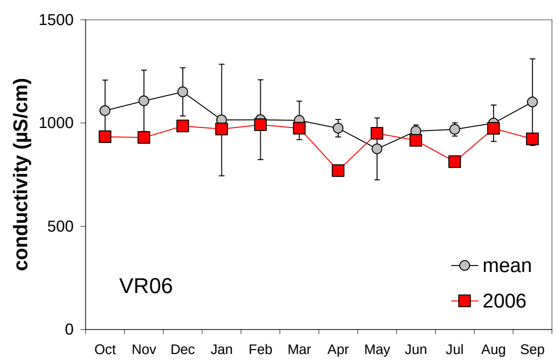


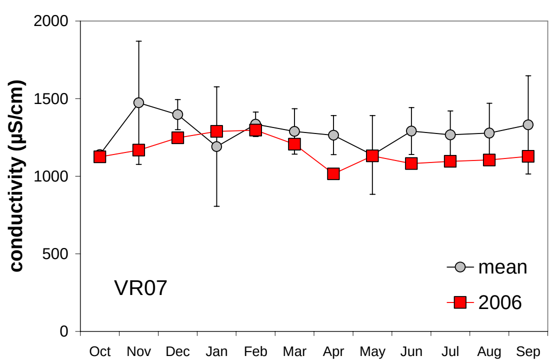


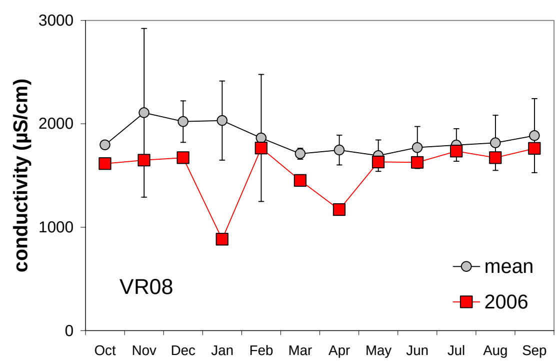












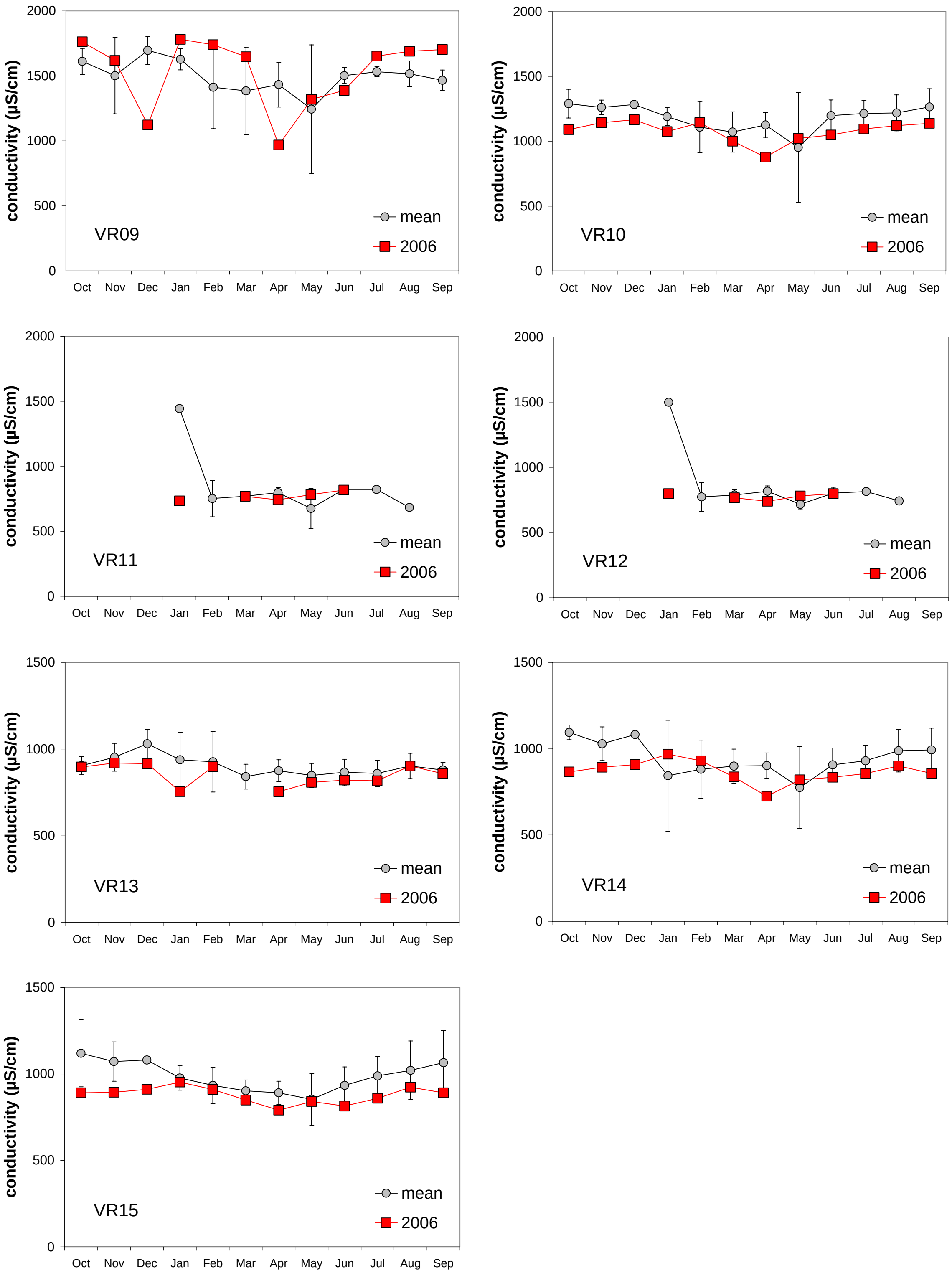


Figure 6. Monthly conductivies for the Ventura Stream Team sampling locations during the 2006 water-year are shown with along with the average monthly conductivity from 2001-2005. Error bars indicate the monthly standard deviation in µS/cm.

In the Ventura watershed, there has been a trend towards increasing conductivity from 2001 until the winter of 2005 (Figure 7). A trend (cf. SBCK, 2004) caused by (1) increasingly depleted and generally older groundwater inflows, (2) enhanced uptake by growing riparian vegetation, and (3) a relative increase in evaporation as dry-season river flows decreased. (All related, as described in the previous section, to increasing amounts of time since the last wet winter of 1997-98.) Conductivity, everything else being equal, generally increases with the age of water – the longer water is in contact with soil or geologic strata, the higher its conductivity; groundwater has higher conductivity than water in the soil, and older groundwater higher conductivity than younger.

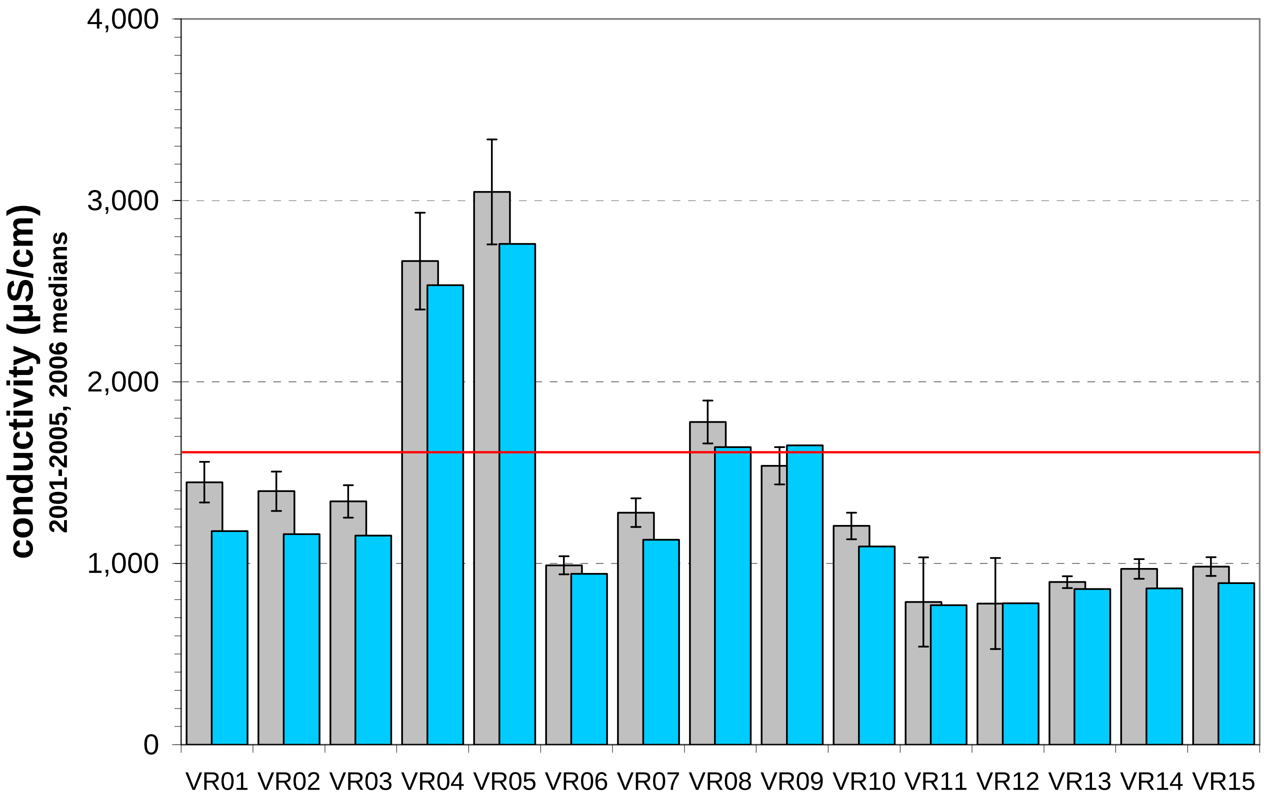


Figure 7. Median conductivities during the 2006 water-year are contrasted with median conductivity for the previous five years (2001-2005). The error bars indicate twice the standard error of the median, i.e., the 2006 median would be expected to lie within these error bars and anything beyond the limits could indicate a significant change (only one out of every 20 years would be expected to naturally fall outside of ± two standard errors). Note that 2006 conductivity at locations with year-round water generally falls below these limits. The horizontal line represents a generally accepted upper conductivity limit of 1,600 µS/cm for drinking water.

In 2005 the situation abruptly changed. The advent of a wet water-year (rainfall of 36.2 inches in Ojai) caused a dramatic increase in dry-season flows. With this increase there was an abrupt decrease in conductivity (Figure 8). Higher water levels, caused by increased flows from higher elevations (which generally have lower conductivity) and increased inputs from replenished water tables (with recent, lower conductivity, runoff) greatly lowered conductivity throughout the system.

When presenting 2006 data, for conductivity and all other parameters, we use two formats. One shows the 2006 monthly variation against a background of average monthly values (determined by averaging monthly results from 2001 through 2005), and the other shows the average 2006 value along with the long-term average from 2001 through 2005. In other words, monthly and average 2006 values are contrasted with previous results. This should enable us to tell at a glance where significant departures from the norm have occurred. Monthly variations in conductivity for each sampling location are shown in Figure 6 and the annual averages in Figure 7.

Figure 6 indicates that 2006 conductivities were almost always below average. This was somewhat to be expected since the monthly average incorporates four years of rising conductivity (2001-2004) and one year (2005) of low conductivity. Error bars in the figure indicate the monthly standard deviation. The inference is that we could expect conductivity to

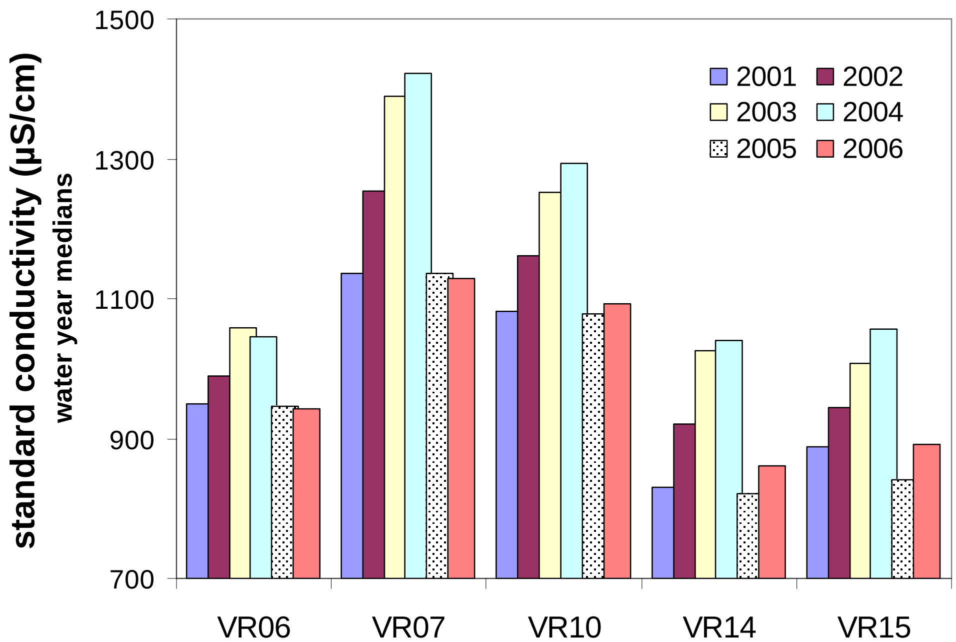


Figure 8.
Changes in annual median conductivity for Ventura Stream Team sampling sites with relatively natural, year-round flows, 2001-2006. There had been a consistent increase in conductivity over the initial four years of sampling; the percent increase from 2001-2004 at VR06 through VR15 was 12, 23, 19, 25 and 19%, respectively. However, in 2005 conductivity abruptly decreased by 20% throughout the Ventura system. In 2006 conductivity generally increased at upper elevation sites (VR14 & 15) and decreased at the lower ones (VR06 & VR07).

fall within the error bars every two out of three years. In other words, a 2006 value within the error bars can be considered relatively normal. For statisticians, reasonable values are those which fit between *two* standard deviations – twice the limits shown by the error bars – and Figure 6 shows very few results that fit this description. Those that do mostly occurred during October, November and December, and are part of the very low values seen in 2005, i.e., they occurred before the winter rains of 2006.[5]

Measurements taken during or soon after storms show very low conductivities due to large amounts of fresh runoff. Rain in this region generally has a conductivity between 10 and 40 µS/cm. Months in Figure 6 that have a large difference between error bars, i.e., indicating a wide variation in monthly values, include storm values in the data record. Similarly, low conductivity in April 2006 identifies rain-influenced measurements. Monthly averages derived from limited data show no error bars and some months are totally absent; these data identify sites that are usually dry during those months (e.g., VR04, VR05, VR11 and VR12). Occasional low 2006 values in December (VR09) or January (VR08) defy explanation and are probably the result of measurement error.

The most unusual site in 2006 was VR09, which showed higher than average conductivity whereas almost all other locations were below average. This is best seen in Figure 7, where median 2006 conductivity is contrasted with the median of all previous data. The median is a better measure of "average" conductivity than the actual average since it reduces the effect of occasional low, storm-influenced values. The error bars in Figure 7 indicate twice the standard error of the median. Note that the majority of sites in 2006 fell below this limit, indicating a significant difference. However, a significant difference may or may not be meaningful, and in this case, since we know too many dry-year data points with increasing conductivities were included in the median, the below-average results are not meaningful.

Figure 8 illustrates the overall trend, showing median annual conductivity for all years since 2001 at locations with relatively natural year-round flows (sites that don't go dry and that are uninfluenced by urban nuisance waters or Ojai sewage treatment plant effluent). Much of what was discussed earlier can be seen here: the abrupt 2005 decrease following the gradual increase from 2001 through 2004. However, sites in 2006 exhibited disparate trends. Locations on the upper Matilija showed the increasing conductivity we might have expected in the second season after a wet winter (VR14 and VR15), but lower-elevation locations had similar or even lower conductivity than during 2005 (VR06 and VR07). One possible explanation could be a greater percentage of 2006 recharge showing up at the lower sites, either due to shorter groundwater travel times or proportionally greater lower-elevation rainfall.

Temperature

The expected annual pattern for water temperature is straight-forward: rising from winter lows to summer highs and then decreasing in early fall. In other words, water temperature follows changes in air temperature. On the Ventura, that pattern is observed at all sites (Figure 9). The error bars in Figure 9 again indicate the monthly standard deviation. And while few of the 2006

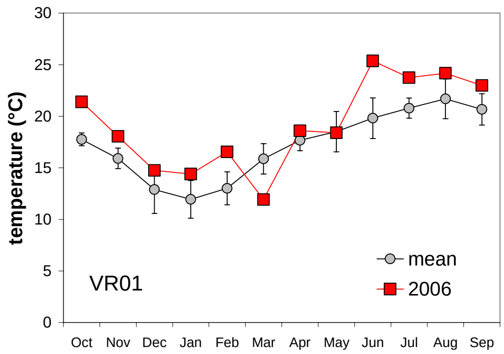
[5] Measurements that fall outside of two standard deviations are considered relatively rare, normally occurring only 5% of the time. Applying this to monthly conductivity, this would occur only once every twenty years, and a value this far outside the norm would be considered significantly different. In essence, this is the statistician's definition of significant.

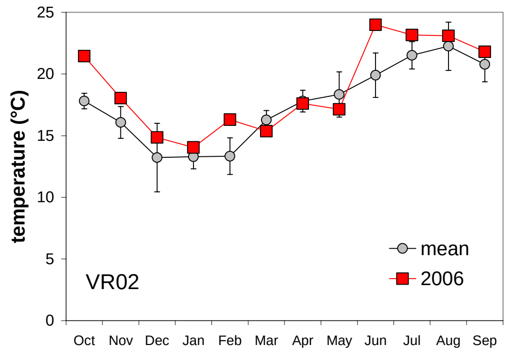
measurements were significantly different from monthly averages (i.e., fall below or above two standard deviations), there were some departures from the established pattern.

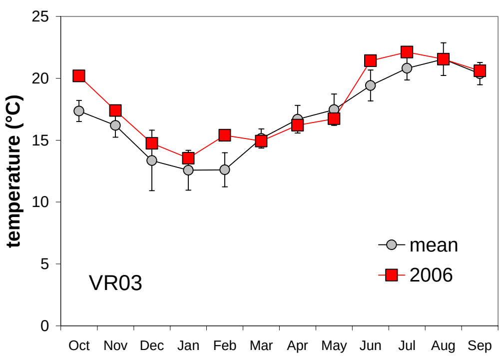
Most obvious were lower water temperatures in March, April and May, particularly at higher elevation locations (VR08-15). At lower elevations, temperatures seem to have been higher during both the earlier and later parts of the water-year. Abundant rain and increased flows probably account for lower temperatures during spring; flows in April were among the highest ever seen, higher than in 2005 or 1998. The lower sites exhibited some of the “apples and oranges” problem seen in the conductivity discussion. The monthly average combines years with different characteristics: years like 2002-2004 when almost complete aquatic plant cover shielded the river from sunlight vs. other years with more open flow. Data from October, November and December were particularly susceptible to this problem since these months in 2005 represent characteristics developed during 2004 instead of the changed circumstances that followed the big storms around the end of the calendar year.

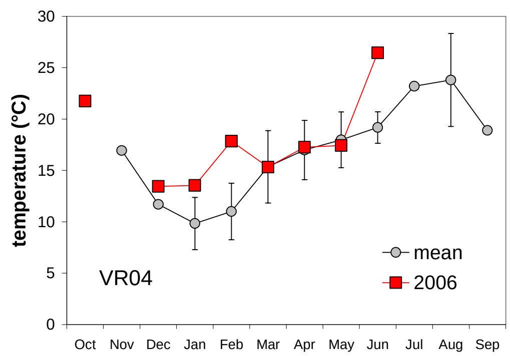
Plant cover, increased flows and cooler weather produce lower water temperatures while the opposite circumstances produce higher. These effects are particularly pronounced on the lower Ventura’s broad and shallow flows. On the other hand, sites that often go dry, like VR04 and 05, often show aberrant results for the low trickling or puddle type flows seen at the beginning and end of wet episodes.

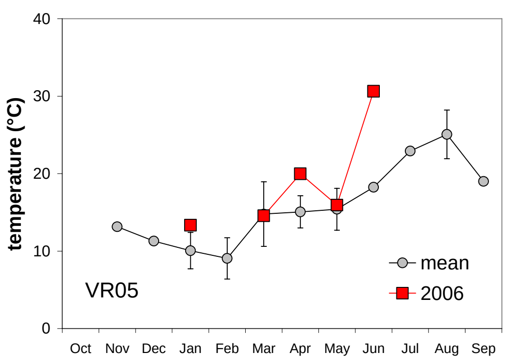
Annual averages (with error bars denoting maximum and minimum water temperatures for both 2006 and the overall average) are shown in the bottom panel of Figure 11. The graph includes three horizontal lines to help put these results in perspective. These mark important threshold temperatures for trout and steelhead: above 24°C leads to death; below 16°C indicates good dry season conditions; and below 11°C in winter is excellent for spawning and incubation (Brungs and Jones, 1977; Armor, 1991; McEwan and Jackson, 1996; Sauter et al., 2001). As temperatures rise, fish have increasing trouble extracting oxygen from water, while at the same time the maximum amount of oxygen able to be held in solution decreases.

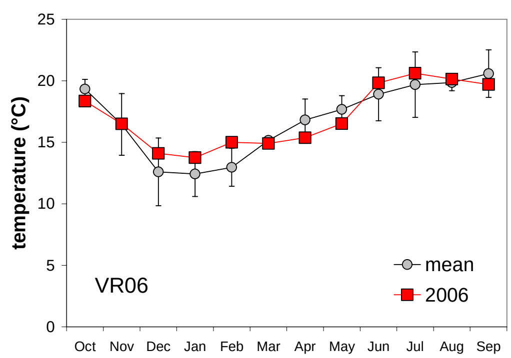

temperature (°C)
0 5 10 15 20 25 30
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep
VR01
mean
2006

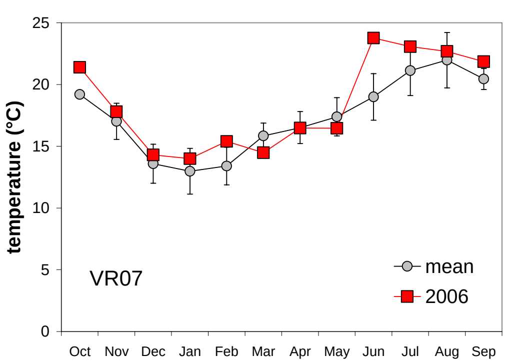

temperature (°C)
0 5 10 15 20 25
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep
VR02
mean
2006

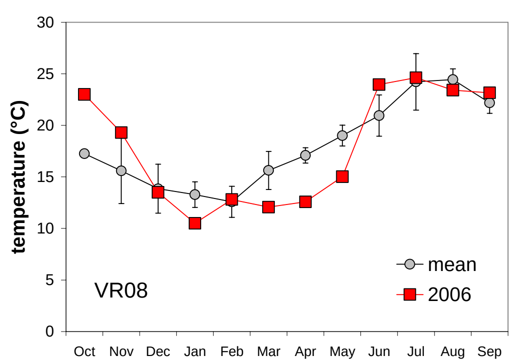

temperature (°C)
0 5 10 15 20 25
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep
VR03
mean
2006


temperature (°C)
0 5 10 15 20 25 30
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep
VR04
mean
2006


temperature (°C)
0 10 20 30 40
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep
VR05
mean
2006


temperature (°C)
0 5 10 15 20 25
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep
VR06
mean
2006


temperature (°C)
0 5 10 15 20 25
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep
VR07
mean
2006


temperature (°C)
0 5 10 15 20 25 30
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep
VR08
mean
2006

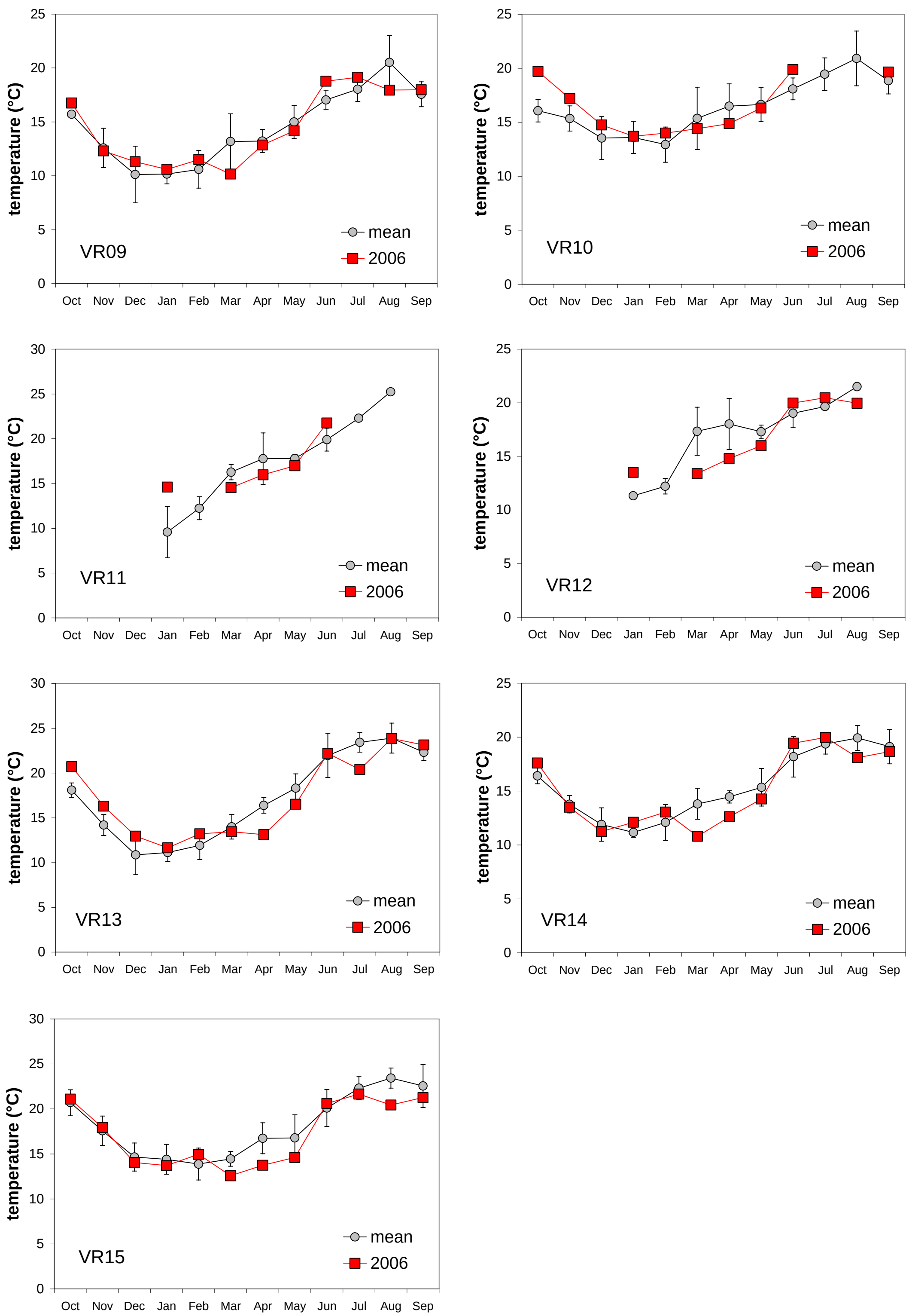


Figure 9. Monthly water temperatures for Ventura Stream Team sampling locations during the 2006 water-year are shown, along with the average monthly temperature from 2001-2005. Error bars indicate the monthly standard deviation in °C.

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

Dissolved Oxygen

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

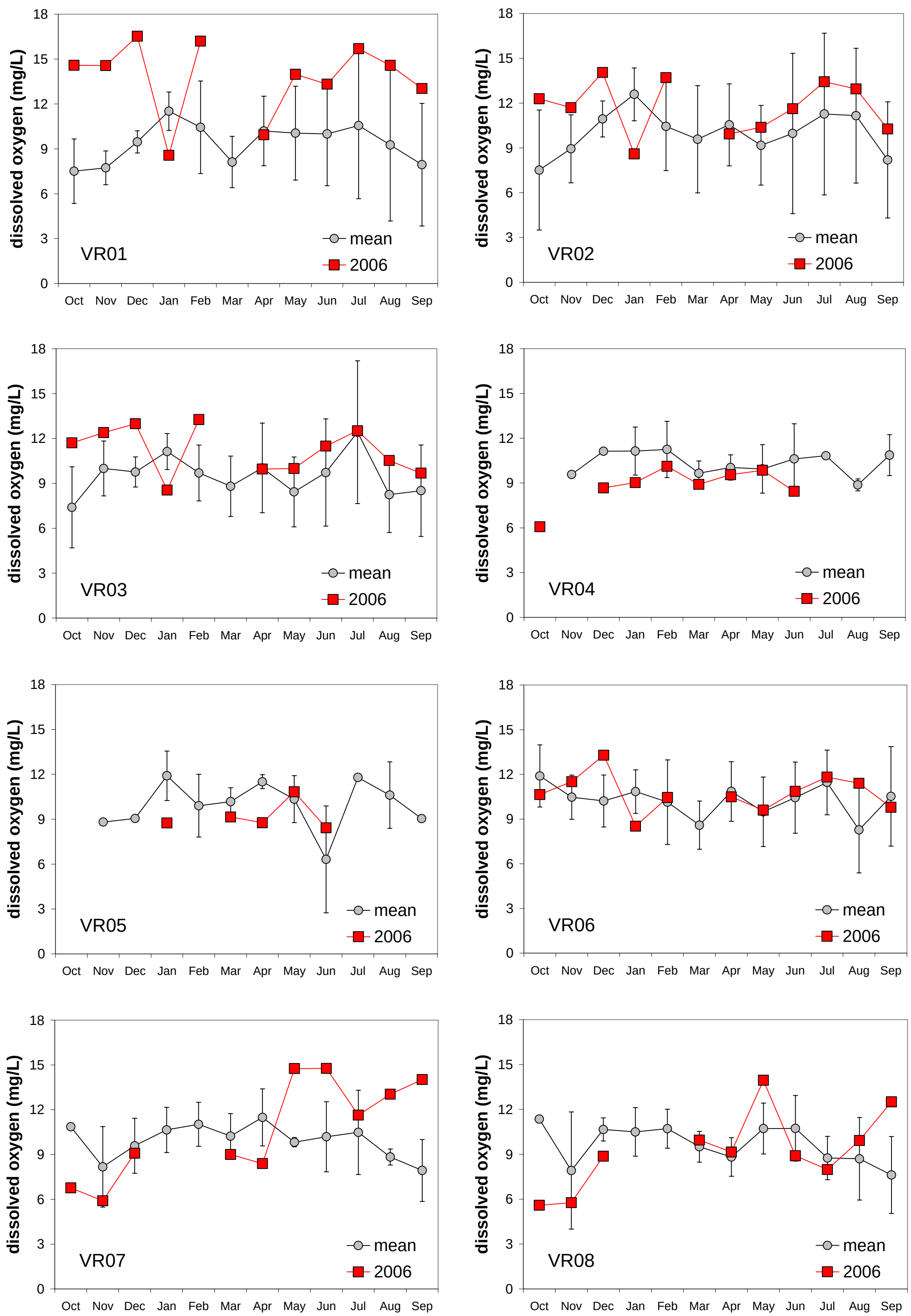
Dissolved oxygen (DO) is usually measured in milligrams per liter (mg/L) or percent saturation. Milligrams per liter is the weight of oxygen in a liter of water. It's often simpler to think of mg/L as "parts per million," since a liter of water weighs a million milligrams, 1 mg/L is the same as one part of dissolved oxygen in a million parts of water.

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

Dissolved oxygen concentrations during 2006 at the Ventura sampling sites are shown in Figure 10. Error bars represent the standard deviation of past monthly concentrations. DO in 2006 was generally higher than the average of past measurements, and in almost all cases monthly concentrations were above 6 mg/L. Unfortunately, this is not good news. DO concentrations were often too high and, as such, indicate trouble.

Stream sampling typically takes place in daylight. During much of the year, algae and underwater aquatic vegetation use sunlight for photosynthesis, removing carbon dioxide from the water column and replacing it with oxygen. This process is reversed at night when oxygen is removed and carbon dioxide added (Carlsen, 1994; NM-SWQB, 2000). Thus very high daytime oxygen concentrations can indicate an overabundance of algae. Under these conditions oxygen reaches a minimum just before sunrise – and it is concentrations during this critical period that determine the actual threat to fish and other aquatic species, a threat that is ordinarily not evaluated (Windel et al., 1987; Deas and Orlob, 1999; PIRSA, 1999).

Summer-time water temperatures in the Ventura River system usually peak around 20°C (Figure 9). Water at this temperature, in equilibrium with a sea-level atmosphere, can contain a maximum concentration of 9 mg/L of dissolved oxygen (i.e., completely saturated). Minimum stream temperatures generally fall to 10-12°C, with a DO concentration of ±11 mg/L at complete saturation. So summer concentrations above 10 mg/L or winter concentrations greater than 12 mg/L are an indicator of too much oxygen during daylight testing (and therefore the possibility of too little during the early morning hours), and most of Ventura Stream Team sampling locations exhibit this problem during at least part of the year. (Note the early spring oxygen peaks on the Matilija; the May and early fall peaks at Foster Park and below Ojai (VR06, VR08, VR09 and VR10); and the almost year-round presence of abnormally high oxygen levels on lower San Antonio Creek and the lower Ventura (VR01-03, and VR07)).



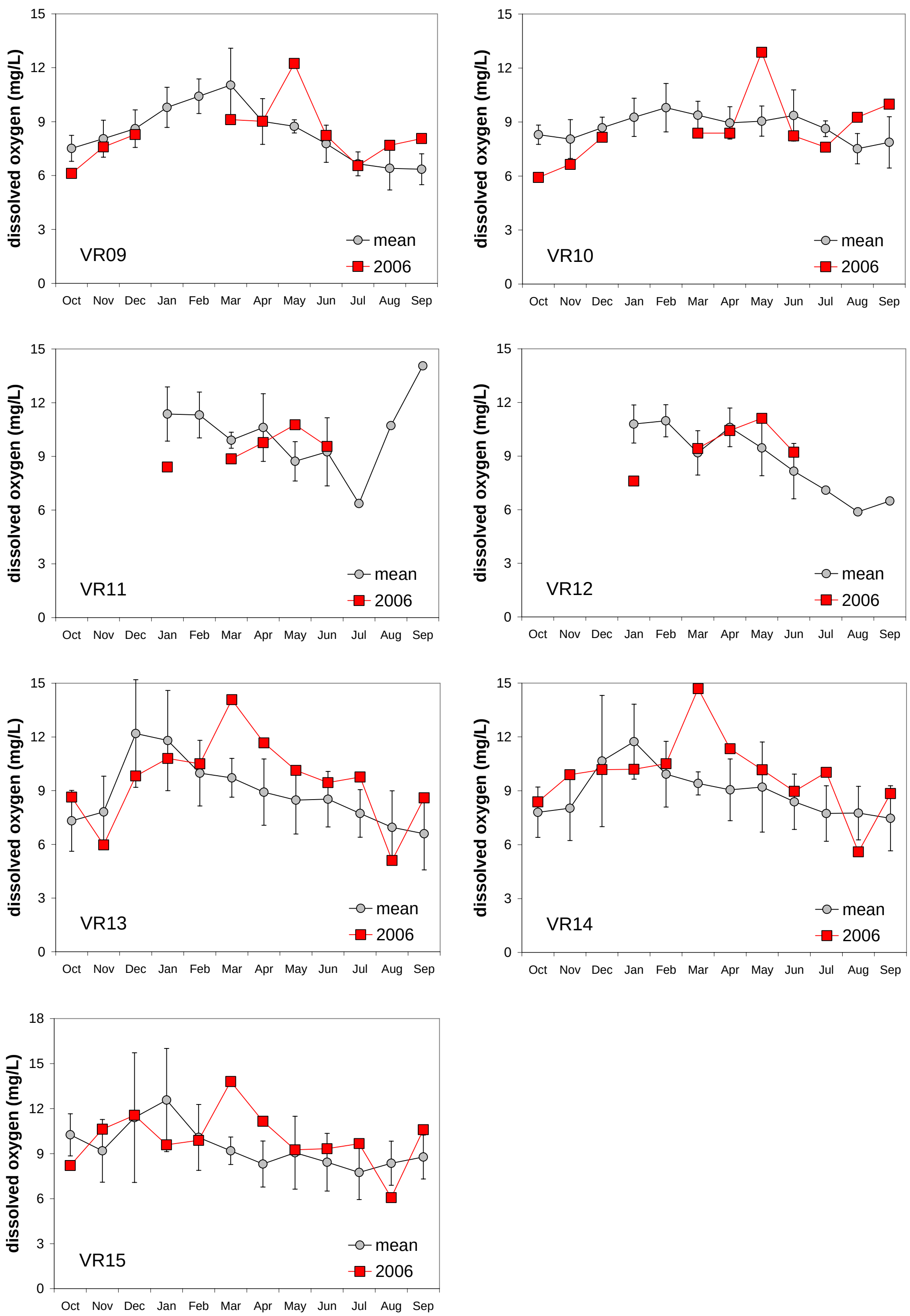


Figure 10. Monthly dissolved oxygen concentrations for Ventura Stream Team sampling locations during the 2006 water-year are shown, along with the average monthly dissolved oxygen from 2001-2005. Error bars indicate the monthly standard deviation in mg/L.

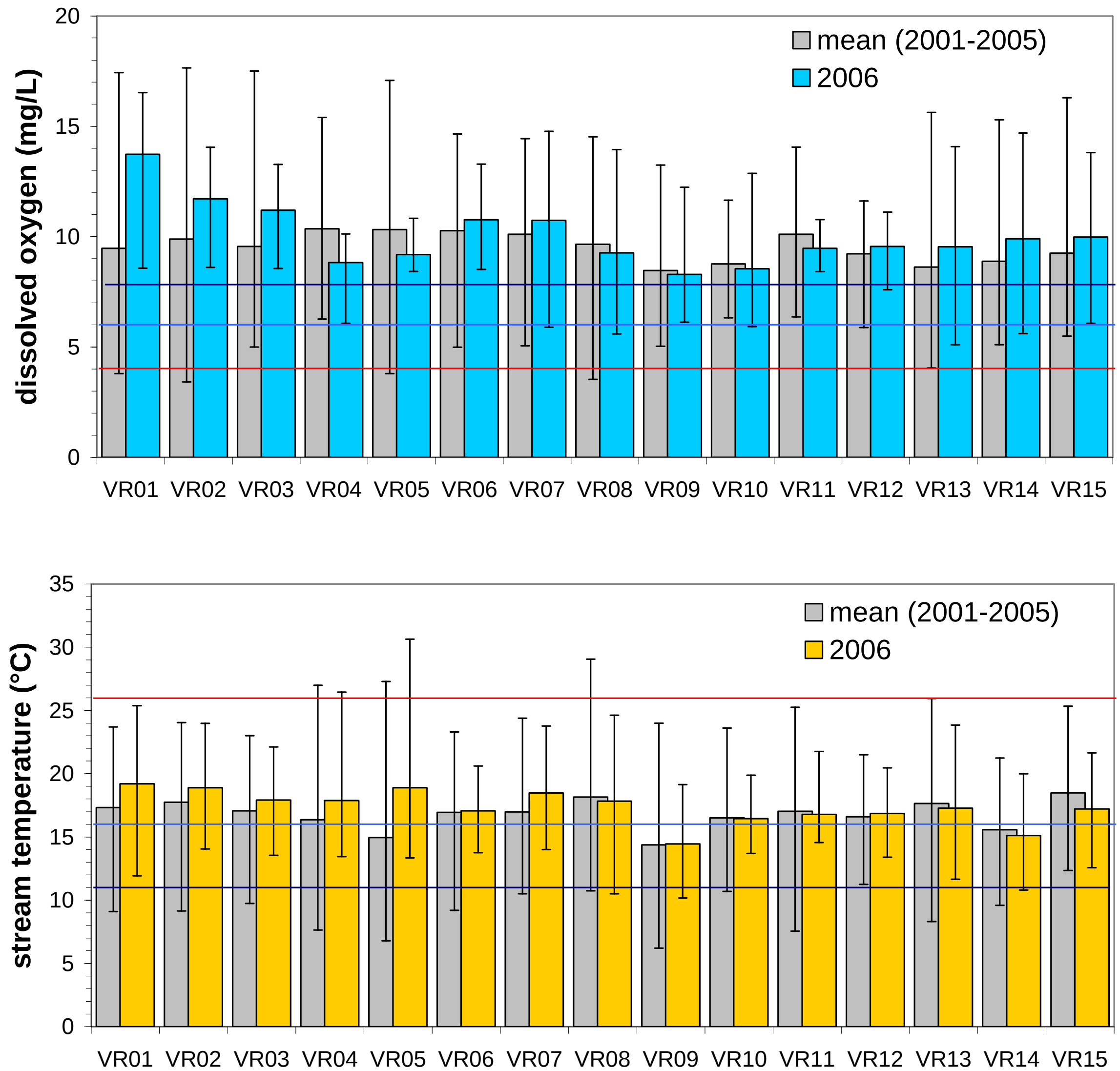
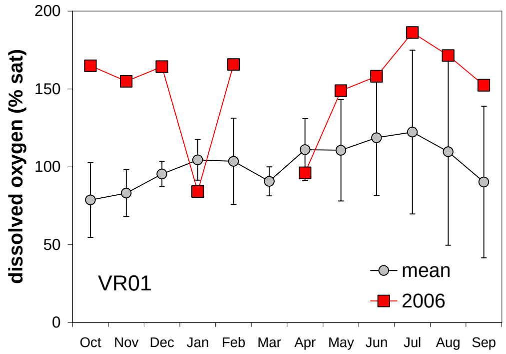
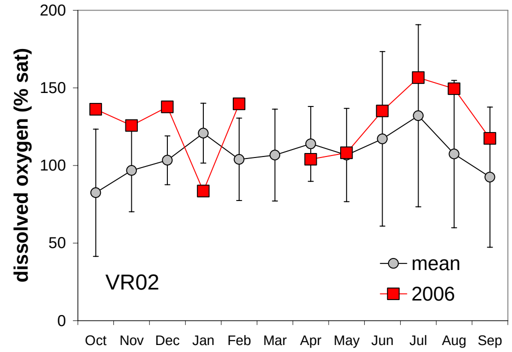


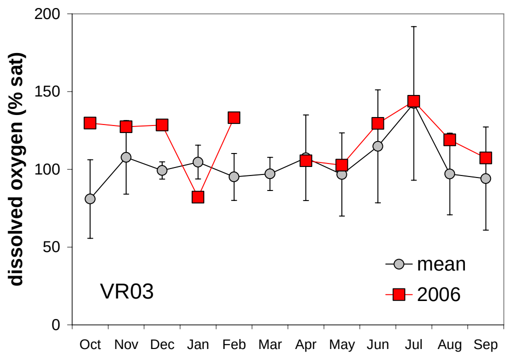
Figure 11. *Upper panel*: Average dissolved oxygen concentrations for Ventura Stream Team sampling locations during the 2006 water-year are contrasted with mean dissolved oxygen from 2001-2005. Error bars indicate the maximum and minimum concentrations for each average. The 3 horizontal lines mark important DO milestones; above 8 mg/L represents near ideal conditions; below 6 trout and steelhead start to feel stress (but no lasting harm is done in the short term); and below 4 lies severe damage and death. (lower panel) Average 2006 stream temperature contrasted with mean temperature from 2001 through 2005; error bars again indicate maximum and minimum temperatures. The lines represent temperature milestones: above 24°C leads to death; below 16°C indicates good dry season conditions; and below 11°C is excellent for spawning and incubation. Extreme values become critical at locations with measurements below (for DO) or above (for temperature) the bold line.

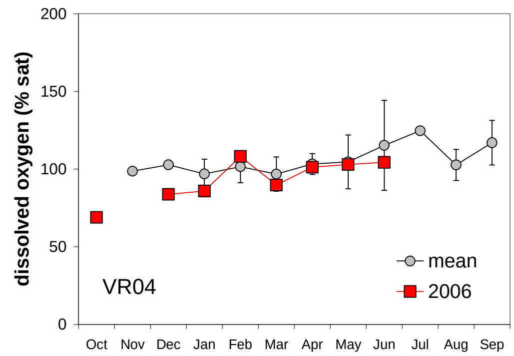
Channelkeeper's Ventura Stream Team sampling program also measures *percent saturation*, the amount of DO compared with what water, at the measured temperature and altitude, can hold at equilibrium; in other words, the oxygen excess or deficiency compared with this theoretical maximum. Theoretical, because a stream or river can become super-saturated with oxygen. The key word is *equilibrium*, meaning the attainment of some steady state, a balance between the amount of oxygen entering and the amount leaving. A stream slowly warming as morning air temperatures rise can become super-saturated, as can a turbulent reach actively entraining oxygen. But the only process capable of achieving high amounts of super-saturation is active photosynthesis. A dissolved oxygen content in excess of 120% of saturation is a good indicator of algal problems (it can go as high as 400%). Figure 12 shows 2006 percent DO saturation results for the sampling sites and demonstrates the large extent of algal problems during the past year.

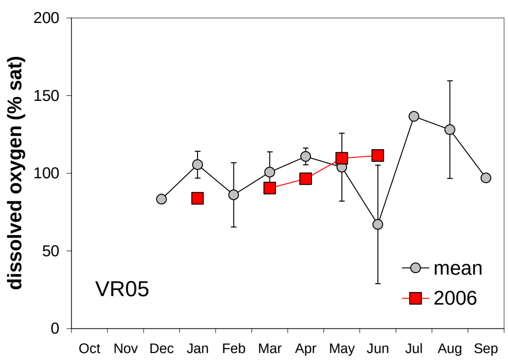
Winter storms in 2005 created ideal conditions for excessive dry-season algal growth in the Ventura River system by: opening the river and tributaries to sunlight; removing competing vegetation; sweeping insect predators out to sea; flushing sediment; restoring a rocky bottom (the ideal substrate for most problem causing algal species in this area); and, through increased groundwater infiltration, insuring expanded habitat and plentiful nutrients. During 2006 these conditions continued. If anything, algal growth during the spring of 2006 may have exceeded that of 2005. Only during the latter part of the year did the heavy growth of aquatic plants inhibit the impact of algae on the lower river (Figure 13). This can be seen in the decrease in % saturation at VR01-03 and VR06 in August and September after peaking in July (Figure 12).

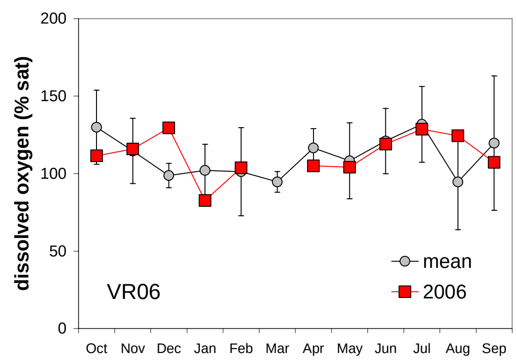

dissolved oxygen (% sat)
200
150
100
50
0
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep
VR01
mean
2006

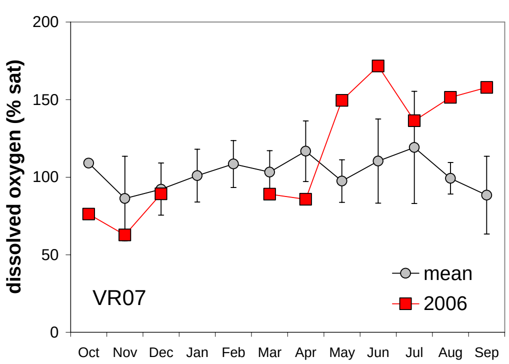

dissolved oxygen (% sat)
200
150
100
50
0
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep
VR02
mean
2006

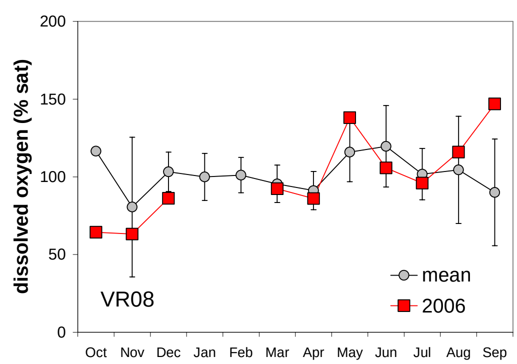

dissolved oxygen (% sat)
200
150
100
50
0
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep
VR03
mean
2006


dissolved oxygen (% sat)
200
150
100
50
0
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep
VR04
mean
2006


dissolved oxygen (% sat)
200
150
100
50
0
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep
VR05
mean
2006


dissolved oxygen (% sat)
200
150
100
50
0
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep
VR06
mean
2006


dissolved oxygen (% sat)
200
150
100
50
0
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep
VR07
mean
2006


dissolved oxygen (% sat)
200
150
100
50
0
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep
VR08
mean
2006

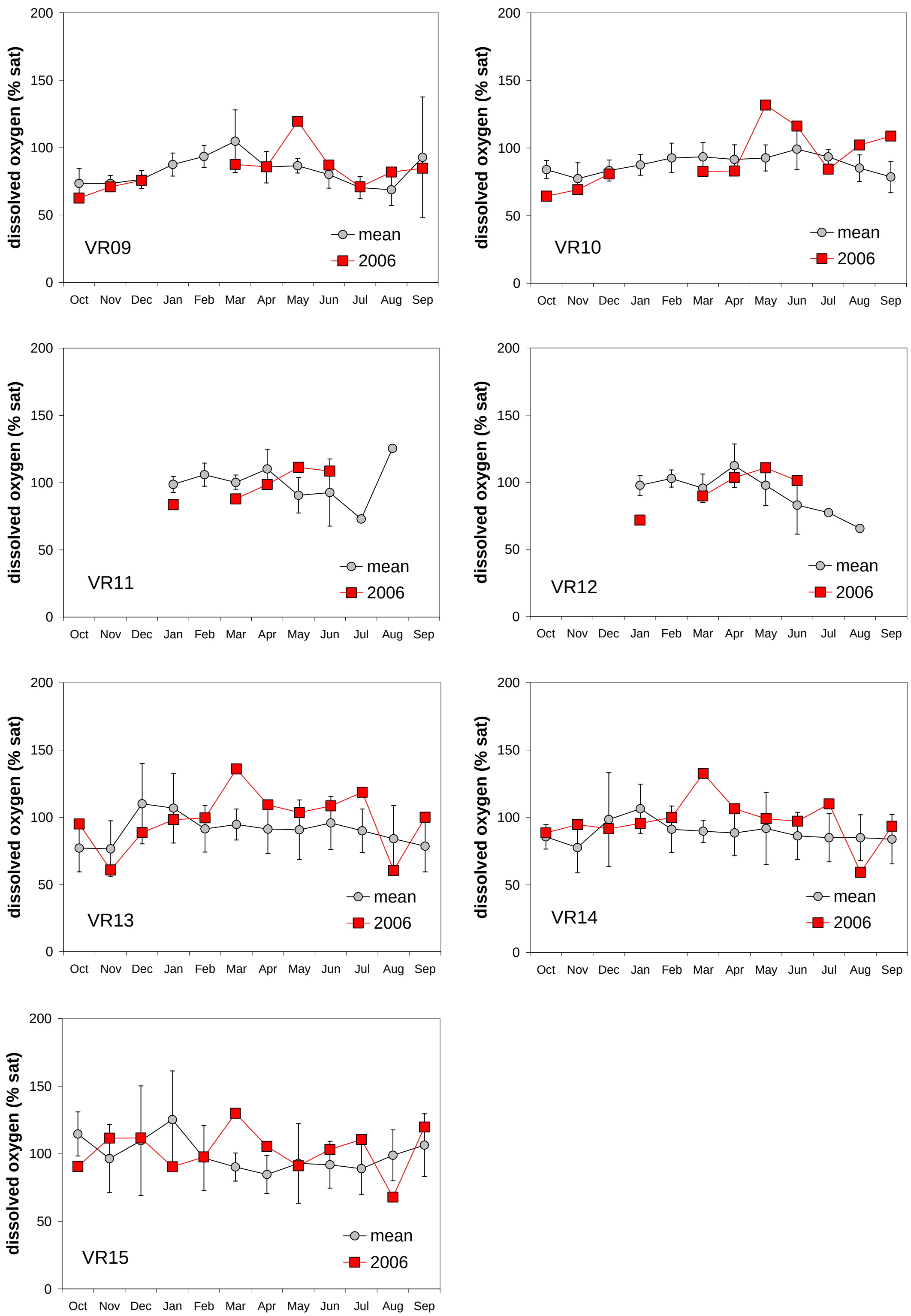


Figure 12. Monthly dissolved oxygen concentrations in percent saturation for Ventura Stream Team sampling locations during the 2006 water-year are shown, along with the average saturation from 2001-2005. Error bars indicate the monthly standard deviation.

Elsewhere the data appear to show two distinct algal blooms, one in early spring (March or May) and another in September (with the possibility of an additional July bloom on the Matilija).

Figure 13. Upstream from the Main Street Bridge (VR01), December 2005 (top) and November 2006 (bottom). By the end of 2006, the lower Ventura was covered with two types of plant cover. Most of what can be seen is watercress, however the arrow marks a line of slightly darker and taller vegetation near the stream edge: *Ludwiga hexapetala* or water primrose. If the past is prologue, this plant will come to dominate the lower river.

Mean annual DO concentrations for Ventura Stream Team sampling sites in 2006, along with mean concentrations from previous years, are shown in the upper panel of Figure 11. The error bars indicate maximum and minimum concentrations for each set of data. As with temperature, three important benchmarks are indicated by horizontal lines: above 8 mg/L represents near ideal conditions; below 6 mg/L trout and steelhead 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 pertain particularly to steelhead and trout; for warm-water fish each limit could be lowered by 1 mg/L, decreasing them to 7, 5 and 3 mg/L, respectively.

Based on the discussion above, locations with an annual mean oxygen concentration greater than 10 mg/L exhibited a severe algal problem: VR01-03, 06 and 07. Figure 14, the average annual percent saturation for both 2006 and past years, reinforces this impression.

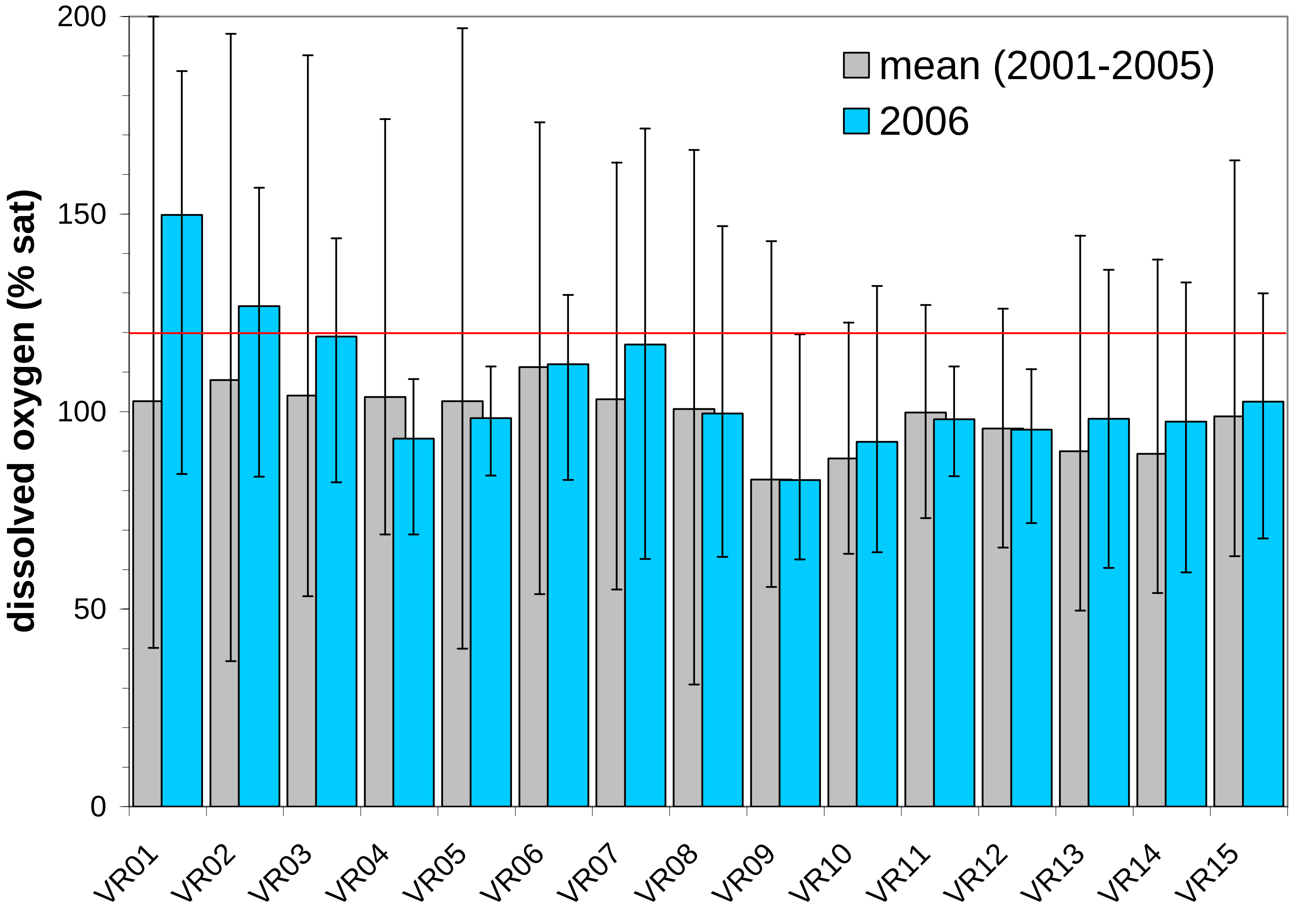


Figure 14. Average dissolved oxygen (in percent saturation) during the 2006 water-year is contrasted with average values from 2001-2005. Concentrations above 120% saturation (horizontal line) usually indicate problems with algal growth: over-saturation during daylight followed by depleted concentrations at night. The error bars indicate the maximum and minimum percent saturation at each site.

Turbidity

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

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

Figure 15 shows 2006 geomean turbidity for each of the sampling locations along with geomean turbidity for the earlier record (2001-2006).[6]

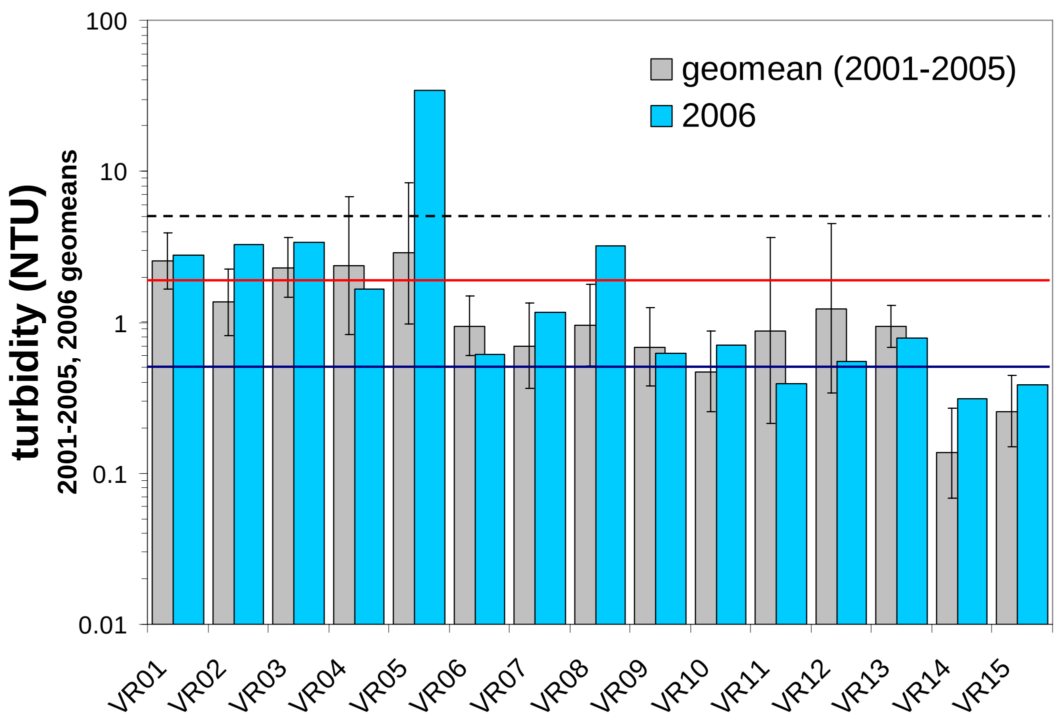


Figure 15. Geomean turbidity during the 2006 water-year is contrasted with the geomean of all measurements from 2001-2006. Error bars indicate the 95% confidence interval for the geomean. Two of the horizontal lines mark typical Public Health drinking water quality benchmarks: a maximum turbidity of 5 NTU and no more than 5% of monthly samples with greater than 0.5 NTU. The bold line indicates the EPA's proposed ecological limit for maximum (non-storm) turbidity in streams of this region, 1.9 NTU.

[6] The geomean is calculated by converting measurements to logarithms, averaging, and then converting the logarithm of the average back to a number. Like the median, it can be a better indicator of "average" conditions than a simple average, particularly when a dataset has numbers that span many orders-of-magnitude – as does turbidity, ranging from near zero into the thousands during storms. The median, the number that falls in the center of a group of measurements, ignores very high or very low numbers as long as they are few. In contrast, the geomean incorporates them but reduces their importance in calculating the average.

Two of the horizontal lines in Figure 15 represent typical Public Health drinking water limits: a maximum turbidity of less than 5 NTU and no more that 5% of monthly samples greater than 0.5 NTU. The third represents an ecological standard. Since increased turbidity may be related to over-productivity or excess nutrient enrichment – more biologically productive water often contains increased amounts of suspended organic matter – the EPA has suggested turbidity standards for various eco-regions in the United States. The goal for Ecoregion III, the xeric (dry) west, in which the most of sampled Ventura watershed is located, is less than 1.84 NTU (US-EPA, 2000a, 2000b). Ecoregion III has been further divided into sub-regions, and the sub-region in which the Ventura lies (sub-region six) has a slightly higher 1.90 NTU limit.

Turbidity measurements in 2006 were roughly compatible with those of earlier years (Figure 15). Some locations had higher turbidity, some lower. Generally, when flows are relatively high, turbidity increases (higher stream velocities tend to keep more particles in suspension), and greater amounts of algae tend to increase the amount of suspended organic matter. Sites with higher turbidity in 2006 (VR01-03, VR07, VR08, and VR10) tended to combine both of these factors. Results for 2005 were also higher for the same reasons. The only exceptionally high result, VR05, is an artifact of three very high, storm-influenced readings during the five months that flow was observed at this site. Using the EPA criterion, only the lower Ventura River and Canada Larga would appear to have persistent problems with excessive turbidity, but even at these sites it is usually below biologically significant limits (7-10 NTU).

***p*H**

*p*H 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. *p*H numbers represent a logarithmic scale, so small differences in numbers can be significant: a *p*H of 4 is a hundred times more acidic than a *p*H of 6. All plants and aquatic species live within specific ranges of *p*H, and altering *p*H beyond these ranges causes injury or death. Pollutants can push *p*H toward the extremes, and low *p*H in particular is highly dangerous because it allows toxic elements and compounds to *mobilize* (go into solution) and be taken in by aquatic plants and animals. A change of more than two points on the *p*H scale can kill many species of fish; the EPA and Regional Water Quality Control Board (SWQCB-LA) regard a *p*H change of more than 0.5 as harmful (SWQCB-LA, 1994).

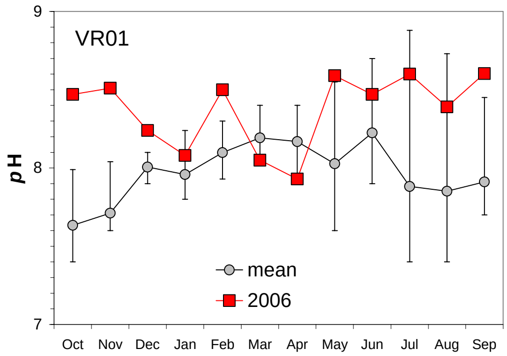
There are numerous available standards for *p*H. Fish live within a range of 5-9, but the best fishing waters lie between 6.5-8.2. The Central Coast Regional Water Quality Board uses a standard of 7.0-8.5 for surface water, 6.5-8.3 for potable water and swimming (SWQCB-CC, 1994); the Los Angeles Regional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

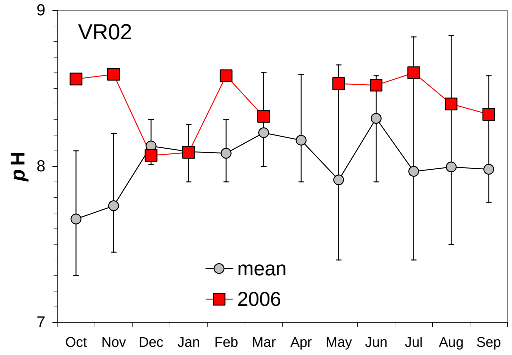
Photosynthesis, discussed earlier in the section on dissolved oxygen, removes carbon dioxide from the water at the same time as it releases oxygen. Removing carbon dioxide is the same as removing acidity, thus photosynthesis increases *p*H at the same time as it increases the amount of dissolved oxygen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

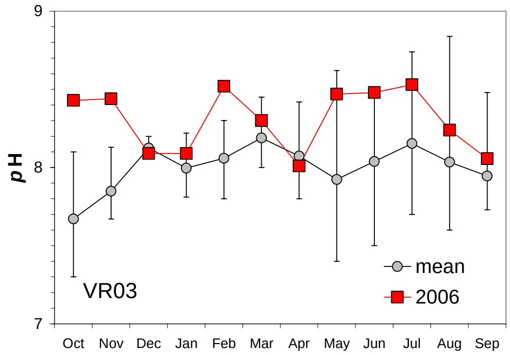
Normally, absent this process, we should see little change in *p*H. The dissolved minerals that give Ventura waters high conductivity contain large amounts of carbonates which “buffer” the river against large variations (waters in the region typically contain around 120 mg/L of acid neutralizing capacity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

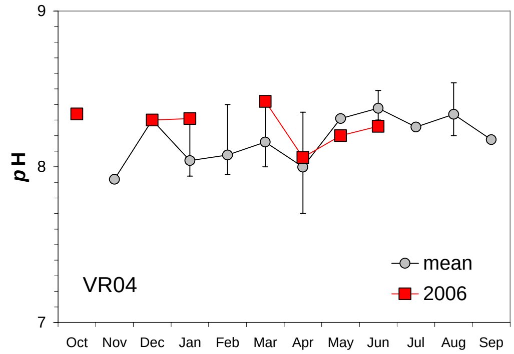
Figure 16 shows monthly 2006 *p*H measurements along with the average monthly results from previous sampling; the error bars represent maximum and minimum values for 2001-2005. Algal productivity on the lower Ventura River did manage to keep *p*H slightly above the 8.5 limit for much of the dry season. Elsewhere, values were in the allowable 6.5-8.5 range. Figure 18 summarizes the 2006 results, comparing the annual mean with the overall mean from previous years. The general trend is a slight increase at all locations with year-round flow (i.e. with appreciable dry-season algal production).

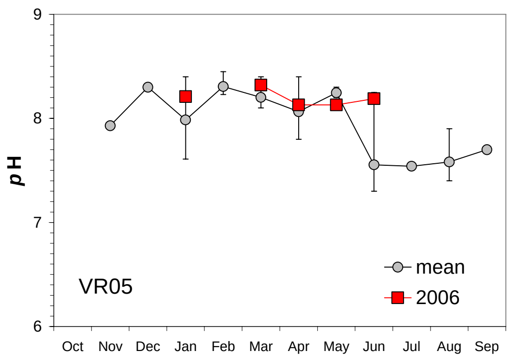
The data, however, show some discrepancy. When significant amounts of algae are present, dissolved oxygen concentrations and *p*H should rise and fall together. In Figure 17, percent DO saturation is plotted, along with *p*H data from Figure 16, for a subset of Ventura locations. The lower river sites (e.g., VR01 and VR02) do show the expected correspondence, but at other locations *p*H decreases as percent saturation rises above 120% (e.g., VR08, VR10 and VR15). *p*H is difficult to measure accurately and this may simply be an example of that.

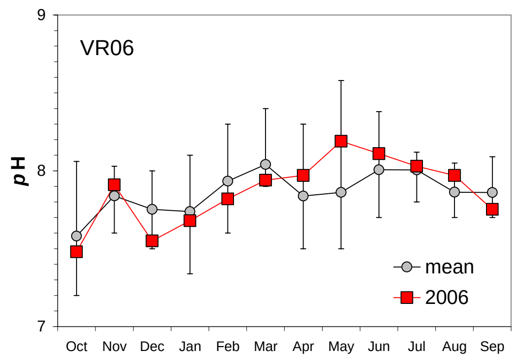

VR01
pH
9
8
7
mean
2006
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep

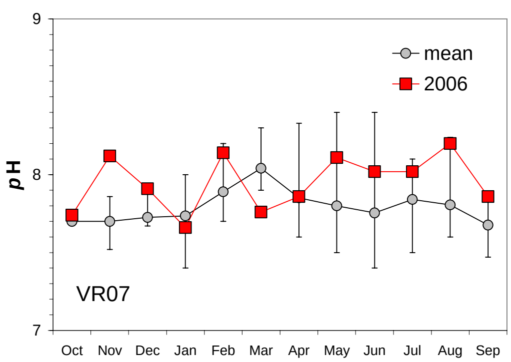

VR02
pH
9
8
7
mean
2006
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep

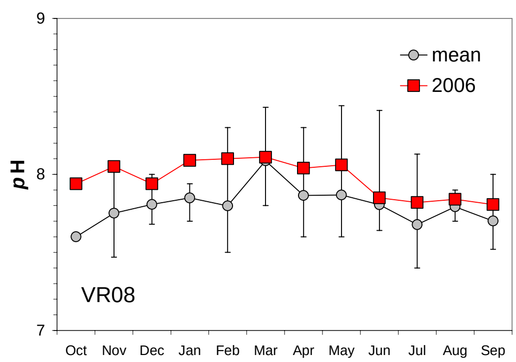

VR03
pH
9
8
7
mean
2006
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep


VR04
pH
9
8
7
mean
2006
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep


VR05
pH
9
8
7
6
mean
2006
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep


VR06
pH
9
8
7
mean
2006
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep


VR07
pH
9
8
7
mean
2006
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep


VR08
pH
9
8
7
mean
2006
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep

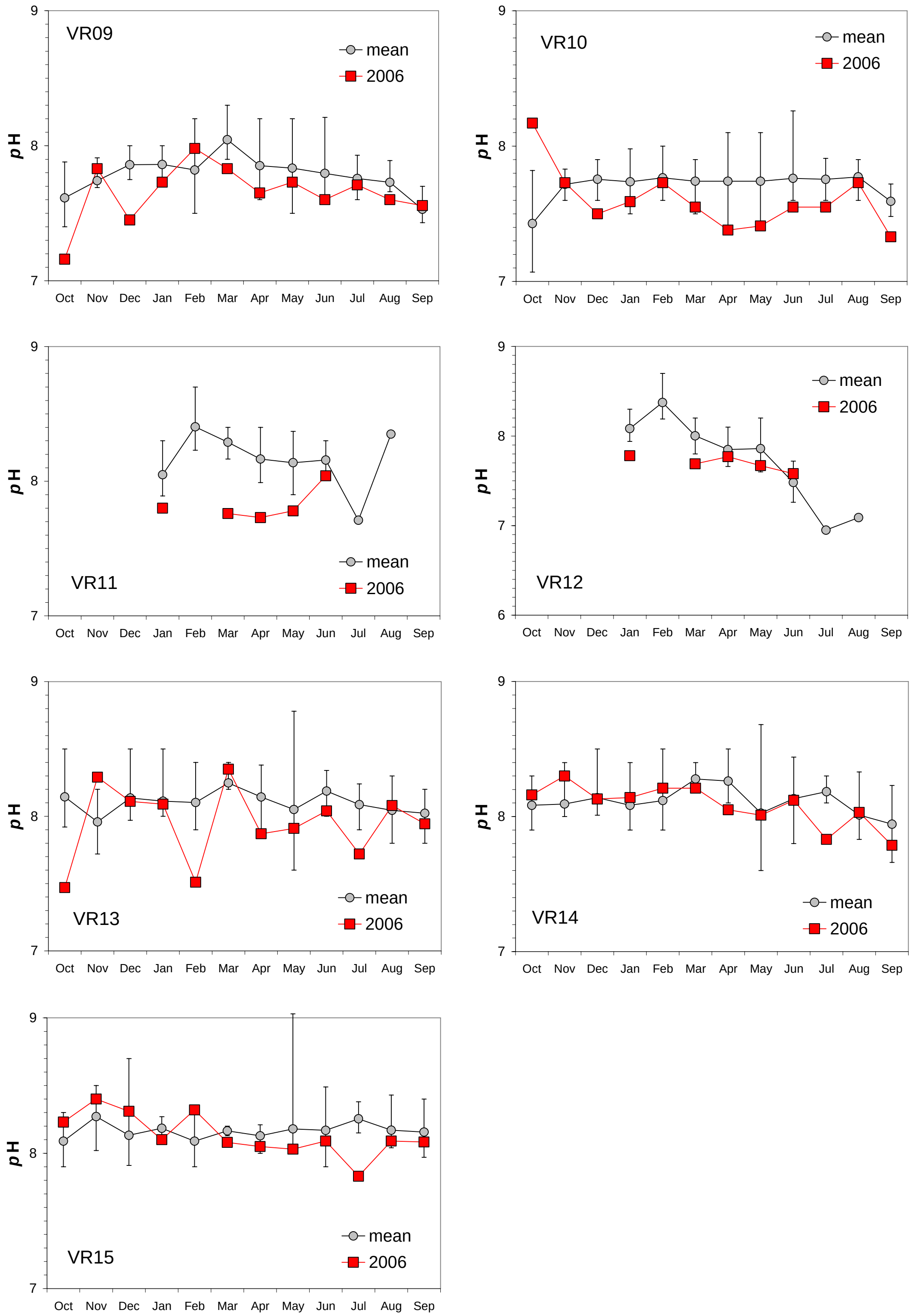


Figure 16. Monthly *p*H values for the Ventura Stream Team sampling locations during the 2006 water-year are shown, along with the average *p*H from 2001-2005 (*p*H of the average H ion concentration). Error bars indicate the maximum and minimum values from 2001-2005.

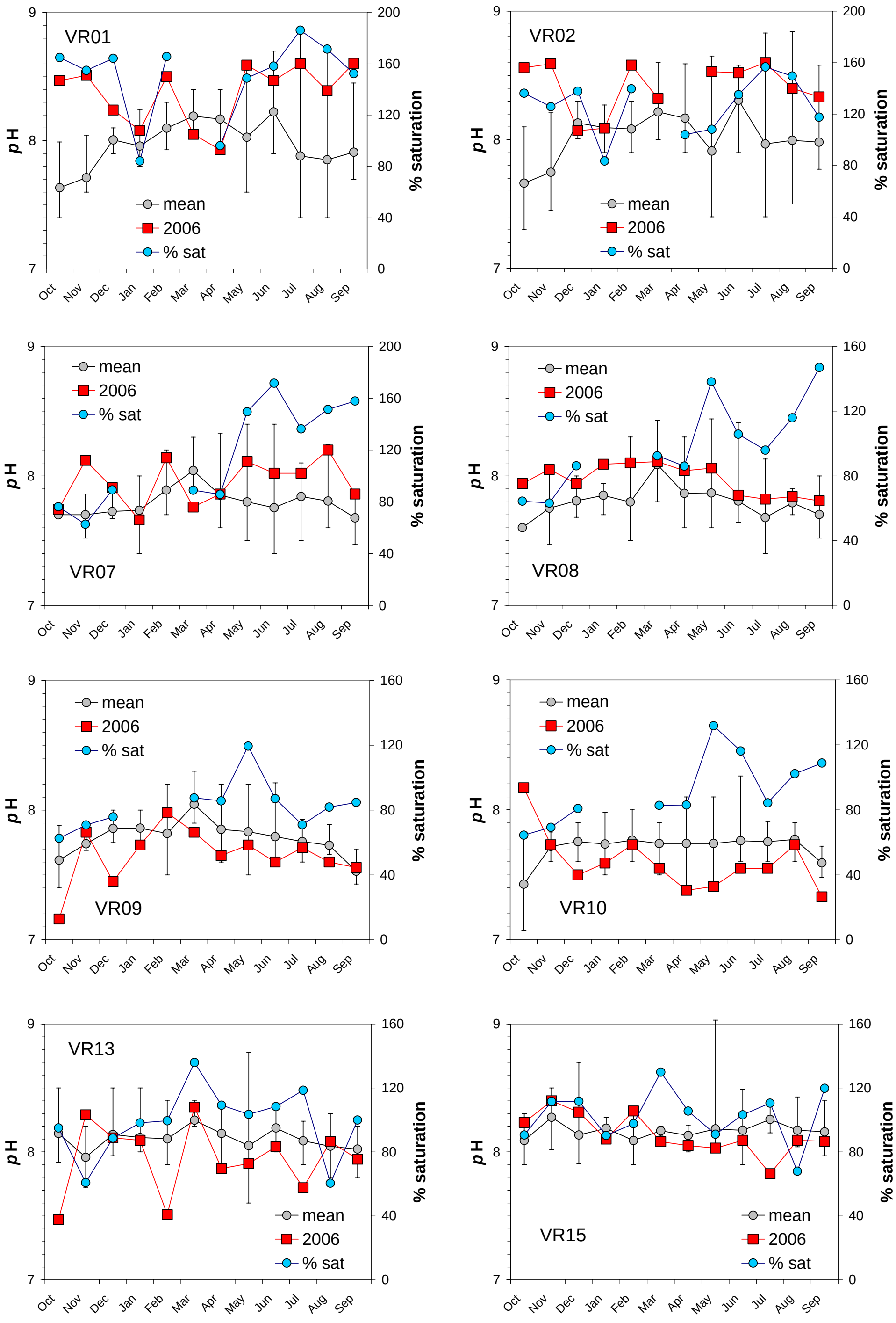


Figure 17. Monthly 2006 percent DO saturation values for selected Ventura Stream Team sampling locations are plotted along with pH data from Figure 16. Since Ventura waters are highly buffered, there should be a reasonable correspondence between pH and % saturation, since both increase with daylight photosynthesis. This is generally the case at the lower river sites and elsewhere during the first part of the year. However at many locations, particularly towards the end of the year, this relationship breaks down.

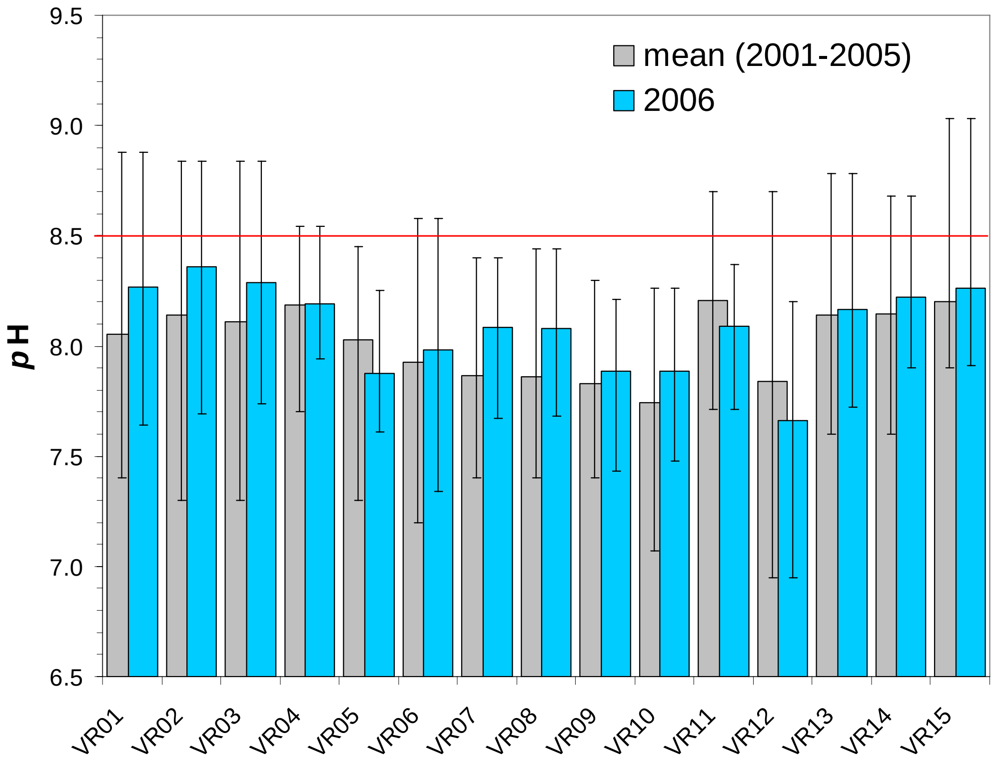


Figure 18. Average *p*H during the 2006 water-year is contrasted with average values from 2001-2005. The error bars indicate the highest and lowest values measured for each time period at the sampling locations. The horizontal line represents the Los Angeles Regional Water Quality Control Board's upper *p*H limit of 8.5 (from the Ventura Basin Plan). Average pH was computed from the mean hydrogen ion concentration. Concentrations above 120% saturation (horizontal line) usually indicate problems with algal growth: over-saturation during daylight followed by depleted concentrations at night. The error bars indicate the maximum and minimum percent saturation at each site. A *p*H above 8.5 is usually associated with excessive algal growth.

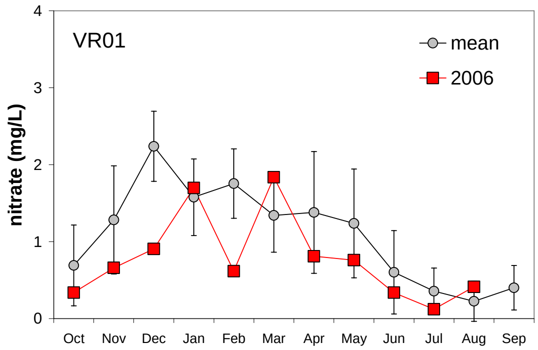
Nutrients

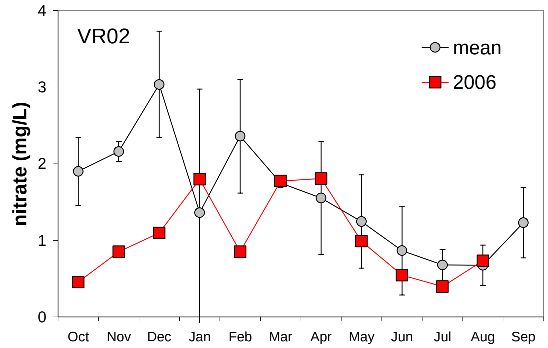
Phosphorus and nitrogen are essential nutrients for all living organisms (nitrogen for protein synthesis and phosphorus for energy transformation in cells), but in excess amounts they cause severe problems (Sterner, 2002, Smith et al, 1999, Carpenter et al., 1989).

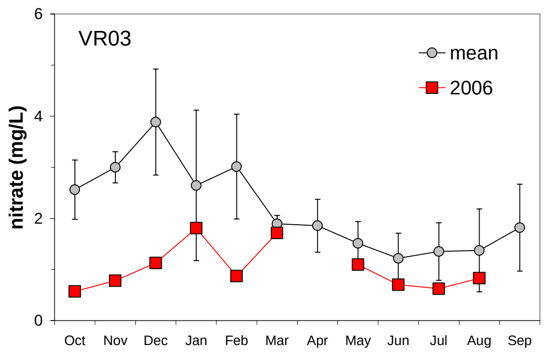
Phosphorus in streams and rivers can come naturally from soil and rocks and decaying plants, or unnaturally in runoff from pastures, fertilized lawns and cropland. Failing septic systems and wastewater treatment plants are also sources, as are disturbed land areas and drained wetlands. Phosphorus, both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

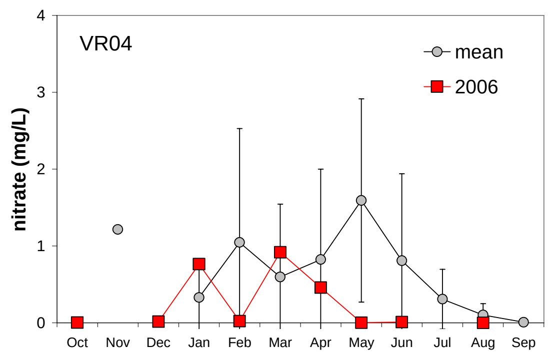
Nitrogen is available as dissolved inorganic molecules (nitrate, nitrite and ammonium) and as dissolved or suspended organic matter (complex compounds associated with living, or once living, tissue). Nitrate, the most common form of nitrogen found in the Ventura watershed, can be toxic to warm-blooded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

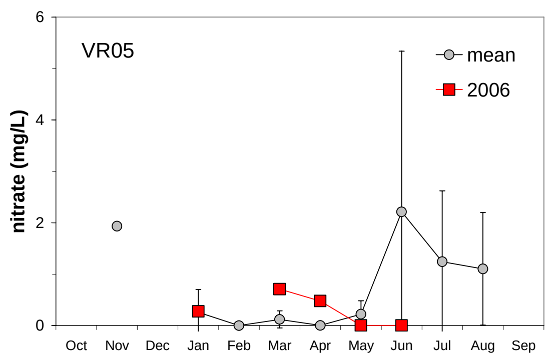
Nutrients in excessive amounts can cause *eutrophication*, defined as over-enrichment or over-fertilization of a lake or stream, which sets off a chain of undesirable events including accelerated plant growth, algal blooms, low dissolved oxygen and, if carried to extremes, the death of all oxygen-dependent aquatic life.

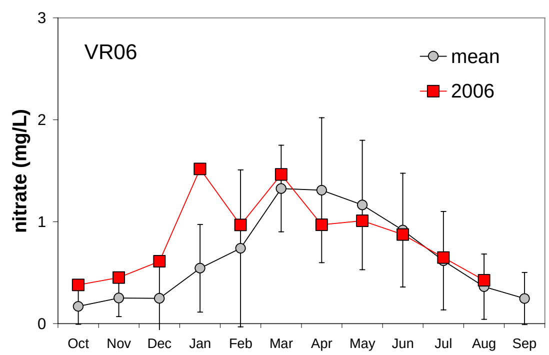

VR01
mean
2006
nitrate (mg/L)
0
1
2
3
4
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep

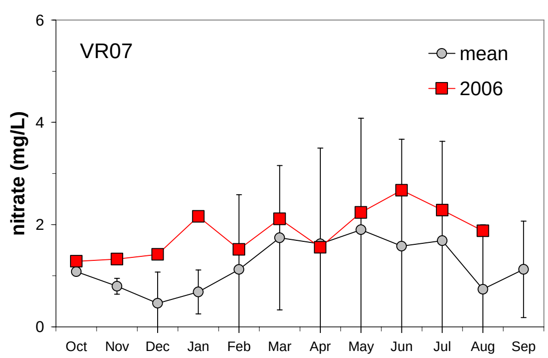

VR02
mean
2006
nitrate (mg/L)
0
1
2
3
4
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep

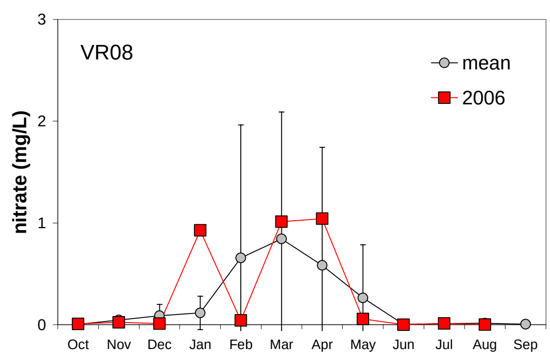

VR03
mean
2006
nitrate (mg/L)
0
2
4
6
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep


VR04
mean
2006
nitrate (mg/L)
0
1
2
3
4
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep


VR05
mean
2006
nitrate (mg/L)
0
2
4
6
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep


VR06
mean
2006
nitrate (mg/L)
0
1
2
3
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep


VR07
mean
2006
nitrate (mg/L)
0
2
4
6
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep


VR08
mean
2006
nitrate (mg/L)
0
1
2
3
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep

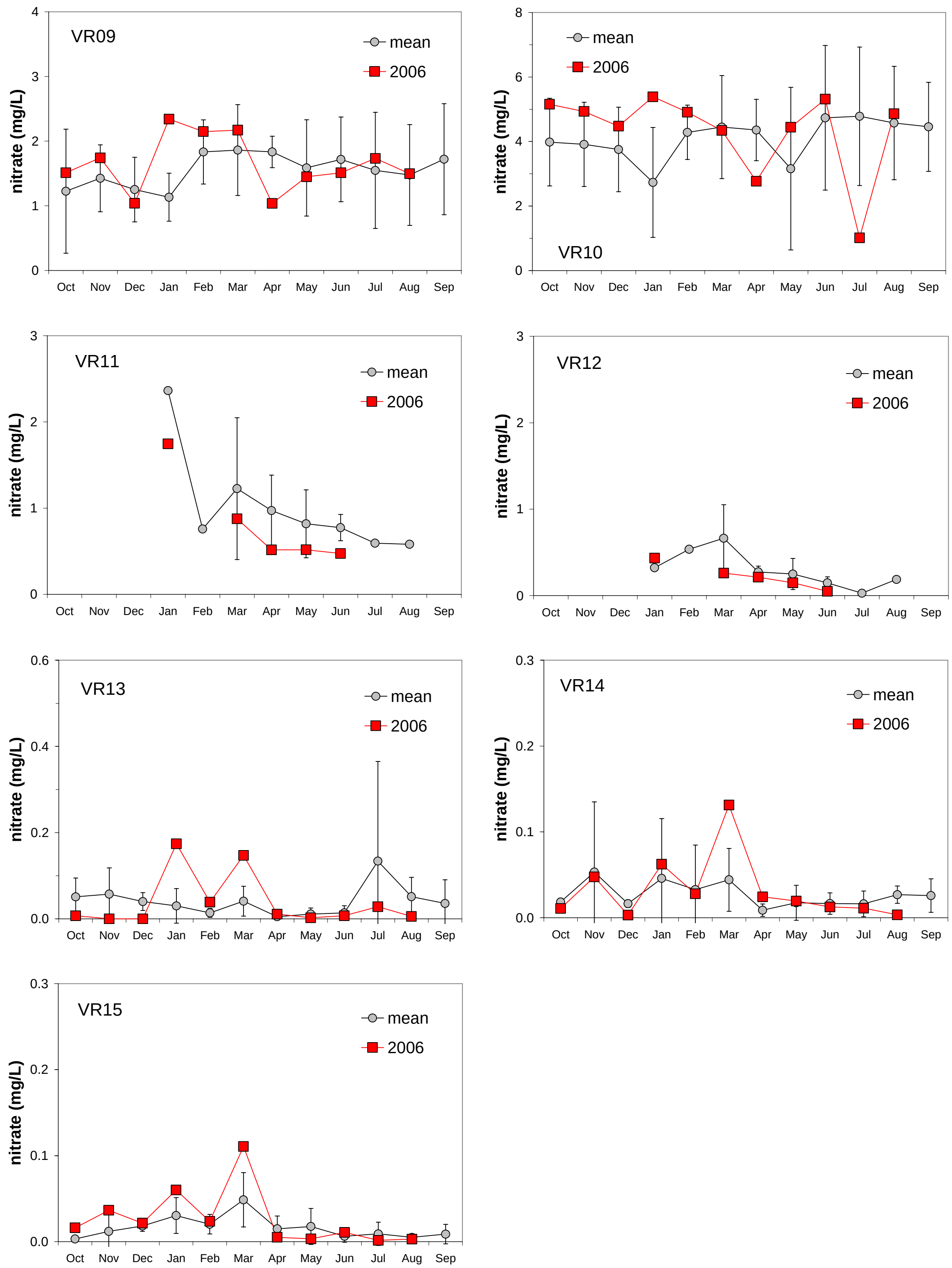


Figure 19. Monthly nitrate concentrations for Ventura Stream Team sampling locations during the 2006 water-year are shown, along with average monthly nitrate from 2001-2005. Error bars indicate the monthly standard deviation in mg/L.

Nitrate

Nitrate is the most important form of dissolved nitrogen in the Ventura River catchment: roughly 70% of the total dissolved nitrogen in river and stream samples is nitrate (ammonium contributes about 1% and organic forms make up the rest). 2006 monthly nitrate concentrations for Ventura Stream Team sampling locations are shown in Figure 19. Concentrations were generally similar to those of past years, i.e., within one standard deviation of the 2001-2005 average. Exceptions were VR01, VR02 and VR03, where lower than normal concentrations were seen during the fall of 2005 due to above average wet-year flows diluting the high-nitrate Ojai sewage treatment plant effluent that usually dominates these sites.

Elsewhere, higher wet-year flows usually produce increased nitrate while lower flows typically have lower, often near-zero, concentrations. Biological uptake (removal by plants, algae and critters) reduces the amount of available nitrate as water flows downstream, and since *amount* is the product of concentration multiplied by flow, the decrease in concentration is much greater when flows are low. This acounts for generally higher than average concentrations at locations with year-round flow (e.g., VR06-10 and on the Matilija) and lower at those that rapidly go dry (VR04-05 and VR11-12) (see Figure 20). Since biological uptake and lower flows are both more common in the summer, concentrations exhibit seasonal patterns at some locations, increasing during the winter from enhanced runoff and groundwater inflows and decreasing thereafter (i.e., VR06). Annual results, expressed as average water-year concentrations, are sumarized in Figure 20.

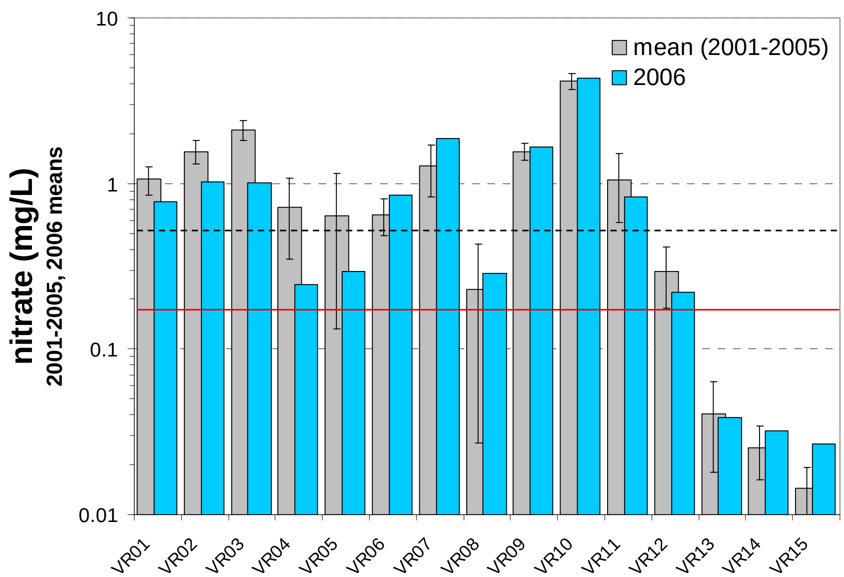


Figure 20. Average nitrate concentrations for the Ventura Stream Team sampling sites during the 2006 water-year are contrasted with average concentrations over the previous five years (2001-2005). The error bars indicate twice the standard error of the mean, i.e., the 2006 average would be expected to lie within these error bars, while anything beyond these limits could indicate a significant change. Note that most 2006 locations are generally within or below the error bars. The bold horizontal line marks the EPA's proposed limit for maximum nitrate in this region (0.16 mg/L); the dashed line is the recommended limit for nitrogen (0.52 mg/L). In 2006, nitrate typically made up about 80% of the total nitrogen in the Ventura system, so most sites considerably exceeded both the recommended nitrate and total nitrogen amounts. Only the higher elevation, relatively pristine, Matilija sampling sites consistently exhibit low nitrogen.

Note that nitrate concentration in the Ventura watershed vary considerably from location to location (Figures 19 and 20). The almost universal Public Health limit is 10 mg-N/L (10 milligrams of nitrogen per liter. However, 10 mg/L is far too much nitrate in terms of eutrophication and river health. The EPA has suggested standards for various eco-regions in the United States, and the goal for Ecoregion III, the xeric (dry) west, in which the Ventura River is located, is less than 0.38 mg/L of total nitrogen (US-EPA, 2000b). Notice that this is less than 4% of the Public Health nitrate limit (e.g., SWQCB-LA, 2001). Ecoregion III has been further divided by the EPA into sub-regions, and for the sub-region in which the Ventura lies (sub-region six) a slightly higher 0.52 mg/L limit has been proposed. Sub-region 6 also has a suggested nitrate limit of 0.16 mg/L. Both these limits are shown on Figure 20.

Considering this, the Matilija sites are in very good shape: nitrate concentrations are usually below the 0.16 mg/L benchmark and average annual concentrations are well below. All other sites have nitrate concentrations above the 0.16 limit: more than an order-of-magnitude greater in many cases. VR10 (Upper San Antonio Creek) continues to have the most severe excess nitrate problem on the river.

Phosphate

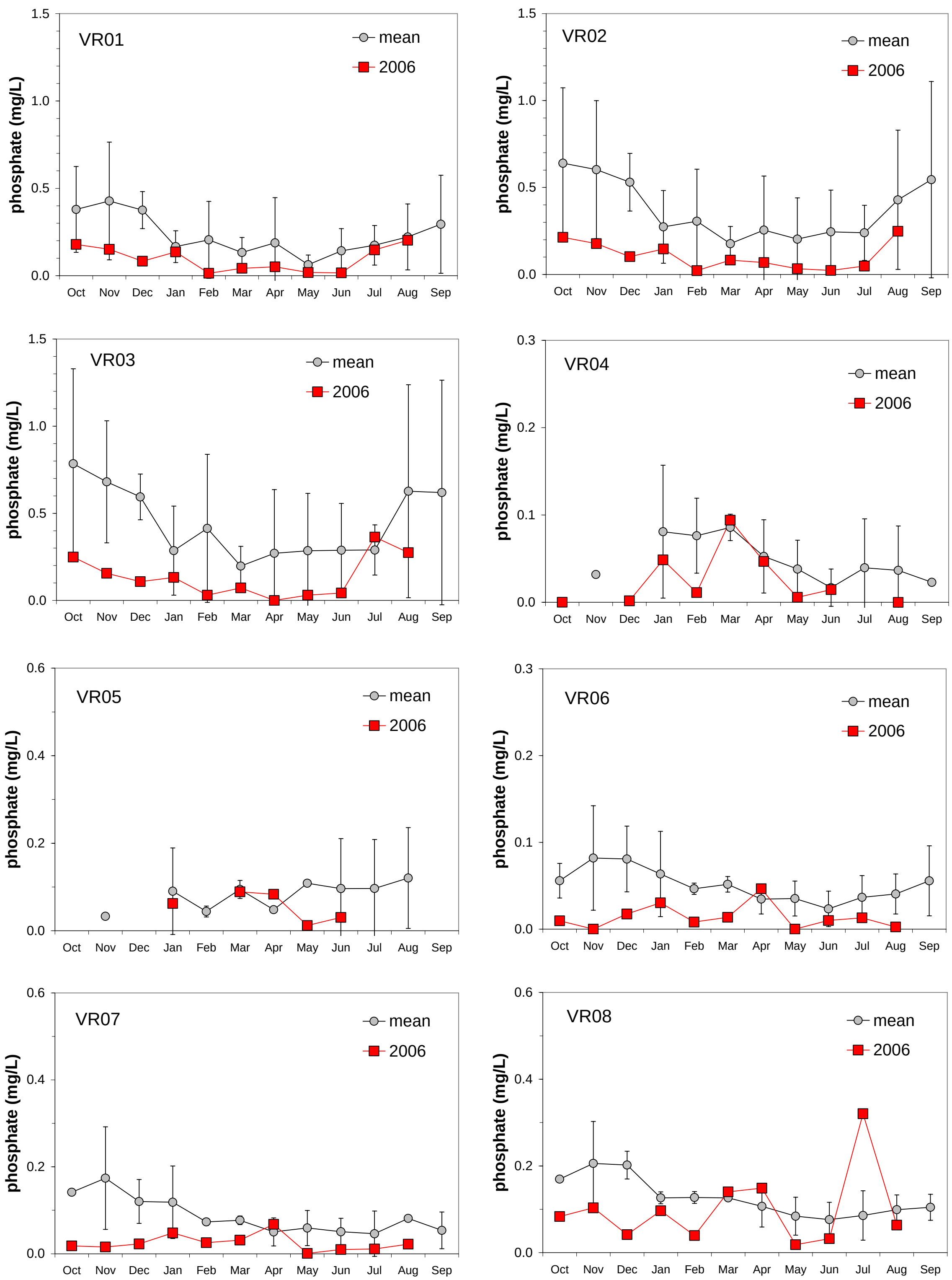
As with nitrate, a question arises of how much phosphorus is too much phosphorus? The EPA has recommended levels of maximum phosphorus concentration for streams in Ecoregion III: an overall recommendation of 0.022 mg/L, increased to 0.030 mg/L for the sub-region 6 that includes the Ventura (US-EPA, 2000b). We use 0.030 mg/L as a benchmark. All streams in Ventura and other watersheds in the area 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 somewhat reflected in the increased sub-region 6 EPA limit.

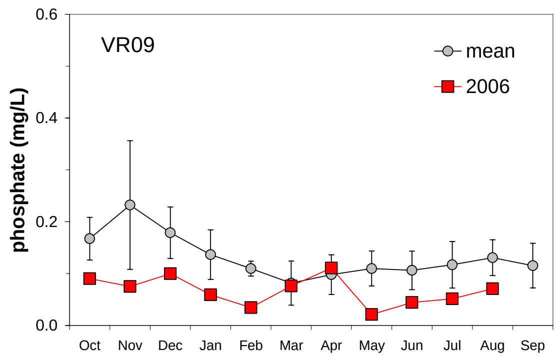
Figure 22 summarizes the 2006 phosphate results, showing annual mean phosphate concentrations at each location and contrasting them with the 2001-2005 average. The results are quite startling: *all* locations had significantly lower average phosphate concentrations than in previous years (2006 results are two or more standard errors below the 2001-2005 mean). The monthly data in Figure 21 verify this conclusion at almost every location. There are two possible explanations: less phosphate is getting into the Ventura River and its tributaries, and/or larger amounts are being removed by biological uptake and productivity.

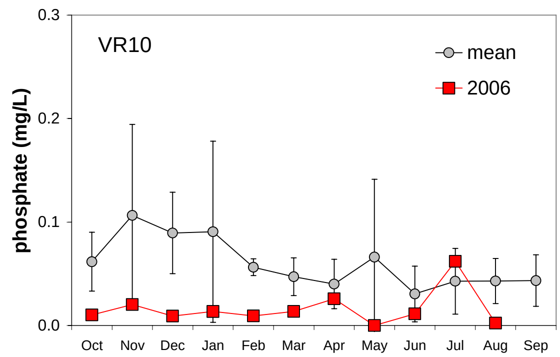
It is most likely a combination of these two reasons. The dry seasons of 2005 and 2006 were characterized by extraordinary algal blooms, and the increased uptake of phosphorus undoubtedly played an important role in reducing concentrations. It is biological uptake that gives form to the pattern seen with most of the average monthly data in Figure 21: lower concentrations during the dry season, with a low seen between April and June.

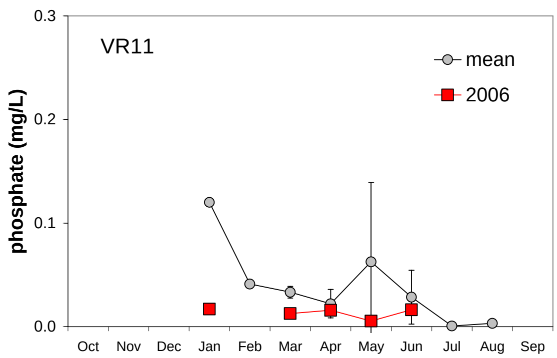
Exceptions to the pattern are usually samples taken during or soon after storms, because high phosphate concentrations are typically caused by high sediment loads. Phosphate molecules are easily attached to soil particles, and the width and condition of streamside buffer areas, the extent of stream bank armoring, and the proximity of un-vegetated, easily erodable soil to channel or storm drain inlet, as well as rainfall intensity, determine how much sediment ends up in the creek. This, in turn, drives the phosphate increase. This is particularly true of the first storm of the season, which usually moves a lot of sediment and accumulated debris in what were initially

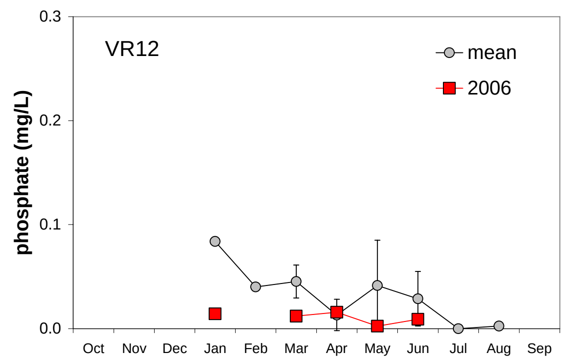
Figure 21. Monthly phosphate concentrations for Ventura Stream Team sampling locations during the 2006 water-year are shown, along with average monthly phosphate from 2001-2005. Error bars indicate the monthly standard deviation in mg/L.

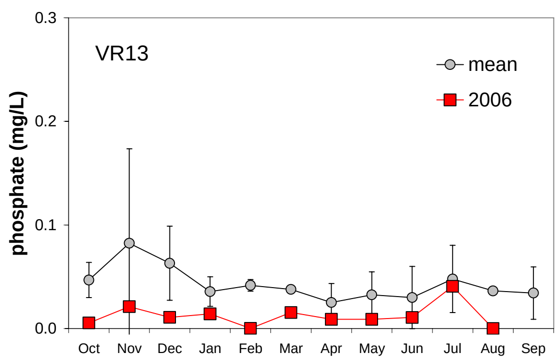


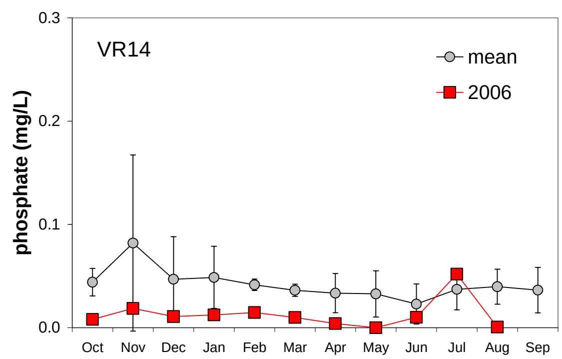

VR09
mean
2006
phosphate (mg/L)
0.0
0.2
0.4
0.6
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep

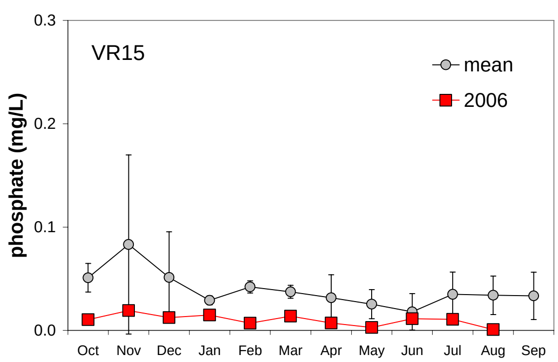

VR10
mean
2006
phosphate (mg/L)
0.0
0.1
0.2
0.3
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep


VR11
mean
2006
phosphate (mg/L)
0.0
0.1
0.2
0.3
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep


VR12
mean
2006
phosphate (mg/L)
0.0
0.1
0.2
0.3
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep


VR13
mean
2006
phosphate (mg/L)
0.0
0.1
0.2
0.3
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep


VR14
mean
2006
phosphate (mg/L)
0.0
0.1
0.2
0.3
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep


VR15
mean
2006
phosphate (mg/L)
0.0
0.1
0.2
0.3
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep

dry or near stagnant streams, explaining why the highest monthly concentrations are usually seen in October or November. In 2006, we saw the effect of storm-influenced concentrations in higher March and April values.

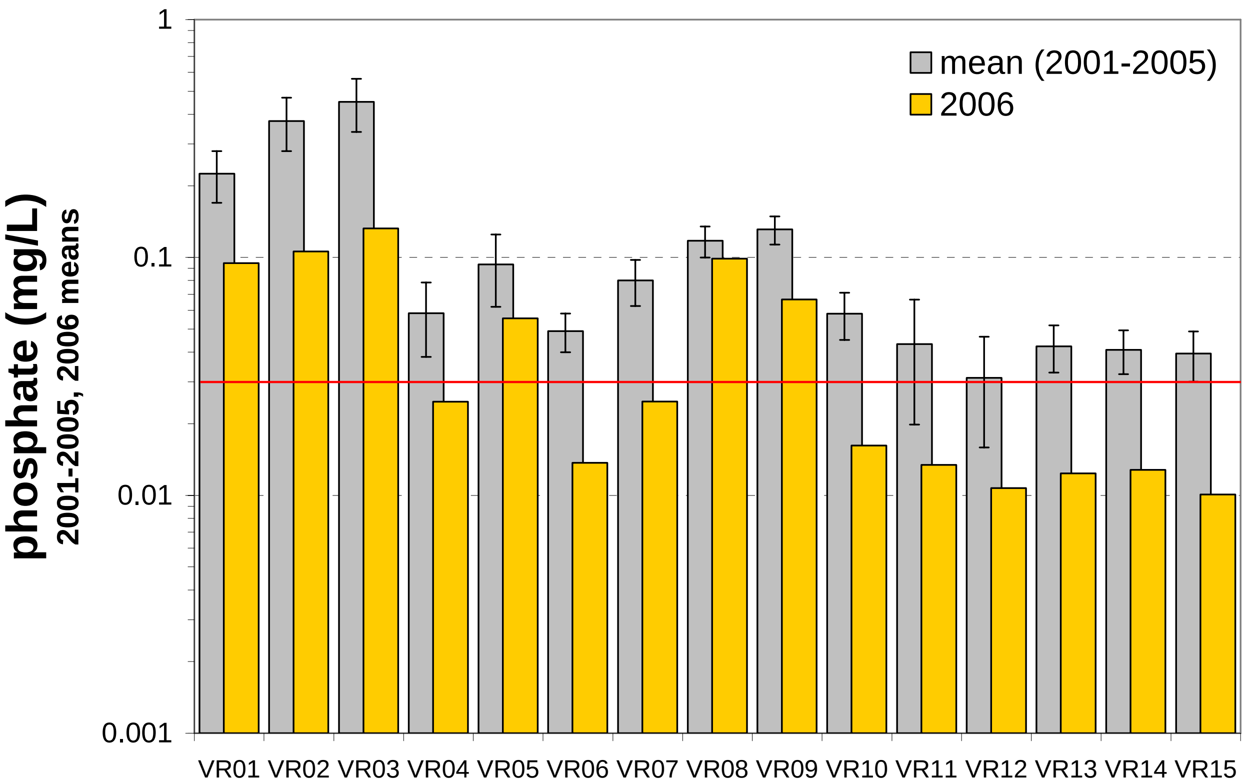


Figure 22. Average phosphate concentrations for the Ventura Stream Team sampling sites during the 2006 water-year are contrasted with average concentrations over the previous five years. The error bars indicate twice the standard error of the mean, i.e., the 2006 average would be expected to lie within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

However, something else appears to be happening. Monthly phosphate concentrations since January 2001 (for locations with year-round flow) are plotted in Figure 23. The figure clearly shows a major shift taking place around April 2005, i.e., at the end of the 2005 rainy season. Along with increased uptake, it is probable that increased groundwater inflows, from a water-table recharged with low-phosphate runoff from 2005 storms, played a role since the effects extend beyond the growing season. This could be similar to the process used to explain the 2005 decrease in conductivity, and the slow rise since: shorter groundwater residence times within the underlying geologic strata leading to lower phosphate concentrations. Like conductivity, phosphate concentrations in 2006 have shown an increase over those of the 2005 dry season. In addition to these other processes, dilution by above-average flows of the high-phosphate effluent from the Ojai sewage treatment plant contributed to lower concentrations at VR01, VR02 and VR03.

The results from 2001-2005 indicate that all sites typically had mean phosphate concentrations above the 0.03 mg/L phosphorus limit. However, lower phosphate in 2006 does not necessarily represent a dramatic improvement since phosphate alone is only part of the total phosphorus concentration in the stream or river, and organic phosphorus makes up the remainder; typically phosphate represents approximately 90% of the total phosphorus in Ventura nutrient samples.[7]

---

[7] Unfortunately, while total dissolved phosphorus (TDP; dissolved organic phosphorus is TDP minus phosphate) is measured in the UCSB nutrient analysis, the results are unreliable. TDP and phosphate are determined by different tests and sometimes the results show phosphate to be higher than the TDP concentration. Obviously, this cannot be true; something either went wrong or the precision of the analysis was not high enough to produce a satisfactory result. Error and imprecision are part of all laboratory analysis; a result is never simply a number, it is a number plus or minus some associated error. This is ordinarily expected to occur some of the time, particularly when overall concentrations are high, i.e., it happens about 4% of the time with nitrate and total dissolved nitrogen samples. Unfortunately, it happens almost half the time with phosphorus and indicates a real problem, one that the UCSB laboratory has not been able to solve; in 2006, 40 % of the TDP samples produced unacceptable results.

However, a high percentage of unacceptable results does not mean that an analysis is entirely meaningless. While any single result has to remain suspect, overall trends in the data are likely to reflect reality (based on the assumption that, in aggregate, "acceptable" results are likely to be either valid or, at worse, contain an error that always underestimates TDP – underestimates because that is the implication of many samples with TDP higher than phosphate). In 2006, samples with realistic values were concentrated in the months of October, January, April and May (samples later than May are, as yet, unavailable) – almost all samples from these months appear valid. Looking only at those results, the percentage of TDP contributed by phosphate was 65, 86, 49 and 26% for the respective months. Overall, acceptable 2006 samples contained an average of 60% phosphate, considerably lower than the 90% of previous years.

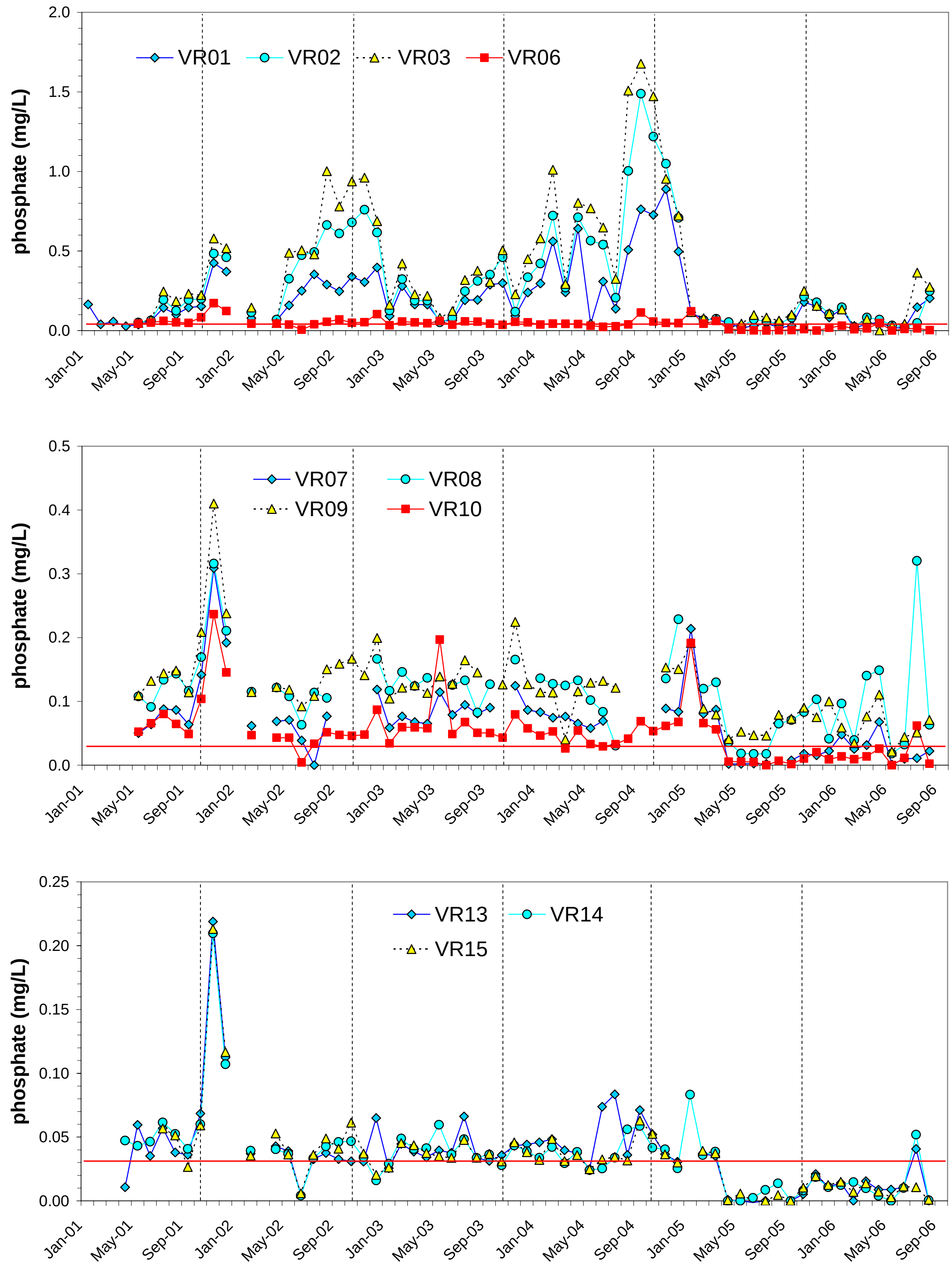


Figure 23. Phosphate concentrations, January 2001-August 2006. Dashed vertical lines mark the start of each water-year. The horizontal line marks the EPA proposed target for maximum phosphorus in this region, 0.030 mg/L (Ecoregion III, sub-region 6). The graphs show phosphate, which typically makes up approximately 90% of total phosphorus in the stream. Note that the graphs use different vertical scales.

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

This complicated and convoluted explanation is simply preparation for a basic point: although phosphate concentrations declined in 2006, the overall phosphorus situation may not have substantially improved because an increase in organic phosphorus accompanied the phosphate decline. We are unable to accurately measure actual organic phosphorus concentrations because of the problematical TDP analysis, but know the increase was appreciable. Even considering phosphate alone, six sites, VR01-03, VR05, VR08 and VR09 had concentrations higher than would be deemed acceptable for total phosphorus. The river reach below the Ojai sewage treatment plant continues to have the highest phosphate concentrations in the watershed.

Combining Nitrate and Phosphate

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

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

Channelkeeper's Ventura Stream Team sampling locations provide examples of both N-limitation and P-limitation, and at some sites the situation flips back and forth. Figure 24 shows median nitrate to phosphate ratios for 2006 and prior years. Error bars mark the quartile points, i.e., the middle 50% of all monthly results fit between these limits. In the figure, the Matilija sites and VR08 have very low ratios; these locations are always N-limited. Conversely, VR10 is always P-limited. At the other locations nitrogen and phosphorus are either roughly in balance or the stream in these areas bounces back and forth depending on circumstances.

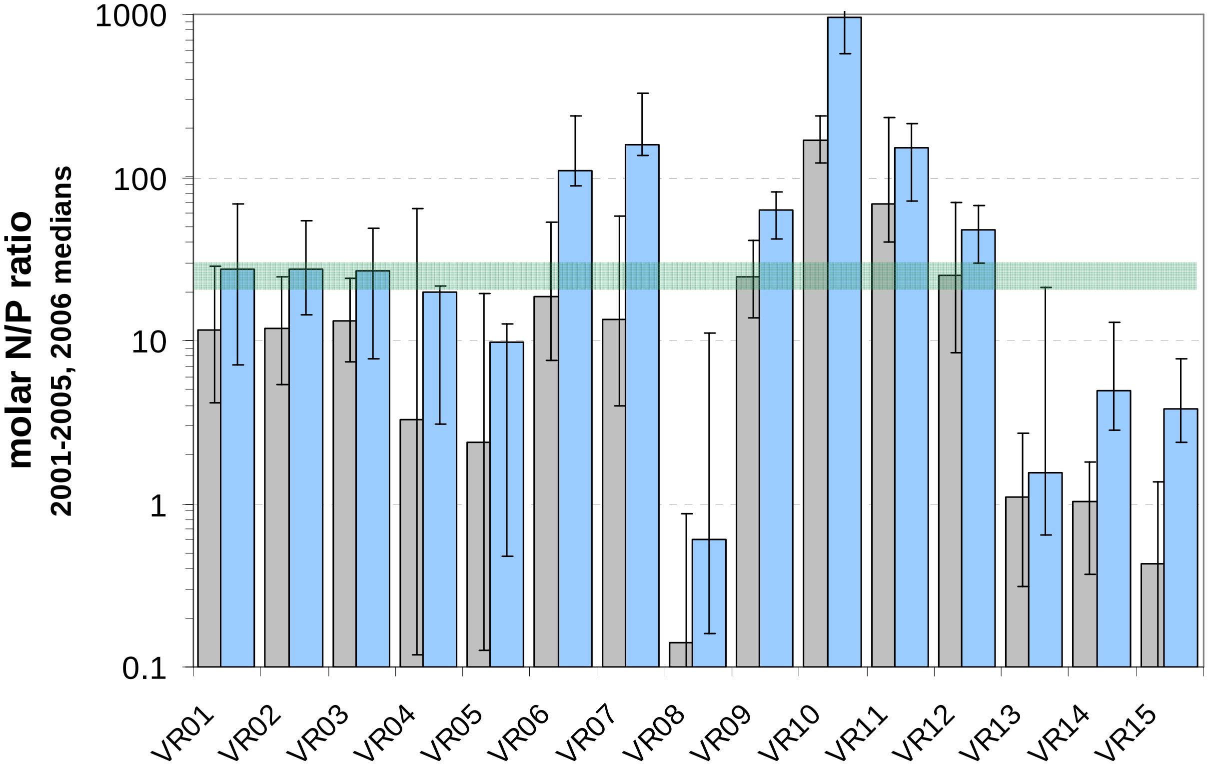


Figure 24. Median nitrate to phosphate ratios for the Ventura Stream Team sampling sites, 2001-2005 and 2006. Life requires both nitrogen and phosphorus, but in different amounts. Plankton, on which the oceanic food chain is based, use nitrogen and phosphorus in a ratio of 16 molecules of nitrogen to one 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 horizontal bar in the figure. The nitrate to phosphate ratio is being used as an approximation of the nitrogen to phosphorus ratio; on average, nitrate is approximately 85% of the total nitrogen and phosphate 90% of the total phosphate in Ventura Stream Team samples). The Matilija tributaries and Lion Canyon are severely "nitrogen limited," meaning that while phosphorus is plentiful, nitrogen is often exhausted. VR10, below Ojai, is "phosphorus limited". All other locations move across the boundary depending on time of year, typically being phosphorus limited during winter and spring, nitrogen limited in summer and fall. The error bars indicate the quartile points, i.e., 50% of the monthly N/P ratios for that location lie within the band represented by the error bar. In 2006, N/P ratios noticeably increased above long-term mean values, mainly as a result of lower than usual phosphate concentrations (see Figure 18).

Relatively dry winters typically produce N-limited conditions, mainly due to reduced inflows of nitrate in storm runoff (recall that approximately 30-times more nitrogen than phosphorus is needed for balance). Wet winters usually produce plenty of high-nitrate groundwater inflows and runoff, resulting in P-limitation. 2006, with reduced phosphate concentrations probably shifted the entire system towards P-limitation. Comparing dry-season (June-September) nutrient ratios, Figure 25 illustrates the changes that occurred from 2004 (a low rainfall year) through 2006. It is important to stress the word "probably" since we have only limited knowledge of organic phosphorus concentrations: the TDN to TDP ratio is usually a better predictor of nutrient status than the nitrate: phosphate relationship used here.[8]

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

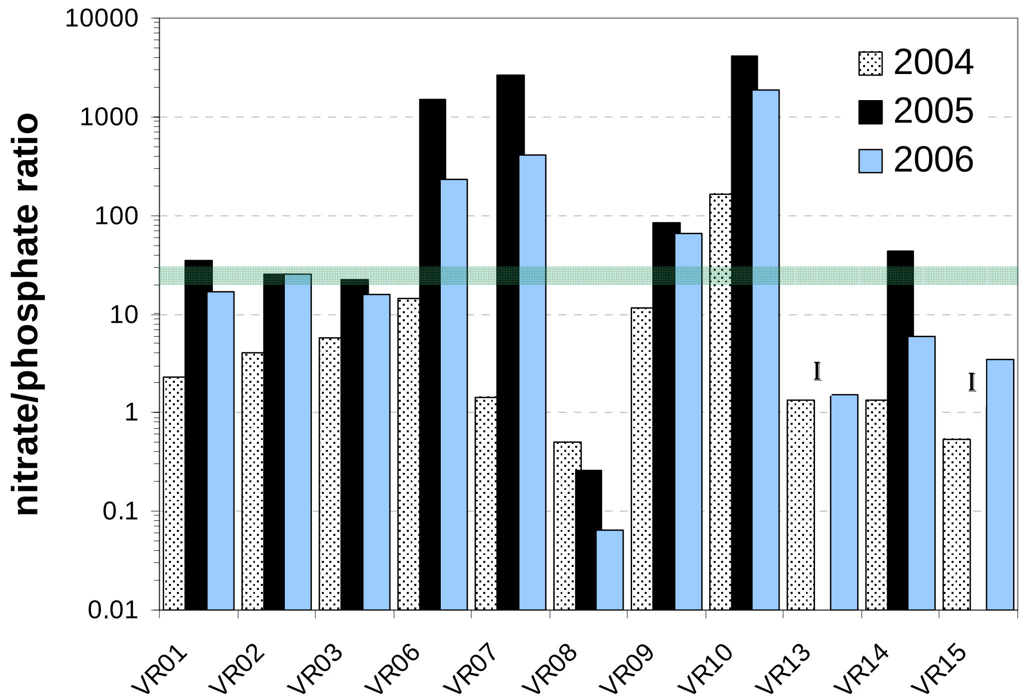


Figure 25. Average dry-season (June through September) nitrate to phosphate ratios for 2004, 2005 and 2006. The horizontal bar marks the approximate 20:1 to 30:1 zone where both nutrients are in balance. The letter "I" indicates sites where phosphate concentrations fell below detection limits (< 0.3 µM) and the N:P ratio was indeterminate. In 2005, increased nitrate concentrations and heavy algal growth following a wet winter produced a substantial increase in N:P ratio at all locations except VR08 (Lion Canyon). Wet years flush out the nitrogen accumulated in higher elevation chaparrel during dry spells, increasing nitrate concentrations in both storm runoff and groundwater seepage. Increased algal growth - which follows a wet winter due to greater availability of nitrogen, sunlight and favorable habitat - disproportionately reduces stream phosphate concentrations. 2006 is an example of the gradual return to conditions seen in 2001-2004: growing season N:P ratios remain high because of heavy algal growth, but they have decreased from the level seen in 2005 as nitrate becomes less plentiful and growing aquatic vegetation reduces available algal habitat.

---

8 Figures 24 and 25 use molar ratios, where the concentrations of nitrate and phosphate were expressed in µM – micromoles per liter – before dividing one by the other. 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 32 µM.

Bacteria[9]

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 they are generally not harmful themselves, they indicate the potential presence of pathogenic (disease-causing) bacteria, viruses, and protozoans that also live in human and animal digestive systems. Their presence in water suggests that pathogenic microorganisms might also be present and that contact with these waters could be a health risk. Since it is difficult, time-consuming and expensive to test directly for a large variety of pathogens, water is usually tested for coliforms and fecal streptococci instead. Channelkeeper analyzes monthly samples for three types of bacteria:

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

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

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

Bacteria are reported as the "*most probable number*" (MPN) of bacteria in 100 milliliters (ml) of water (100 ml is about 4 ounces). Channelkeeper uses a statistical test instead of directly counting bacteria so the reported number is actually a statistical estimate. California Public Health requirements for bacteria counts are complicated and vary somewhat by jurisdiction; what follows is an amalgam of EPA recommendations and various California standards. Generally, there are two limits for each test, a single sample limit and a limit for a geometric average of five or more samples collected over a period of either five weeks or a month.[10]

For freshwater recreational use, the total coliform limits are "not to exceed 10,000 per 100 ml in a single sample, and a geomean of less than 1,000." For *E. coli* the geomean requirement is less than 126 bacteria/100 ml of water and the single sample limit varies from 235 to 500 depending on intensity of use (not to exceed 235 for beach areas, 576 for occasional recreational use). For enterococcus the "geomean average of five or more samples" limit is less than 33/100 ml and the single sample limit can vary from 61 to 151/100 ml, again depending on frequency of use.

---

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

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

The total coliform limits are a geomean of less than 1,000 with single samples not to exceed 10,000, *as long as the fecal/total coliform ratio is less than 0.1* (in other words, as long as less than 10% of the coliforms are of fecal origin). If the ratio rises above 0.1, then the single sample limit decreases to 1,000.[11]

Since Channelkeeper only samples once a month, using "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 for all samples collected at each Ventura location during the 2006 water-year are shown, for each of the three types of bacteria, in Figures 26 and 27. For comparison, geomeans calculated from data collected from January 2001 through September 2005 are also exhibited. Fecal to total coliform ratios for both 2001-2005 and 2006 are included in the lower panel of Figure 27. The single sample standards discussed above are shown as horizontal lines on the charts.

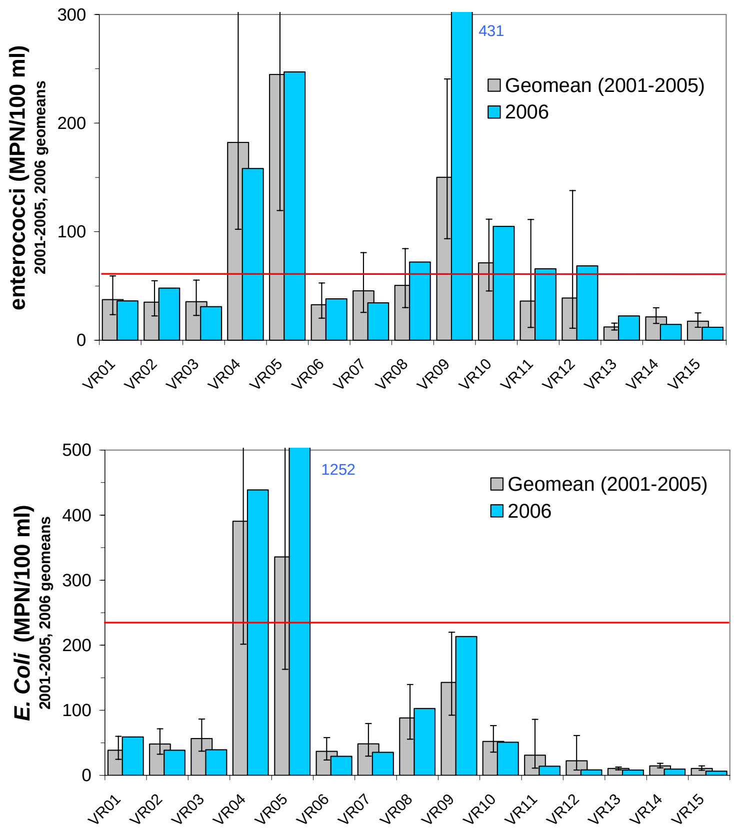


Figure 26. 2006 geomean enterococci (upper panel) and *E. coli* (lower panel) concentrations compared with geomeans from 2001-2005. Error bars represent the 95% confidence interval for the long-term geomeans. Solid horizontal lines mark the EPA's recommended freshwater beach Public Health limits for maximum enterococcus (61 MPN/100 ml) and *E. coli* (235 MPN/100 ml).

[11] The most recent Basin Plan update for the Los Angeles Regional Water Quality Control Board, which sets standards for Ventura, requires, for water-contact recreation in freshwater, a single sample *E. coli* limit of 235 and a 30-day geomean below 126. In marine waters, the single sample enterococcus number is not to exceed 104 with a 30-day geomean limit of 35; single total coliform samples have a limit of 10,000 and a 30-day geomean requirement of 1,000, unless the ratio of fecal to total coliform exceeds 0.1, in which case the single sample total coliform limit is reduced to 1,000. Currently, the Los Angeles Regional Water Board does not have a freshwater standard for either enterococcus or total coliform. It does, however, retain a fecal coliform requirement of 400 for a single sample, 200 for the geomean. Agencies are allowed to use either the fecal coliform or *E. coli* test.

The error bars in Figures 26 and 27 indicate the 95% confidence interval of the long-term geomeans. Think of this as similar to the "twice the standard error of the mean" criteria shown in previous figures. Both indicate the bounds within which an annual geomean might be expected to vary. Note that in 2006, enterococcus and total coliform counts at VR09, and *E. coli* counts at VR05, were significantly higher than past results. Geomeans for 2006 at all other locations were consistent with past results (enterococcus did show a significant increase at VR13).

When it comes to determining which locations generally have the highest levels of bacteria, there is relatively good agreement between all three tests, but in terms of 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. All three tests agree that VR04 and VR05 (Canada Larga) are highly polluted and do not meet any standard. However, while VR09 and VR10 (Pirie and Upper San Antonio creeks) usually fail to meet the enterococci standard, they have acceptable levels of *E. coli* and total coliform (2001-2005 geomeans). In 2006, VR08 through VR12 generally exceeded the enterococcus limit, but not that for *E. coli* or total coliform.

This is not an unusual result. Studies show that while there is usually agreement between the three tests at either highly polluted or pristine locations, they can appreciably disagree at sites that lie in the middle (Kinzelman, 2003; Nobel et al., 2003). As to why the enterococcus standard is often exceeded in Channelkeeper results while the *E. coli* limit almost never is, it is possible that enterococci are able to live and reproduce in some local waters during the summer. Predation is the primary driver that removes indicator organisms from open water and not adverse environmental conditions (Rassoulzadegan and Sheldon, 1986), and research has shown that coliforms and enterococci can often survive, grow (Francy et al., 2000; Nasser and Oman, 1999) and reproduce in plants and soil (Solomon et al., 2002; Hardina and Fujioka, 1991; Marino and Gannon, 1991).

In any event, aside from VR04, VR05 and possibly VR09, all other Ventura locations are generally safe for water-contact recreation; test results at these sites usually have no problems meeting the applicable *E. coli* standard. Figure 28 repeats the 2006 results: annual geomeans for *E. coli* and enterococcus, as well as the fecal to total coliform ratio, are shown in the upper panel, while all three indicator bacteria are shown in the lower.[12]

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

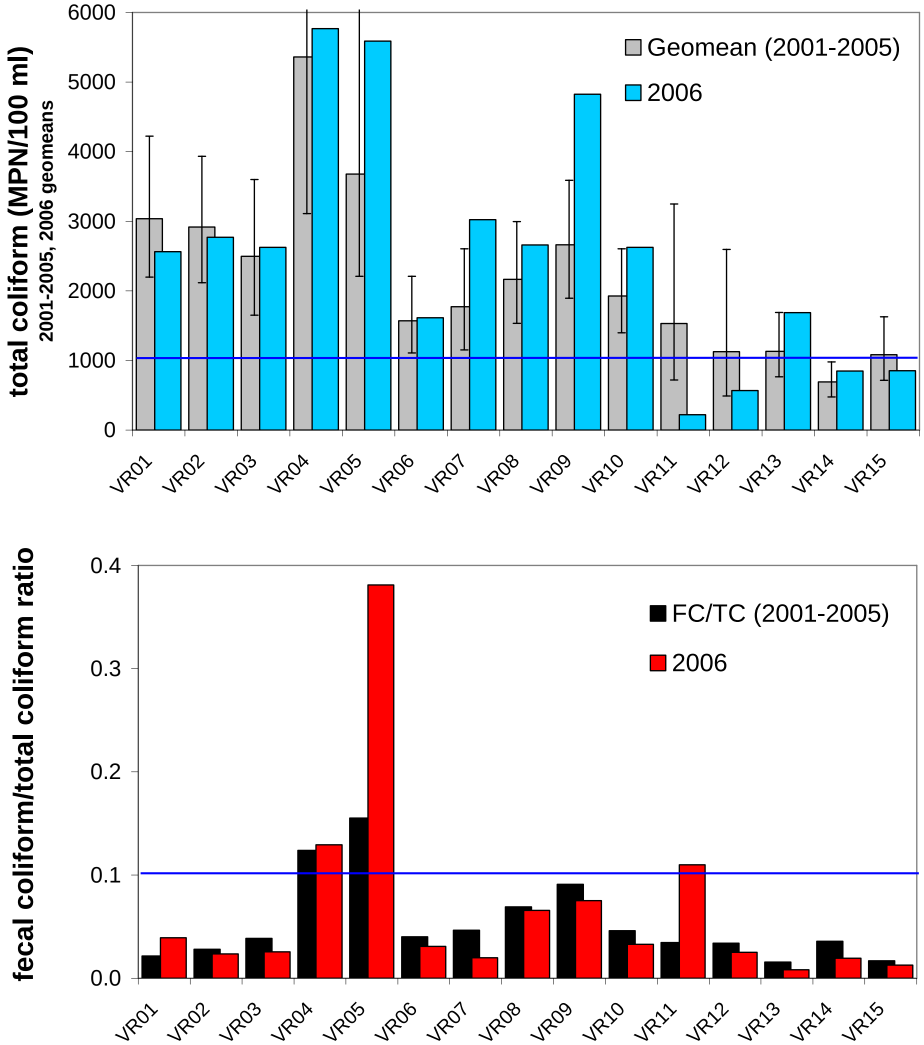


Figure 27. *Upper panel*: 2006 geomean concentrations for total coliform compared with 2001-2005 geomeans. Error bars represent the 95% confidence interval for the long-term geomeans. The California limit for total coliform is 10,000 MPN/100 ml.
Lower panel: 2006 and 2001-2005 fecal to total coliform ratios (the California limit for total coliform decreases to 1,000 MPN/100 ml if the fecal coliform/total coliform ratio exceeds 0.1 (horizontal line)).

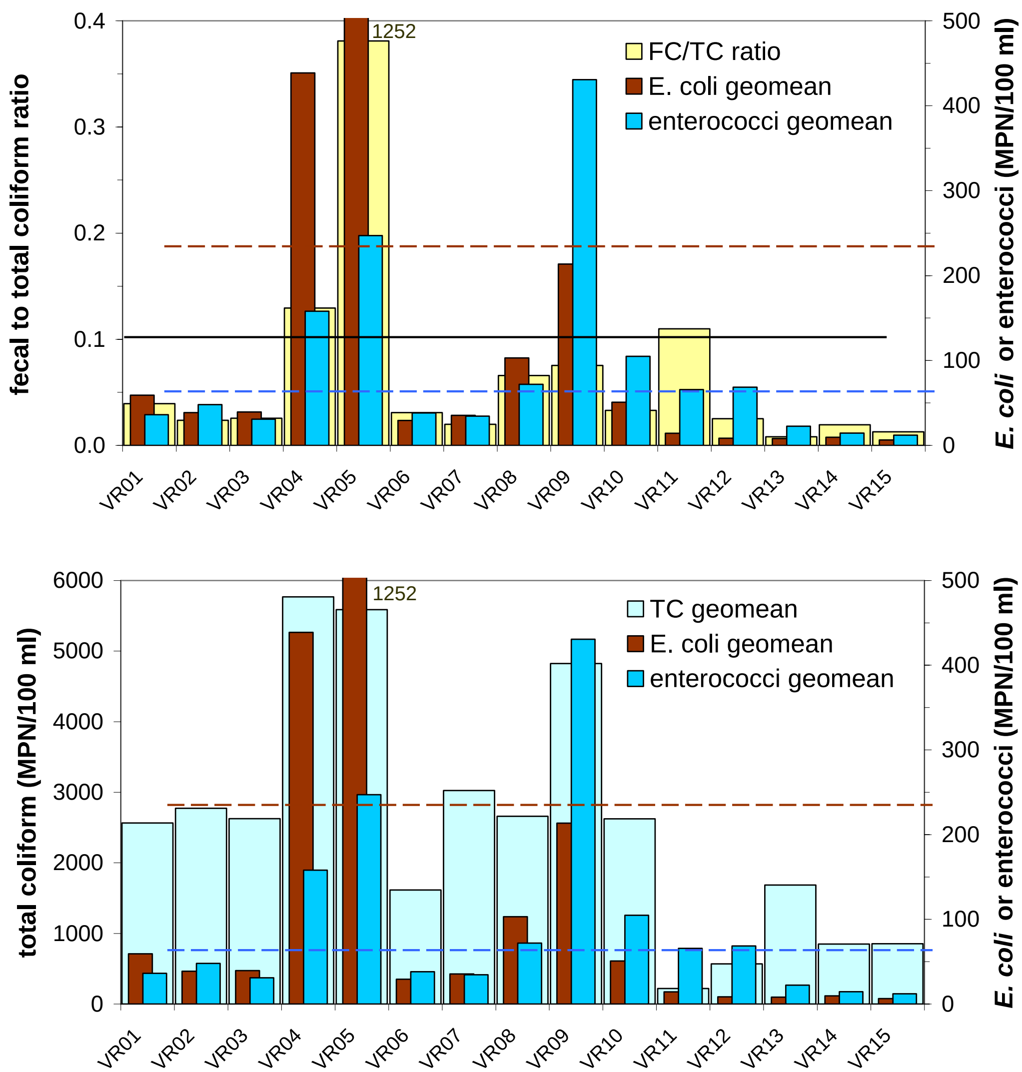


Figure 28. *Upper panel*: The average 2006 fecal to total coliform ratio with *E. coli* and enterococci concentrations (as geomeans). Dashed horizontal lines mark the EPA's recommended freshwater beach Public Health limits for maximum enterococcus (61 MPN/100 ml) and *E. Coli* (235 MPN/100 ml). The California 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, 2006.

Summary of Results: Problem Areas

In this section, Channelkeeper's 2006 sampling results are reviewed to identify problems and potential causes. Problem locations indicated by abnormal physical parameter values (conductivity, water temperature, *p*H and turbidity) are summarized in Table 1.

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.

Table 1. Physical parameters. Numbers in the table are calculated criteria values that identify specific problems during 2006 at the Ventura sampling sites. Column headings show the parameters, measurement units and the criteria used flag problem areas. Values in parentheses are those from the 2001-2005 report. The specific criteria were: (1) median conductivity > 2,000 µS/cm; (2) 10% of monthly water temperatures ≥ 26.4°C; (3) 10% of monthly *p*H values > 8.5; and (4) median non-storm turbidity > 1.9 NTU.

	µS/cm	percent	percent	NTU
	median	10 % ≥ 26.4 °C	10 % ≥ 8.5	median
site	**conductivity**	**temperature**	***p*H**	**turbidity**
VR01			33% (*12.3%*)	2.0
VR02			45% (*25.0%*)	
VR03			33% (*15.8%*)	2.3
VR04	2,534 (*2,663*)	13%	11%	
VR05	2,760 (*3,048*)	20%		3.5
VR06				
VR07				
VR08				
VR09				
VR10				
VR11				
VR12				
VR13				
VR14				
VR15				

Canada Larga is the only Ventura tributary with excessive conductivity. The probable causes are grazed pasture runoff at the upper site and industrial nuisance flows at the lower. Both locations are prone to low flows with high evaporation, and the concrete canal above VR05 may also contribute to the problem. 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). Although conductivity during 2006 at VR08 and VR09 did not exceed the 2,000 µS/cm standard, high median conductivities (1604 at VR08, from pasture runoff and high evaporation, and 1,650 at VR09) are of some concern.

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 is 10% higher than the maximum temperature benchmark of 24°C used earlier). Excessive temperatures are caused by un-shaded, shallow trickling flows, i.e., the absence of riparian vegetation. Both VR04 and VR05 had excessive temperatures in June 2006; at no other sites did recorded temperature exceed 26.4°C.

The similar criterion was used for *p*H: excessive pH was identified as greater than 10 percent of the monthly values exceeding 8.5 (8.5 is the SWQCB-LA upper limit for surface waters). Excess *p*H in the Ventura River and its tributaries is almost always caused by algal blooms.

High *p*H on the lower river in 2006 (VR01-03) and at VR04 was due to excessive algae throughout the summer.

Excessive turbidity was identified as non-storm median values exceeding the suggested EPA limit of 1.9 NTU. Failed sites are usually characterized by either periodic disturbance or relatively stagnant waters and excessive biological productivity (the presence of microscopic algae and bacterial films at the site or immediately upstream). VR01, VR03 and VR05 exceeded the 1.9 NTU criterion in 2006. Cattle were probably responsible at VR05 and there is some as yet unknown source of disturbance upstream of VR01. It is possible that Ojai sewage treatment plant outflows may bear some responsibility for higher turbidity at VR03.

Biological problems, identified by aberrant parameter values and concentrations (nitrate, phosphate, minimum dissolved oxygen and excessive DO saturation), are summarized in Table 2. Excessive biological productivity or eutrophication is the major biological problem identified by Channelkeeper's sampling. Excessive nutrient concentrations are major causal factors and both minimum DO values and excessive DO saturation pinpoint the deleterious effects. The criteria used to identify excessive nutrients were median nitrate concentrations above 0.52 mg/L and median phosphate concentrations above 0.030 mg/L. These limits are, respectively, the suggested EPA values for nitrogen and phosphorus in the Ventura region. As applied here, they are slightly less conservative since they evaluate only the nitrate and phosphate fractions of these elements.

Almost all sampling locations have excessive nutrients. To distinguish locations and reaches with severe concentrations *far above the norm* are shown in red: we have defined far above the norm as five times the EPA limit. Urban and agricultural runoff are the major causes of high nitrate at VR09 and VR10 (below Ojai) if the definition of agriculture is extended to include “urban agriculture,” i.e., runoff from the fertilization and over-watering of lawns, landscaping, parks and golf courses. However, on the lower river (VR01-03), treated sewage effluent is the primary source of high nitrate. VR07 and VR06 also had excessive nitrate in 2006, probably caused by greater contributions from upstream sites on San Antonio Creek and increased groundwater inflows. Other sources contribute to the overall nitrate problem in the Ventura watershed: 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 Channelkeeper sampling takes place during the dry weather – when nuisance urban flows and the discharge of treated sewage effluent dominate.

Channelkeeper's 2006 results demonstrate a substantial improvement in phosphate concentrations on the Ventura River. Previously, every sampling location had problems with high phosphate – all sites having median phosphate concentrations that exceeded the EPA recommended limit for total phosphorus. This is primarily a consequence of natural geological conditions in the watershed. However, the release of treated sewage effluent above VR03 adds considerably to the problem on the lower river (VR01-03). In 2006, only six of the fifteen sampled locations had excessive phosphate. Other than VR01-03, these were VR05, VR08 and VR09. The probable cause at VR08 and VR05 is animal waste from cattle and horses. The precise cause of high phosphate concentrations at VR09 remains unknown, but urban agriculture (fertilizer, pesticides, etc.) and domestic pets and horses undoubtly contribute. It is important to stress the caveat stated in the section on phosphate: that the overall phosphorus situation may not have improved as much as decreases in phosphate concentrations indicate because an increase in organic phosphorus, which we were unable to accurately measure, accompanied the phosphate decline.

Table 2. Biological parameters. Numbers in the table are calculated criteria values that identify specific problems at Ventura Stream Team sampling sites in 2006. Values in parentheses are those from the 2001-2005 report. Column headings show the parameters, measurement units and the criteria used 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 exceeding 120 % DO saturation. Particularly egregious results are shown in bold.

	mg-N/L	mg-P/L	% (mg/L)	percent
	median	median	5% < 5 (min)	10% < 120%.
site	**nitrate**	**phosphate**	**minimum DO**	**% DO sat.**
VR01	0.66 (*1.04*)	0.083 ***(0.164)***		**80% *(26.3%)***
VR02	0.85 (*1.67*)	0.083 ***(0.270)***	{*8.1 % (4.0)*}	**64% *(37.5%)***
VR03	0.85 (*2.00*)	0.108 ***(0.312)***		**55% *(22.8%)***
VR04		(*0.044*)	{*10.8 % (3.5)*}	(*12.9%*)
VR05		0.062 (*0.080*)		
VR06	0.87	(*0.044*)		**27% *(31.6%)***
VR07	1.88 (*0.66*)	(*0.076*)	{*11.1 % (3.9)*}	**50%** (*14.9%*)
VR08		0.083 (*0.121*)	{*11.1 % (3.9)*}	**20%** (*11.1%*)
VR09	1.51 (1.44)	0.071 (*0.124*)		
VR10	**4.68 *(3.75)***	(*0.051*)		
VR11	(*0.87*)	(*0.033*)		(*11.8%*)
VR12		(*0.034*)		(*11.8%*)
VR13		(*0.037*)		
VR14		(*0.039*)		
VR15		(*0.036*)		17 % ***(23.4%)***

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: (1) minimum concentrations equal to or below 4 mg/L, and (2) greater than 5% of the monthly 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 monthly DO saturation exceeded 120% are identified in bold.

The DO criteria are somewhat contradictory, as excessive percent saturation values are likely to be found only during daylight, while minimum DO concentrations generally occur at night. Since almost all Channelkeeper sampling currently takes place in daylight, excessive % 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 with 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. This is particularly true for locations with the most egregious percent saturation values - where low DO concentrations are unlikely to be found during daylight hours.

In 2006, no locations had DO concentrations below 5 mg/L. The lowest recorded concentration was 5.59 mg/L in October 2005 at VR08. However, as indicated by the percent oxygen saturation, excessive algal growth in 2006 was a problem throughout the watershed. The lower Ventura River (VR01-03 and VR06), lower San Antonio Creek (VR07), Lion Canyon (VR08) and Matilija Creek above the reservoir have the greatest problems with over-saturation. These problem locations all feature open reaches with high levels of sunlight. High nutrient levels at VR01-03 undoubtedly contribute, and the algal problem at these three locations is the primary cause of excessive *p*H (Table 1). Although critically low values of "just before sunlight" dissolved oxygen were not investigated in 2006 at these sites, we suspect they may have3 occasionally occurred.

Finally, indicator bacteria concentrations and the fecal to total coliform ratio (FC/TC) were used to identify public health threats. Results are summarized in Table 3. Geomean concentrations above acceptable EPA, County or State of California limits were used as selection criteria to identify locations unsuitable for water contact recreation. This may be too high a standard since these concentrations (*E. coli* < 235 MPN/100 ml; enterococci < 61; total coliform < 10,000, 1,000 if FC/TC > 0.1) are applicable to freshwater public beaches. 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.

Very few sites fail to meet Public Health standards for swimming, and only VR04 and VR05 (Canada Larga) may 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 problems, and only these two locations had concentrations consistently exceeding the "infrequent use" standard. Some of the possible reasons for high enterococci counts at VR09 and VR10 were discussed in earlier sections of the report; high enterococci numbers may not be related to actual pathogenic pollution problems. The very high FC/TC ratios at Canada Larga probably result from cattle grazing and are an additional reason for occasional visitors to be wary around this stream.

Table 3. Public Health parameters. Numbers in the table are calculated criteria values for the 2006 water-year that identify specific potential contamination problems at the Ventura Stream Team sampling sites. Values in parentheses are those from the 2001-2005 report. Column headings show the parameters, measurement units and the criteria used 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 geomean ratio > 0.1 ; and (4) total coliform geomean > 10,000 MPN/100 ml, unless FC/TC exceeds 0.1, then 1,000. Geomeans exceeding the EPA standards for "infrequent full body contact recreation" are shown in bold.

	MPN/100 ml	MPN/100 ml	ratio	MPN/100 ml
	geomean	geomean	geomean	geomean
site	***E. Coli***	**enterococci**	**FC/TC**	**total coliform**
VR01				
VR02				
VR03				
VR04	439 ***(595)***	**158 (*176*)**	0.13 (*0.21*)	5,768 (*4,905*)
VR05	**1,250** (*403*)	**247 (*245*)**	0.38 (*0.20*)	5,586 (*3,490*)
VR06				
VR07				
VR08		72		
VR09		**431 (*150*)**		
VR10		135 (*71*)		
VR11		66	0.11	
VR12		69		
VR13				
VR14				
VR15				

References

Armor, C.L. 1991. Guidance for evaluating and recommending temperature regimes for protecting fish. US Fish. Wildl. Serv., Biol. Rep. 90(22). 13 p.

Bjornn, T.C., and D.W. Reiser. 1991. Habitat requirements of salmonids in streams. In: W.R. Meehan (ed.) Influences of Forest and Rangeland Management on Salmonid Fishes and their Habitats. American Fisheries Special Publication #19. pp. 83-138.

Borchardt, M.A. 1996. Factors affecting benthic algae: Nutrients. pp. 184-217. In Stevenson, R.J., M.L. Bothwell and R.L. Lowe (editors). 1996. Algal Ecology: Freshwater Benthic Ecosystems. Academic Press, San Diego.

Brungs, W.A. and B.R. Jones. 1977. Temperature criteria for freshwater fish: Protocol and procedures. EPA-600-3-77-061. Environmental Research Laboratory-Duluth, Office of Research and Development, US Environmental Protection Agency. 136 p.

California Climate Data Archive (CCDA). http://www.calclim.dri.edu/ccda/ccacoop.html

California Data Exchange Center (CDEC). http://cdec.water.ca.gov/

California State Water Quality Control Board (SWQCB). 2004. Amendment of the Water Quality Control Plan for ocean waters of California. Sacramento, CA. (http://www.swrcb.ca.gov/plnspols/oplans/docs/bactffed.pdf)

California State Water Quality Control Board (SWQCB). 2003. Public scoping meeting for the proposed amendment of the Water Quality Control Plan for ocean waters of California. Sacramento, CA. (http://www.swrcb.ca.gov/plnspols/oplans/)

California State Water Quality Control Board, Central Coast Region (SWQCB-CC). 2004. Staff Report: Proposed amendment of the Central Coast Water Quality Control Board Basin Plan to revise bacteria objectives for all inland surface waters and enclosed bays and estuaries designated water contact recreation and shellfish harvesting. San Luis Obispo, CA. 17p. (http://www.waterboards.ca.gov/centralcoast/BasinPlan/Documents/3BactiObjsStaffReport05-04-04.doc)

California State Water Quality Control Board, Central Coast Region (SWQCB-CC). 1994. Water Quality Control Plan: Central Coast Region. San Luis Obispo, CA. (http://www.swrcb.ca.gov/rwqcb3/WMI/Index.htm)

California State Water Quality Control Board, Los Angeles Region (SWQCB-LA). 2004. Watershed Management Initiative: Ventura River Watershed. Monterey Park, CA. 7p. (http://www.swrcb.ca.gov/rwqcb4/html/meetings/tmdl/Basin_plan/basin_plan_doc.html)

California State Water Resources Control Board, Los Angeles Region (SWRCB-LA). 2002. State of the watershed – Report on surface water quality: The Ventura River Watershed (draft). Monterey Park, CA. (http://www.swrcb.ca.gov/rwqcb4/html/programs/regional_program/wmi2004/VenturaRiverState.html)

California State Water Quality Control Board, Los Angeles Region (SWQCB-LA). 2001. Report: proposed amendment of the Water Quality Control Plan, Los Angeles Region, to revise bacteria objectives for waters designated contact recreation. Monterey Park, CA. 7p.

(http://www.swrcb.ca.gov/rwqcb4/html/meetings/tmdl/Basin_plan/basin_plan_amendment_tmdl.htm#6)

California State Water Quality Control Board, Los Angeles Region (SWQCB-LA). 1994. Water Quality Control Plan: Los Angeles Region. Monterey Park, CA. (http://www.swrcb.ca.gov/rwqcb4/html/meetings/tmdl/Basin_plan/basin_plan_doc.html)

Carlsen, W. 1994. Environmental inquiry: Diurnal cycling experiments. Cornell University, Ithaca, NY. 6p. (http://ei.cornell.edu/watersheds/Diurnal_Cycling_Experiments.pdf)

Carpenter, S.R., N.F. Caraco, D.L. Correll, R.W. Howarth, A.N. Sharpley and V.H. Smith. 1989. Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecological Applications 8: 559-568.

CCREM (Canadian Council of Resource and Environment Ministers - now the CCME - Canadian Council of Ministers for the Environment). 1987. Canadian Water Quality Guidelines. Task Force on Water Quality Guidelines of the Canadian Council of Resource and Environment Ministers. 256 p.

Cude, C.G. 2005. Accommodating change of bacterial indicators in long term water quality datasets. JAWRA 41:47-54.

Davis, J.C. 1975. Minimal dissolved oxygen requirements of aquatic life with emphasis on Canadian species: A review. J. Fish. Res. Board., Can. 32: 2295-2332.

Deas, ML., and G.T. Orlob. 1999. Klamath River Modeling Project: Project #96-HP-01. Assessment of Alternatives for Flow and Water Quality Control in the Klamath River below Iron Gate Dam. University of California Davis Center for Environmental and Water Resources Engineering, Report No. 99-04. 236 p. (http://www.krisweb.com/biblio/klamath_ucd_deasorlab_1999_wq.pdf) (additional info on monitored parameters)

Desert Research Institute: Western Regional Climate Center (DRI-WRCC). http://www.wrcc.dri.edu/

Dillon, P.J., and W.B. Kirchner. 1975. The effects of geology and land use on the export of phosphorus from watersheds. Water Res. 9:135-148.

Francy, D.S., E.R. Helsel and R.A. Nally. 2000. Occurrence and distribution of microbiological indicators in groundwater and stream water, Water Environmental Research 72: 152-1610.

Grobler, D.C., and M.J. Silberbauer. 1985. The combined effect of geology, phosphate sources and runoff on phosphate export from drainage basins. Water Res. 19:975-981.

Hardina, C.M., and R.S. Fujioka. 1991. Soil: the environmental source of *Escherichia coli* and enterococci in Hawaii's streams. Environmental Toxicology and Water Quality 6: 185-195.

Heal the Bay. 2003. The freshwater and marine team field guide. Heal the Bay, Santa Monica, CA. (http://www.healthebay.org/streamteam/).

Joint Institute for the Study of the Atmosphere and Ocean (JISAO). http://tao.atmos.washington.edu/greg/southwest/states/CA/

Kinzelman, J., N. Clement, E. Jackson, S. Gradus, and R. Bagley. 2003. Enterococci as indicators of Lake Michigan recreational water quality: Comparison of two methodologies and their impacts on public health regulatory events. Applied and Environmental Microbiology 69: 92-96. (http://aem.asm.org/cgi/content/full/69/1/92)

Leydecker, A., J. Simpson, and Leigh Ann Grabowsky. 2003. Nutrient Uptake and Cycles of Change: The Ventura River in Southern California. *EOS Trans. AGU 84*(46), Fall Meet. Suppl., Abstract H41F-1052.

Leydecker, A., and J. Altstatt. 2002. Nutrient Response of the Ventura River to Drought Conditions in Southern California. *EOS Trans. AGU 83*(47), Fall Meet. Suppl., Abstract H21A-0787.

Mantua, N.J. 2000. The Pacific decadal oscillation and climate forecasting for North America. The Climate Report 1(1). (http://www.atmos.washington.edu/~mantua/REPORTS/PDO/PDO_cs.htm; http://www.guaranteedweather.com/page.php?content_id=73)

Mantua, N.J., S.R. Hare, Y. Zhang, J.M. Wallace, and R.C, Francis. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. Bulletin of American Meteorological Society 78: 1069-1079. (cf. http://www.atmos.washington.edu/~mantua/REPORTS/PDO/PDO_cs.htm)

Marino, R.P., and J.J. Gannon. 1991. Survival of fecal coliforms and fecal streptococci in storm drain sediment. Water Research 25: 1089-1098.

Matthews, K.R., and N.H. Berg. 1997. Rainbow trout responses to water temperature and dissolved oxygen stress in two southern California stream pools. J. of Fish Biology 50: 50-67. (http://www.fs.fed.us/psw/publications/matthews/psw_1997_matthews003.pdf)

McEwan, D., and T.A. Jackson. 1996. Steelhead restoration and management plan for California. California Dept. of Fish and Game, Sacramento Ca. 244 p. (http://www.krisweb.com/biblio/cal_cdfg_mcewan_1996.pdf)

Minobe, S. 1997. A 50-70 year climatic oscillation over the North Pacific and North America. Geophysical Research Letters 24: 683-686.

Monteverdi, J., and J. Null. 1997. El Niño and California Precipitation, Western Region Technical Attachment No. 97-37, NOAA. San Francisco, CA. (http://tornado.sfsu.edu/geosciences/elnino/elnino.html)

Munn, M.D., L.L. Osborne and M.J. Wiley. 1989. Factors influencing periphyton growth in agricultural streams of central Illinois. Hydrobiologia 174: 375-370.

Nasser, A.M., and S.D. Oman. 1999. Quantitative assessment of the inactivation of pathogenic and indicator viruses in natural water sources, Water Research 33: 1089-1098.

National Weather Service: Los Angeles/Oxnard Climate Data (NWS-LA). (http://www.wrh.noaa.gov/climate/local_data.php?wfo=lox)

Newcombe, C.P. and D.D. MacDonald. 1991. Effects of Suspended Sediments on Aquatic Ecosystems. North American Journal of Fisheries Management 11: 72-82.

New Mexico Environmental Department, Surface Water Quality Bureau (NM-SWQB). 2000. Total maximum daily load for the Sante Fe River for dissolved oxygen and pH. Santa Fe, NM. 24p. (http://www.nmenv.state.nm.us/swqb/Santa_Fe_River_Oxygen-pH_TMDLs.pdf)

Noble, R.T., D.F. Moore, M.K. Leecaster, C.D. McGee and S.B. Weisberg. 2003. Comparison of total coliform, fecal coliform and enterococcus bacterial indicator response for ocean recreational water quality testing. Water Research 37: 1637-1643. (http://www.ochealthinfo.com/docs/public/h2o/Water-Research-Publication-2003.pdf)

Nordin, R.N. 1985. Water quality criteria for nutrients and algae. Ministry of Environment, Province of British Columbia. Canada. (http://wlapwww.gov.bc.ca/wat/wq/BCguidelines/nutrientstech.pdf)

Oregon Dept. of Environmental Quality (ODEQ). 2001a. Umatilla Basin TMDL and WQMP, Appendix A-5. Portland, OR. (http://www.deq.state.or.us/wq/TMDLs/Umatilla/UmatillaTMDLAppxA-5.pdf)

Oregon Dept. of Environmental Quality (ODEQ). 2001b. Umatilla Basin TMDL and WQMP, Appendix A-6. Portland, OR. (http://www.deq.state.or.us/wq/TMDLs/Umatilla/UmatillaTMDLAppxA-6.pdf)

Primary Industries and Resources, South Australia (PIRSA). 1999. Fact sheet: Water quality in freshwater aquaculture ponds. Adelaide, SA. 9p. (http://www.pir.sa.gov.au/pages/aquaculture/species_profiles/water_quality_fs.pdf)

Quinn, J.M., R.J. Davies-Colley, C.W. Hickey, M.L. Vickers and P.A. Ryan. 1992. Effects of clay discharges on streams 2: Benthic invertebrates. Hydrobiologia 248: 235-247.

Rassoulzadegan, F., and R.W. Sheldon. 1986. Predator-prey interactions on nonozooplankton and bacteria in an oligotrophic marine environment. Limnology and Oceanography 31: 1010-1021.

Santa Barbara Channelkeeper (SBCK). 2004. Stream Team quarterly newsletter: Ventura edition. Vol. 4. Santa Barbara, CA. (http://www.stream-team.org/Ventura/Newsletters/Vol4July2004.pdf)

Santa Barbara Channelkeeper (SBCK(b)). The Ventura River: Cycles of change. Santa Barbara, CA. (http://www.stream-team.org/report.html)

Sauter, S.T., J. McMillan and J. Dunham. 2001. Salmonid behavior and water temperature. US Environmental Protection Agency, Washington, D.C. EPA-910-D-01-001. 38 p.

Scott, K.M., and R.P. Williams. 1978. Erosion and sediment yields in the Transverse Ranges, southern California. U.S.G.S. Professional Paper 1031, 38 p.

Sigler, J.W., T.C. Bjornn and F.H. Everest. 1984. Effects of Chronic Turbidity on Density of Steelheads and Coho Salmon. Transactions of the American Fisheries Society, 113: 142-150.

Schlesinger, W.H. 1997. Biogeochemistry: An analysis of global change. Academic Press, San Diego, CA.

Slack, K.V. 1971. Average dissolved oxygen-measurement and water quality significance. J. Water Pollut. Control Fed. 43: 433-446.

Smith, V.H., G.D. Tilman and J.C. Nekola. 1999. Eutrophication: Impacts of excess nutrient inputs on freshwater, marine and terrestrial ecosystems. Environmental Pollution 100: 179-196.

Solo-Gabriele, H.M., M.A. Wolfert, T.R. Desmarais and C.J. Palmer. 2000. Sources of *Escherichia coli* in a coastal subtropical environment. Applied and Environmental Microbiology 66: 230-237.

Solomon, E.B., S. Yaron and K.R. Matthews. 2002. Transmission of Escherichia coli O157:H7 from contaminated manure and irrigation water to lettuce plant tissue and its subsequent internalization. Applied and Environmental Microbiology 68: 397-400.

Sterner, R.W., and J.J. Elser. 2002. Ecological Stoichiometry. Princeton University Press, Princeton, NJ. 439p.

Stoecker, M.W. 2002. Steelhead assessment and recovery oppportunities in southern Santa Barbara County, California. Conception Coast Project. Santa Barbara, CA. 439p. (http://conceptioncoast.org/projects_steelhead_maps.html)

University of California, Santa Barbara: Santa Barbara Coastal Long Term Ecological Reasearch (UCSB-LTER). (http://sbc.lternet.edu/; http://www.lternet.edu/sites/sbc/; http://www.lternet.edu/sites/)

U.S. Environmental Protection Agency (US-EPA). 2004. Water quality standards for coastal and Great Lakes recreation waters. EPA 40 CFR 131, Washington, DC. (http://www.epa.gov/waterscience/beaches/bacteria-rule.htm#final)

U.S. Environmental Protection Agency (US-EPA). 2003. Guidelines establishing test procedures for the analysis of pollutants; Analytical methods for biological pollutants in ambient water; Final Rule. EPA 40 CFR 136, Washington, DC. (http://www.epa.gov/waterscience/methods/update2003/)

U.S. Environmental Protection Agency (US-EPA). 2002. Implementation Guidance for Ambient Water Quality Criteria for Bacteria (draft). US Environmental Protection Agency, EPA-823-B-02-003, Washington, DC. (http://www.epa.gov/waterscience/standards/bacteria/)

US Environmental Protection Agency (US-EPA). 2000a. Ambient water quality criteria recommendations: Rivers and streams in nutrient ecoregion II. EPA 822-B-00-015, Washington, DC. (http://www.epa.gov/waterscience/criteria/nutrient/ecoregions/rivers/)

US Environmental Protection Agency (US-EPA). 2000b. Ambient water quality criteria recommendations: Rivers and streams in nutrient ecoregion II. EPA 822-B-00-016, Washington, DC. (http://www.epa.gov/waterscience/criteria/nutrient/ecoregions/rivers/)

US Environmental Protection Agency (US-EPA). 1997. Volunteer stream monitoring: A methods manual. EPA 841-B-97-003, Washington, DC. (http://www.epa.gov/owow/monitoring/volunteer/stream/).

US Environmental Protection Agency (US-EPA). 1986. Ambient Water Quality Criteria for Dissolved Oxygen. Criteria and Standards Division. US Environmental Protection Agency, Washington, D.C. EPA. 440/5-86-003. (http://www.epa.gov/waterscience/pc/ambient2.html)

US Environmental Protection Agency (US-EPA). 1983. Nitrogen, nitrate-nitrite: Method 353.2 (colorimetric, automated, cadmium reduction). Methods for chemical analysis of water and wastes. EPA-600/ 4-79-020: 353-2.1 and 353-2.5.

US Geologic Survey, NWISWeb Data for California (USGS-NWIS): Station 11118500, Ventura River near Ventura.
(http://waterdata.usgs.gov/ca/nwis/uv/?site_no=11118500&agency_cd=USGS)

Valderrama, J.C. 1980. The simultaneous analysis of total nitrogen and total phosphorus in natural waters. Mar. Chem. 10: 109-122.

Ward, M.H., S.D. Mark, K.P. Cantor, D.D. Weisenburger, A. Correa-Villasenor and S.H. Zahm. 1996. Drinking water nitrate and the risk of non-Hodgkin's lymphoma. Epidemiology 7: 465-471. (http://www.cheec.uiowa.edu/nitrate/health.html#Risks)

Willason, S.W. and K.S. Johnson. 1986. A rapid, highly sensitive technique for the determination of ammonia in seawater. Mar. Biol. 91: 285-290.

Windell, J.T., L.P. Rink, L.P. and C.F. Knud-Hansen. 1987. A one year, biweekly, 24-hour sampling study of Boulder Creek and Coal Creek Water Quality. City of Boulder, Public Works Department, Boulder, CO. (http://bcn.boulder.co.us/basin/data/COBWQ/diurnal/)

Appendix: Methodology

Water sampling and chemical analyses

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

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

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

Bacteriological analysis

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

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

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

In-field measurements

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

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

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

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