Dissolved Oxygen Variation:
Ventura River Watershed, April through July 2010

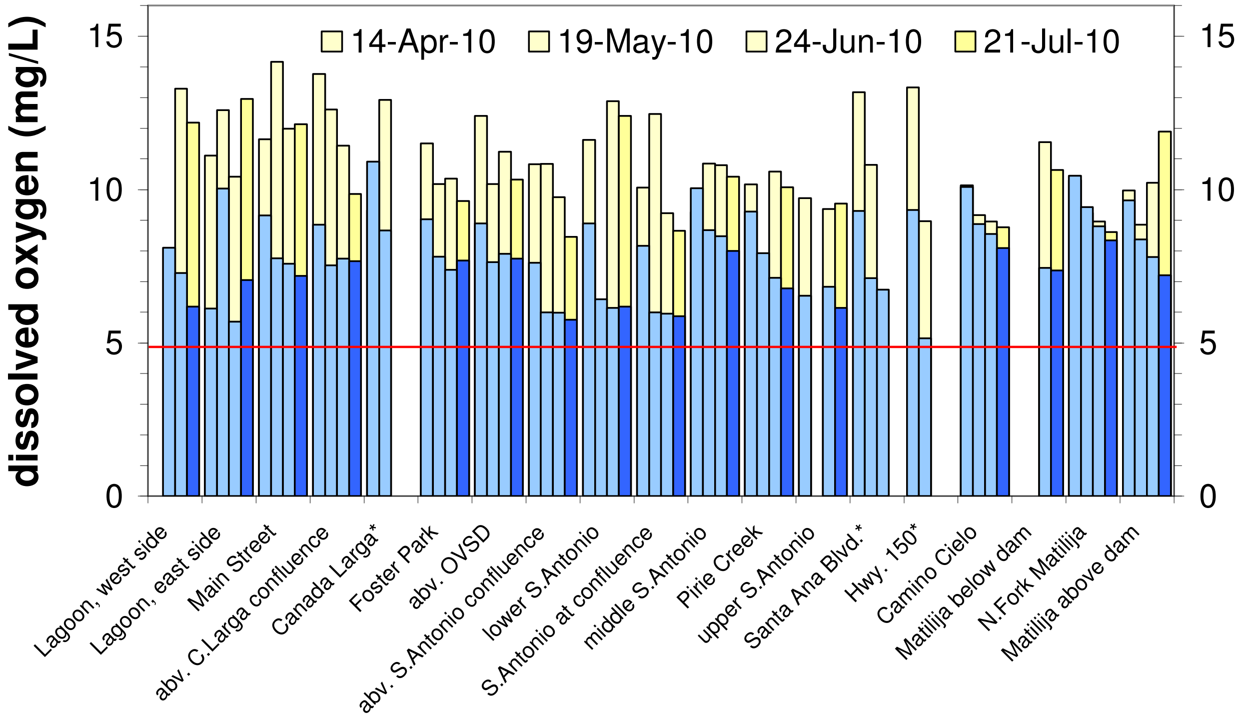
During the dry-season of 2005, Santa Barbara Channelkeeper (SBCK) began measuring pre-dawn dissolved oxygen (DO), *p*H and water temperature at selected locations in the Ventura River watershed. Pre-dawn measurements of DO were meant to serve as an estimate of minimum daily concentrations. This turned out to be not quite true; the daily minimum, to simplify somewhat, being the result two opposing trends: declining concentrations from cumulative biologic respiration vs. increased oxygen solubility as water temperatures decrease. Even so, there are usually only minor differences in DO throughout most of the night-time hours and pre-dawn measurements remain a reasonable estimate of minimum levels.

In 2005, only two monitoring events were conducted, in June and July during the peak of a spectacular algal season following an extremely wet winter. Since no locations were found to have minimum DO below the Basin Plan limit of 5 mg/L, these measurements were not continued into the following dry-seasons since 2006 and 2007 exhibited much less algal growth than 2005. In retrospect, this proved to be a mistake, 2006 proved to be highly unusual, having the wettest April on record, and 2007 for some as yet unexplained reason exhibited massive algal blooms in the upper basin (above the San Antonio confluence and on the Matilija tributaries). Be that as it may, with the advent of the TMDL project, and in coordination with the UCSB algal study (performed under contract with the LA RWQCB), pre-dawn monitoring of DO was again taken up. This monitoring was extended to include similar measurements in the mid-afternoon of the same day, mid-afternoon being approximately the time of peak DO in locations affected by algal growth.

Monitoring in 2008 was monthly, from April through September, and roughly the same schedule was continued through the dry-season of 2009. And now this year. We began monitoring in mid-April and intend continuing into August or September. However, since the majority of the algal season is now past (along with the exciting part – the major algal bloom occurred in March and April) this report is being submitted early – so that the data can be considered before the draft nutrient/algal TMDL is presented.

As in prior years, pre-dawn measurements were made between 4:30 to 6:30 AM, mid-afternoon measurements between 1:30 and 3:30 PM. The dissolved oxygen values recorded this year are displayed in Figure 1, both as concentrations in mg/L (i.e., ppm) and as percent saturation. Nineteen locations were monitored including two on the Ventura Lagoon (but not all on every monitoring date, since some sites went dry in subsequent months). Figure 1 also displays the key milestone in DO measurement: the Basin Plan minimum concentration of 5 mg/L. Other, less precise, indicators might also be kept in mind: A mid-afternoon percent saturation in excess of 120 % usually indicates a location heavily impacted by algae, as does a DO concentration in excess of 11 or 12 mg/L.

The graphs indicate that while the minimum limit of 5 mg/L was never reached (the lowest was 5.15 at the Highway 150 Bridge in May; no other location fell below 5.5), a large majority of the sites had at least one month of greater than 120 % of saturation, indicating that algal problems were wide spread. Only four sites never reached this 120 % marker: upper San Antonio, Pirie and N.F. Matilija creeks, and the upper Ventura River at Camino Cielo. And we may well have missed the peak of the bloom at all these locations.



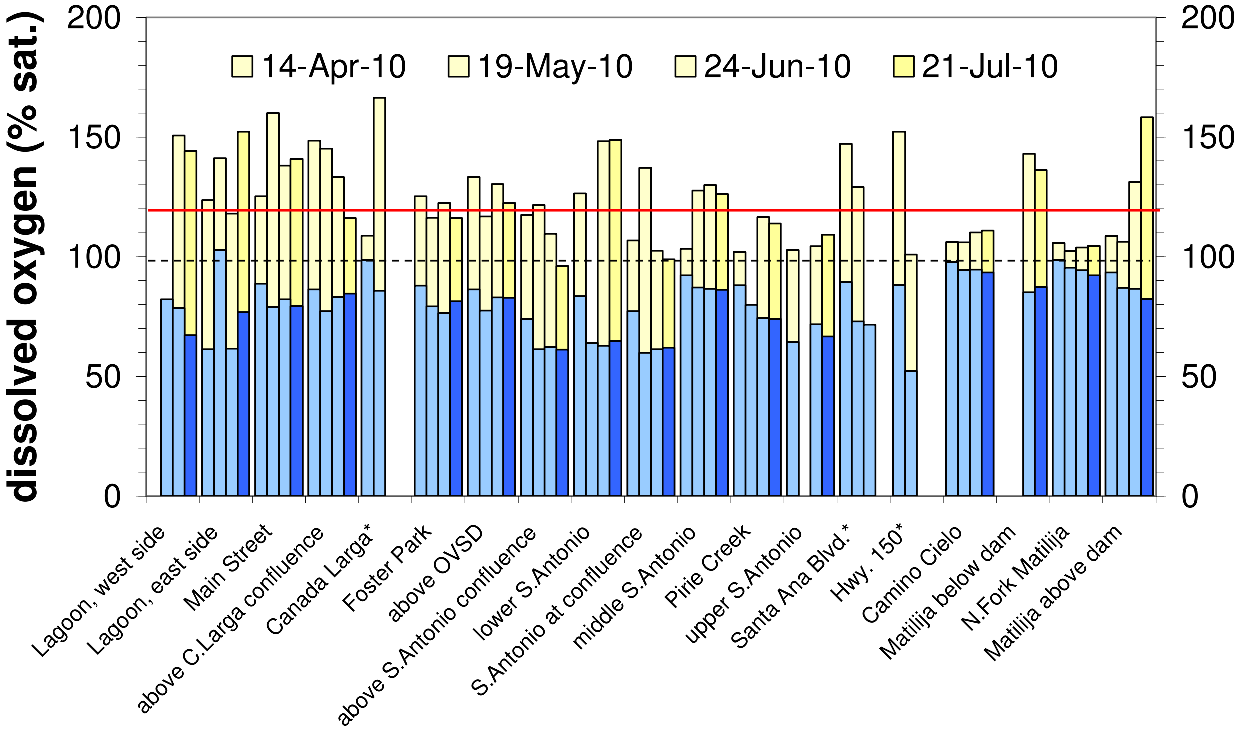


Figure 1. Pre-dawn and mid-afternoon dissolved oxygen concentrations at SBCK Ventura watershed monitoring locations: (top) in mg/liter; (bottom) in percent saturation. Sampling dates are shown in the legend; bars for pre-dawn DO on July 21 are shown in darker blue. Horizontal lines drawn on the graphs show the 5 mg/L basin plan lower limit (top, in red), 100 % saturation and 120 % saturation (bottom, black & red). Sites showing greater than 120 % saturation can be regarded as having a significant algal problem (see text).

2010 proved to be an interesting water-year. Dry-season average daily flows (as recorded at the USGS Foster Park gauge) are shown in the top graph of Figure 2. The dates of pre-dawn monitoring and average Foster Park flow on those days are also shown. Notice that 2010 closely resembles 2008, while 2009 looks very much like the median year. In other words, dry-season flow in 2009 was almost exactly what we might expect in any given year, while both 2008 and 2010 were very much wetter than normal.

This presents a something of a conundrum: algal growth in 2008 having been very much greater than anything seen this year. To put some numbers to this (imprecise estimates, since I'm using modeled values of Chl-a and the mix of sites varied somewhat from year to year), algal density in 2010 on the lower river was roughly only 25% of what we saw in 2008, somewhat higher, 70 %, in the upper basin. Compared with 2009, the lower basin had roughly 200-250% greater algal density in 2010, about 90% greater in the upper basin.

Most of the explanation lies in the bottom graph of Figure 2, which compares wet-season flows for the three years. The first thing to notice is while flows from February on were similar in both years, flows between October and February were very different. In 2008, baseflows from October until the first major storm in early January were much lower, 2007 having been one of the driest years of the past decade (years here referring to "water-years," i.e., the 2008 water-year began on October 1, 2007 and ended on September 30, 2008). And the storms in 2008 were very much larger than those of 2010 (in the graph, flow is plotted on a logarithmic scale where small differences in appearance represent very large differences in quantity). The biggest 2008 storm caused a flow almost 10-times larger than anything seen in 2010 (an average daily flow of 6,340 vs. 687 cfs).

The result being, whereas almost all aquatic plants and lots of riparian brush were uprooted and washed out to sea in 2008, only the more fragile and exposed plant parts left the scene in 2010. Brush and the root systems of aquatic plants remained to give vegetative growth a head start and leg-up in the annual dry-season competition with algae for sunlight and living-space in the waterway.

The lower graph in Figure 2 also emphasizes the storm of April 12, 2010. This was a reasonable size storm, dropping about 1.5 inches on Ojai and perhaps as much as 3 inches in the upper canyons (somewhat aided by an earlier 0.7-0.9 inches on April 6), but since it occurred long after most of the watershed had had adequate time to dry out from previous rainfall, it didn't generate very much runoff. Very little increase in flow was noted at Foster Park (average daily flow went from 40 to 61 cfs, although peak flow, at 150 cfs, was greater), although flows were somewhat more enhanced on the smaller drainages of San Antonio Creek, and in the canyons of the upper watershed (the Matilija creeks and upper Ventura) where rainfall was significantly greater.

What it did do, however, was bring an abrupt halt to the developing algal bloom in these smaller and up-canyon drainages. The lack of appreciable rain since February produced an early start to the 2010 algal season; by the beginning of April significant blooms had developed throughout the watershed (photos included in this report show the bloom well in progress by March 6, 2010). The April 12 storm either removed or appreciably diminished growing algae in smaller streams and may have also impacted the algal bloom on the lower river, particularly at Main Street where urban runoff from impervious surfaces usually results in much greater flows than those recorded at Foster Park during smaller events.

Unfortunately, we have no way of measuring the storm's impact. Happenstance scheduled the first pre-dawn monitoring date on April 14, two days afterward. In retrospect, it would have been very

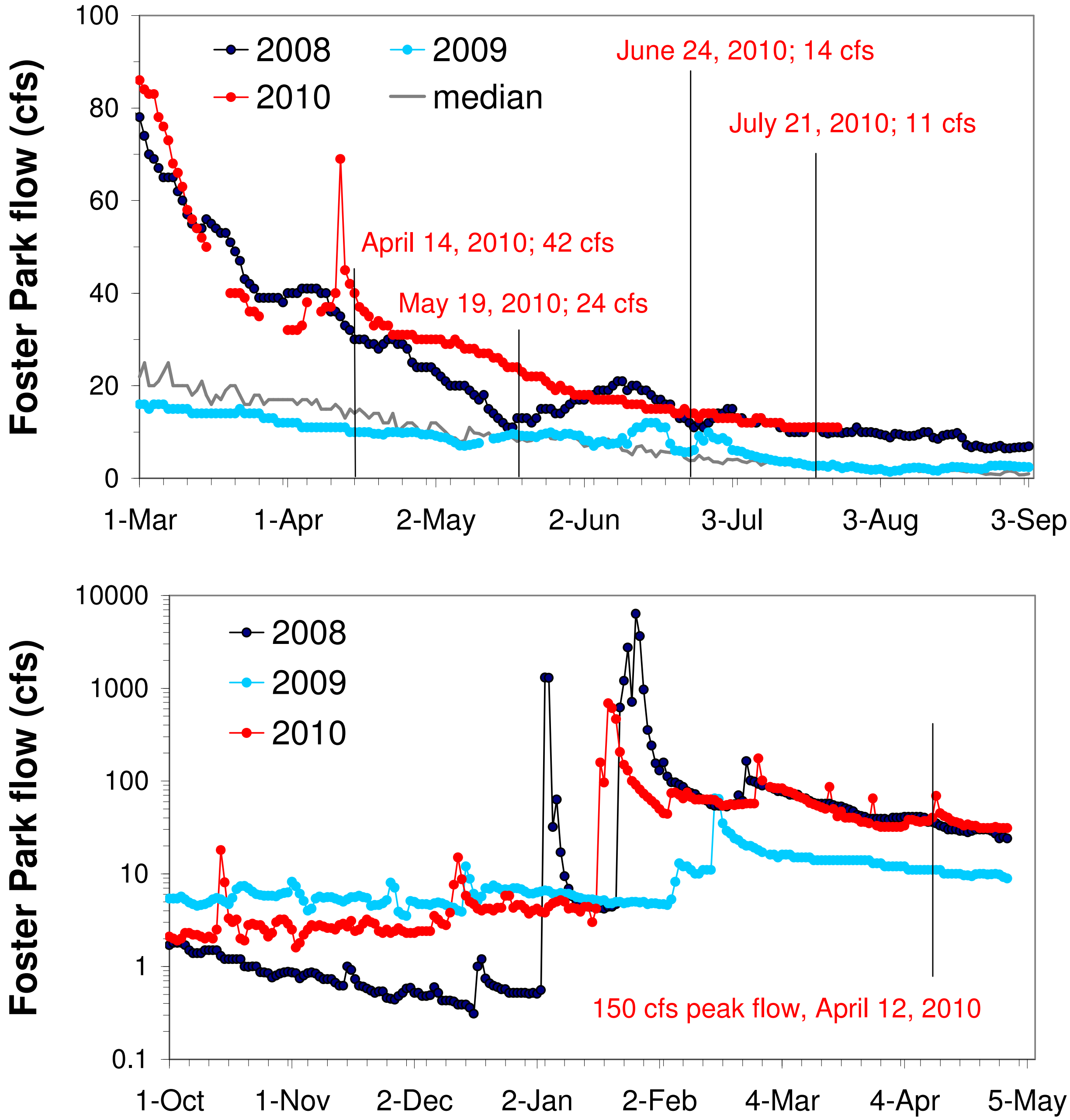


Figure 2. Average daily flow (in cubic feet per second) at the USGS Foster Park gauging station: (top) from March 1, (bottom) rainy-season flows from October 1 to May 1. Flows from 2008, 2009 and 2010 are shown – with 2010 pre-dawn monitoring dates, and their respective flows, in red – and, in the top graph, median dry-season flows for the period of record.

Note that dry-season flows in 2010 are very similar to those of 2008, while 2009 was, more or less, a "median," and much drier, year. The bottom graph, however, indicates that rainy-season flows in 2008 and 2010 were quite different, and that 2008 was characterized by several storms an order-of-magnitude greater than anything experienced in 2010. This, along with the storm of April 12, 2010, had important implications on the kind of algal year we are experiencing.

interesting to have begun monitoring in March. But irrespective of the magnitude of the early algal bloom, river flows this early in the season were high enough to virtually preclude dissolved oxygen levels anywhere near the 5 mg/L limit.

Delta-DO, defined as the difference between the maximum and minimum daily dissolved oxygen concentrations (or in Channelkeeper's case, the difference between mid-afternoon and pre-dawn concentrations, the approximate times when these extremes normally occur) is a more complete measure of the *effect* of algae on the stream reach being monitored. The daily variation in dissolved oxygen (an alternate way to define delta-DO) depends both on the *amount* of algae present and the strength of their collective photosynthetic effort, and the *volume* of water (the flow) that they have to exert this effort on. A lot of algae may not have a big effect if flow is high. Conversely, it may not take much algae to drastically change oxygen concentrations when flows slow to a trickle.

There are many factors other than algae that affect the dissolved oxygen concentration in water: (1) the respiration of other critters; (2) the percent of oxygen saturation already present; (3) the rate of various decay processes taking place in both the water column and bottom sediment; (4) the efficiency and rate of oxygen exchange between the water column and atmosphere; (5) the depth of flow . . . and probably others I've forgotten. Most of these are somewhat dependent on sunlight, water temperature and flow, which vary over the course of a day. But compared with the impact of algae, their variation is relatively minor. When algae are present in sufficient quantities to be noticed, all other factors involved in the diel variation of oxygen can be ignored.

Figure 3 shows delta-DO values for all sites measured during the four monitoring days held so far this dry-season. The Central Coast RWQCB has adopted a *maximum oxygen deficit* standard of 1.25 mg/L to determine which stream reaches do not meet objectives for excessive biostimulatory substances. Fluctuations below this limit offer little risk of algal growth depressing dissolved oxygen to unacceptable levels. This corresponds to a delta-DO of 2.5 mg/L, and this standard is shown on the graph as a red line. While not directly applicable to the Ventura (under the jurisdiction of a different agency, the Los Angles RWQCB) it provides a convenient yardstick to judge when delta-DO may be reaching problematic levels.

Note that some locations, on some days, had negative delta-DO values indicating that pre-dawn values were lower than concentrations found in mid-afternoon. This situation is occasionally found at sites with large water temperature variations (warmer waters being unable to hold as much oxygen at saturation as colder waters); needless to say, sites with negative delta-DO have no algal problems.

Note also that delta-DO values generally show a decrease after May at most sites, indicating that the amount of algae are substantially decreasing. (Flow typically decreases throughout the dry-season, so the expectation, if algal density remained the same, would be an increase in delta-DO. Thus a decrease in delta-DO can only happen if a decrease in algal density, even more rapid than the decrease in flow, is taking place.) However, some sites, show a continual increase in delta-DO, e.g., middle San Antonio Creek and in the upper basin. This indicates either that flow is decreasing much faster than algal numbers or that algal density is on the increase, or both. On the middle San Antonio it's the former, but in the upper basin the flow decrease is being aided by a Mougeotia bloom that began developing in June.

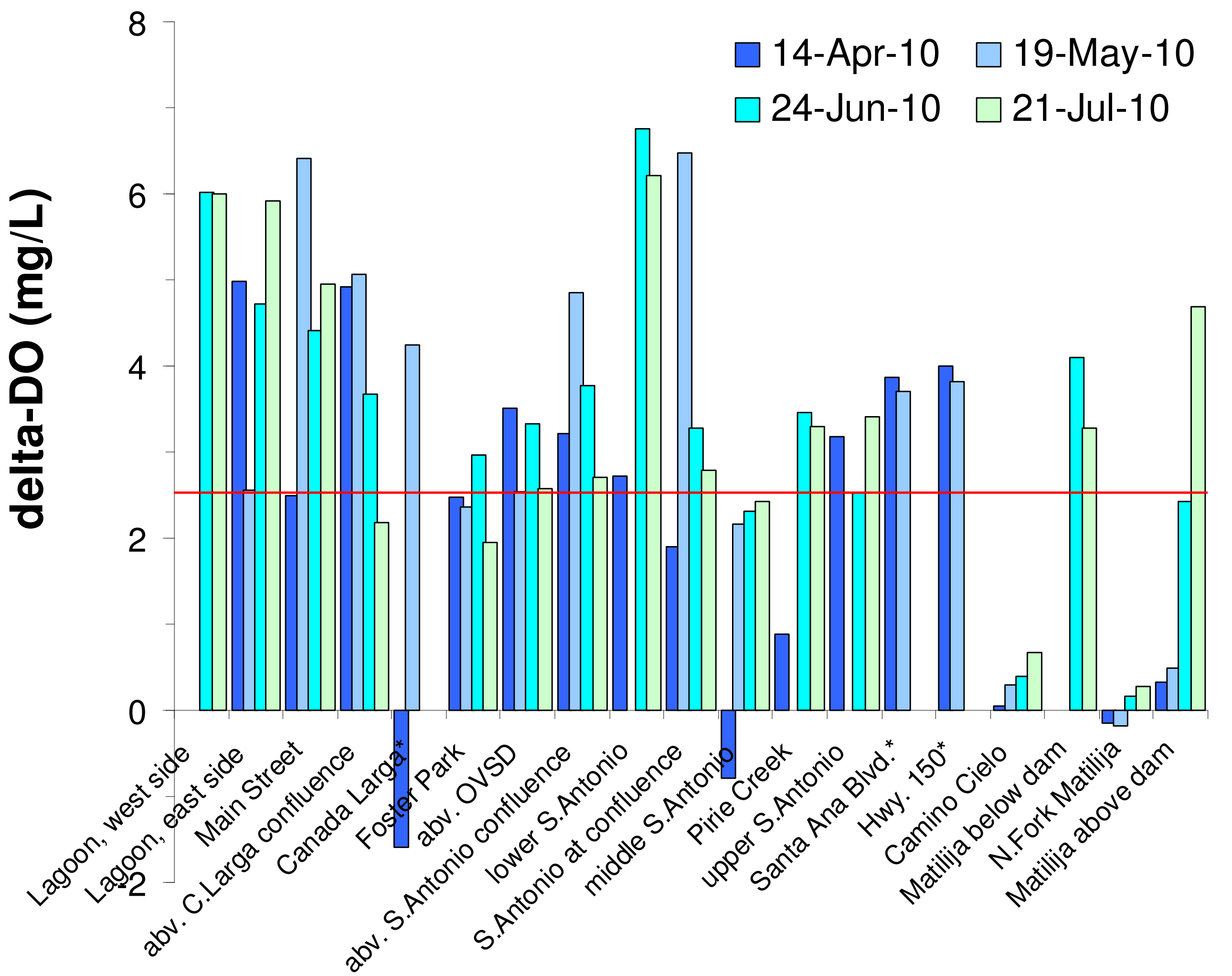


Figure 3. Delta-DO values, the maximum daily dissolved oxygen concentration minus the minimum (or in this case an estimate calculated as mid-afternoon DO - pre-dawn DO) for SBCK monitored locations in the Ventura River watershed. Sampling dates are shown in the legend. The red line indicates a delta-DO of 2.5 mg/L; this is the allowable limit used by the Central Coast RWCB to indicate a significant algal-caused problem with dissolved oxygen (more precisely, an oxygen deficit > 1.25 mg/L as indicating a biostimualatory substances problem). Negative values result when pre-dawn values were lower than concentrations found in mid-afternoon. This situation is occasionally found at sites with large water temperature variations (warmer waters being unable to hold as much oxygen at saturation as colder waters); needless to say, sites with negative delta-DO have absolutely no algal problems.

Since delta-DO is dependent on the amount of algal density and flow (delta-DO is directly proportional to the amount of algae and inversely proportional to flow), we can reverse the terms of this relationship an estimate algal density (measured as Chl-a in mg/m^2) from delta-DO and flow. We have such a model, based on data collected during the 2008 UCSB-TMDL algal study, modified by additional data collected by Julie Simpson in 2003 and Diana Engle in 2008. Since the model, in both its original and modified forms, was obsessively explained in last year's series of Diel Reports I'll say nothing further here. Other than 2010 estimated Chl-a densities are shown in Figure 4. And that flows used for the Chl-a estimates came from either Ventura County, USGS or Channelkeeper flow records.

The UCSB Report recommended Chl-*a* standards of: (1) less than 50 mg/m^2 defining "unimpaired" reaches, (2) greater than 200 mg/m^2 considered " impaired"; with (3) anything falling in-between requiring further study or monitoring. Alternately, 150 mg/m^2 was offered as a single limit. Presumably, these standards or something similar will be adopted in the eventual TMDL. The 50 and 200 mg/m^2 limits are shown on Figure 4 as red lines. To date, only three 2010 locations could be classified as unequivocally "impaired," each during a single month; but all but three sites had at least one month where they fell into the "above 50" category.

Measured water temperatures are shown in Figure 5.

Measuring Chl-a:

What follows is a polemic – some might say a rant – on something that's been bothering me for more than a few years: the imprecision and inaccuracy of measuring Chl-a, and its inadequacy as a parameter for determining TMDL compliance. Not to mention the time-consuming effort and expense required to make these measurements. Most of you – except perhaps stakeholders who might have to monitor TMDL attainments – can skip all that follows.

On, or within a day of, the 2010 pre-dawn monitoring events, Ben Pitterle, Penny Owens and Joe Burgess have been going out, with the direction and help of Dr. Kristie Close out at UCSB, and collecting algal samples for measurement of Chl-a. (Enough cannot be said about Kristie's help on this project, not to mention her willingness to finish off sample preparation and analysis in her lab.) As I'll discuss later, a lot of hard work goes into making these measurements and only a handful of sites have been measured (not to mention a number of samples were spoiled as Channelkeeper personnel climbed a rather steep learning curve in mastering these skills).

The purpose was to provide additional data for a check on, and improvement of, the Chl-a regression model. However, a comparison between measured Chl-a and model estimates, shown in Figure 6, doesn't provide much room for joy – unless, perhaps, you have an easy-to-measure location without all that much Chl-a to begin with (like Matilija above the dam). On May 19, just above the Canada Larga confluence (VR03.5), the measured/modeled comparison was 1,336 vs. 198 mg/m^2 – a measured density almost 7-times greater than the modeled; on June 24 it was 31 vs. 82 mg/m^2. A little closer, only about a 3-fold difference, but measured values were now less than modeled. At least on the Matilija measured values were consistently lower than modeled. To believe in the validity of measured Chl-a at the confluence you have to be able to accept that algal density in June had decreased to around 2 % of what it had been in May. A look at the photos would probably disabuse one of that notion.

Modeled Chl-a estimates for algal density just above the Canada Larga confluence showed a continual

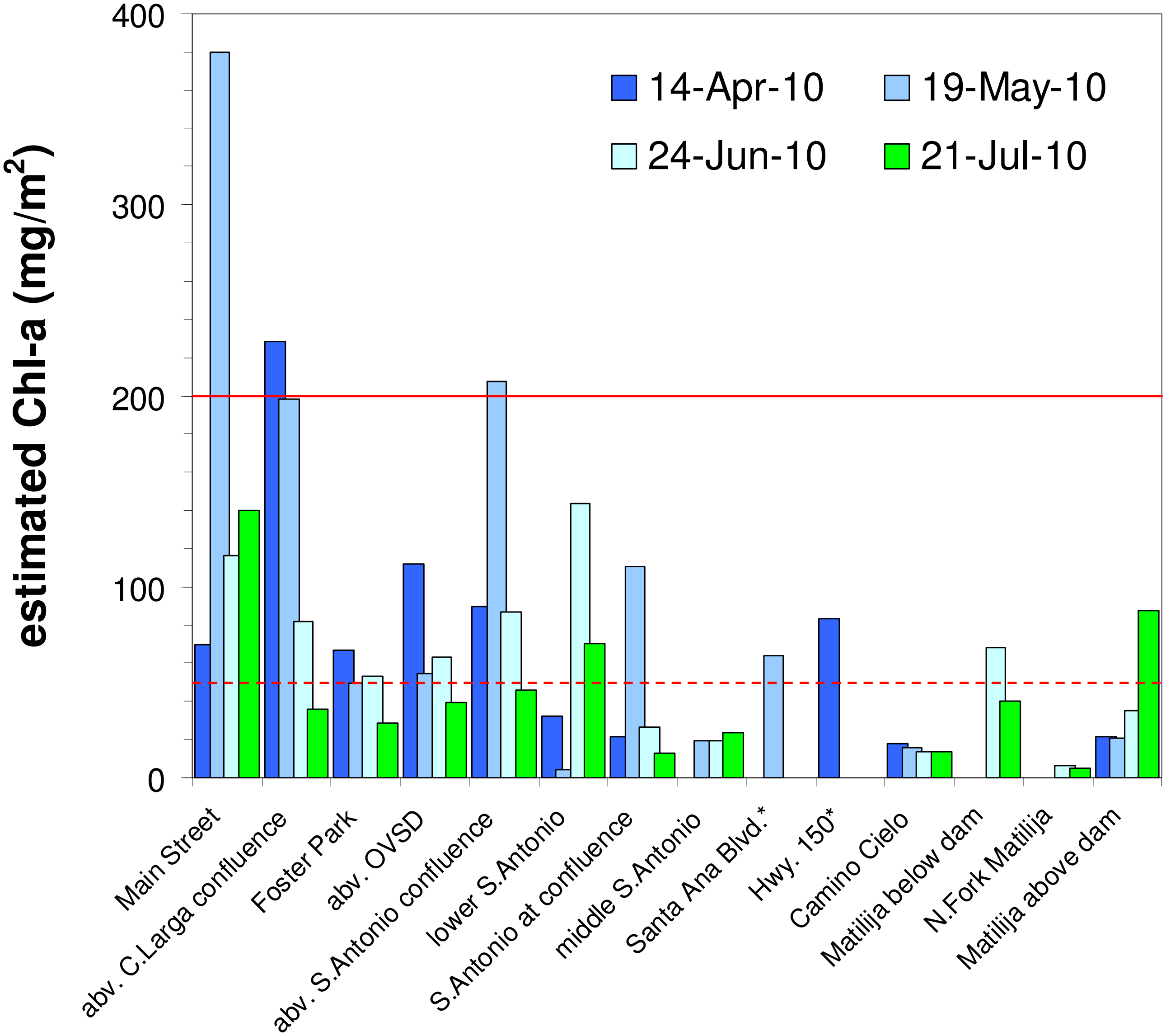


Figure 4. Estimated Chl-a densities (mg/sq-meter), on the dates shown, for SBCK monitored locations in the Ventura River watershed. Values were estimated using the model developed in the 2008 UCSB algal report, revised as described in the 2009 SBCK diel dissolved oxygen reports. The model calculates estimated Chl-a based on delta-DO and flow: delta-DO being directly proportional to Chl-a but inversely proportional to flow.

The UCSB Report recommended Chl-*a* standards of: (1) less than 50 mg/sq-m defining "unimpaired" reaches, (2) greater than 200 mg/sq-m considered " impaired"; with (3) anything falling in-between requiring further study or monitoring. These limits are shown as horizontal lines on the graph. Alternately, 150 mg/sq-m was offered as a single limit. Presumably, these standards or something similar will be adopted in the eventual TMDL.

The highest algal density estimated by the model in 2010 was 380 mg/m^2 at Main Street in May; this is in contrast with estimated maximum values at the same location of 1,782 and 38 mg/m^2 for 2008 and 2009, respectively.

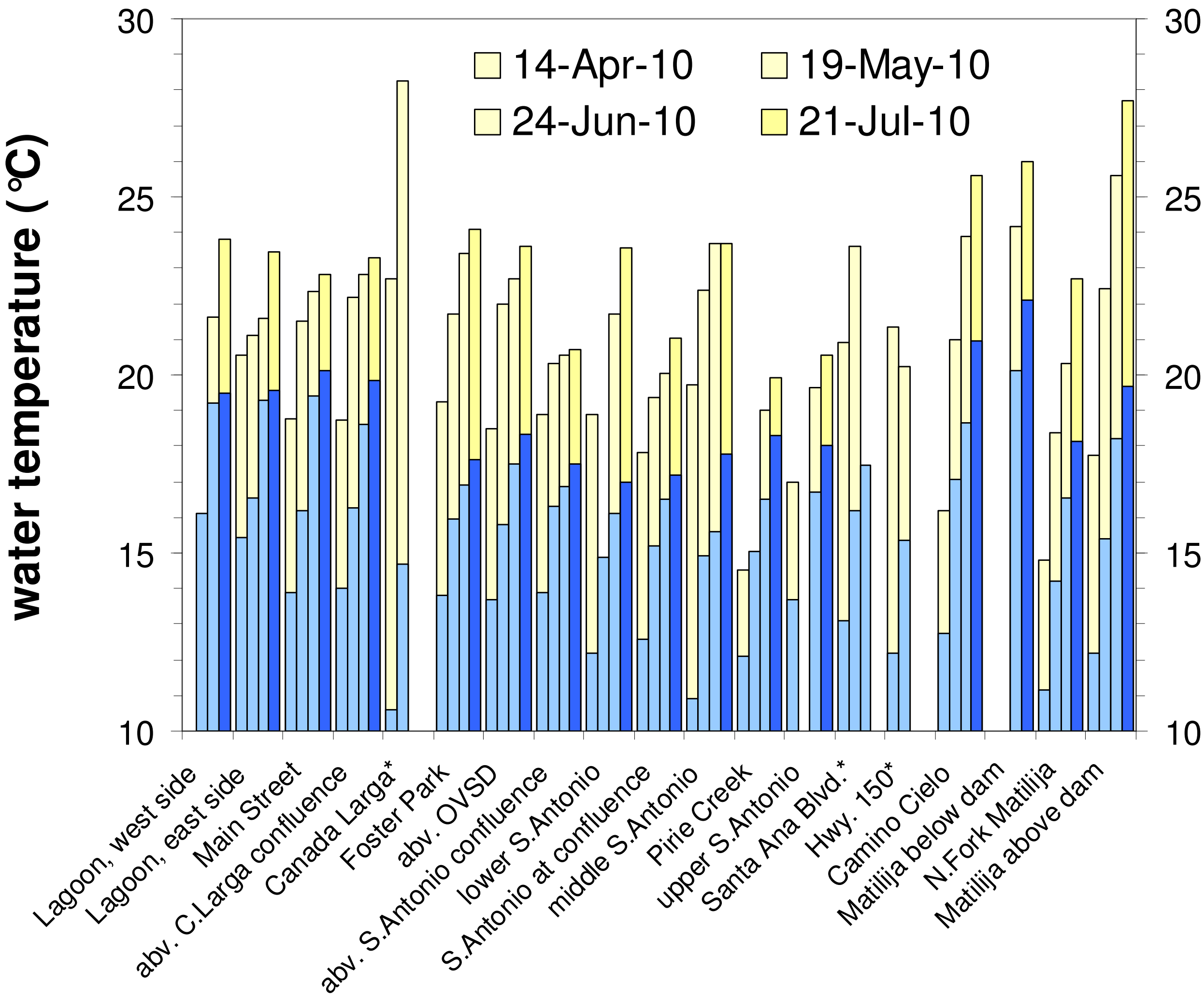


Figure 5. Pre-dawn and mid-afternoon water temperatures at SBCK Ventura watershed monitoring locations. Sampling dates are shown in the legend; bars for measurements made on July 21 are shown in a darker blue. Locations in the upper watershed (the upper Ventura and Matilija creeks), located above the coastal fog belt, typically exhibit higher water temperatures. By August, temperatures in this region may climb alarmingly high due to increasing air temperatures and declining flows; 30 ° C is approximately 86 ° F. The very high water temperature recorded at Canada Larga on May 19 was due to very low flow in a drying-up creek bed (see photos).

decline from mid-April to mid-July: 229 to 198 to 82 to 36 mg/m^2. This roughly 6-fold decrease seems to better match the photos. River flows used to calculate these estimates may well be off since I simply took the average daily flow at Foster Park for the date of pre-dawn monitoring and added average daily WWTP outflow (~3 cfs) to it. However, changing the flow would not vary the Chl-a estimates by all that much: doubling flow changes the April value from 229 to 310, halving flow reduces it to 169.

Perhaps more to the point, Julie Simpson's 2003 measurements at Shell Road (approximately 1.7 miles downstream) show a not dissimilar progression: 217-457-301-296 mg/m^2, mid-April to mid-July; 2003 was a much bigger algal year than 2010. In 2008, an even bigger algal year, June density at VR03.5 was measured at 710 mg/m^2. The mid-May, 2010, measurement of 1,336 mg/m^2 was higher than anything recorded by UCSB in 2008. That alone should raise some questions.

I'm bothered by the Regional Board's insistence that benthic and floating algal Chl-a is not only a necessary, but a reasonable parameter on which to base the eventual TMDL criteria upon. "Necessary," I'm probably willing to concede – the momentum for the acceptance of this parameter seems to be too great to be avoided. But "reasonable," in the sense that the present protocol will produce statistically valid and empirically reproducible results? I think not.

However, the State has approved and adopted the Chl-a measurement protocol, and we will probably be required to work with it. If problems and questions later arise, as I'm sure they will, we can all simply hope that they are addressed, and the protocol revised or modified accordingly. To me, its scientific validity remains in question. It's not that Chl-a is not a valid measure of algal density, or that algal density isn't a completely valid parameter, but that the present measurement is not precise nor accurate enough to decide whether or not stakeholders are meeting TMDL criteria.

Consider the following: Under the protocol 30 samples are combined and then analyzed to produce a single value. This single value is considered the "average" algal Chl-a density (in mg/m^2) for the reach. It's a *mean* value for which there will be no knowledge of the underlying distribution (highly skewed, normal, whatever), no standard deviation to describe the distribution, no standard error of the mean, and no way of determining the confidence interval of the result.

If the width of the stream is 10 meters or less, the reach from which samples are collected is 150 meters long, i.e., the same length is used for a 1 meter-wide stream as for a 10 meter-wide stream. If the stream is over 10 meters in width a 250 meter reach is used, the same length for an 11 meter stream or for one of 100 meters. In other words, the sample size (30 samples) remains the same irrespective of how the population varies – the population being the total area of the sampled reach. Thirty samples for a river 200 meters wide, 30 samples for a stream less than 1 meter wide.

Assume a stream 10 meters wide (typical for much of the Ventura at the peak of the algal season). The "syringe scrubber" described in the protocol, and used to collect all algal density data on the Ventura since 2003, collects a sample with a surface area of 5.3 cm^2 (about the size of a quarter); 30 samples have a combined area of 159 cm^2, or 0.0159 m^2. The area or "population" of our assumed 10 meter wide stream is 10 x 150 meters, i.e., 1500 m^2. So we've sampled just slightly more than 0.001 % of the total area of the measured reach. Seeing we're facing another election here in California, we might express this as similar to a political survey in which roughly 1 in every 100,000 voters was polled – something less than 6 people if we were trying to determine what all those old enough to vote in Ventura County were thinking.

Now consider that one of the primary requirements for any statistical sample, a sample purporting to

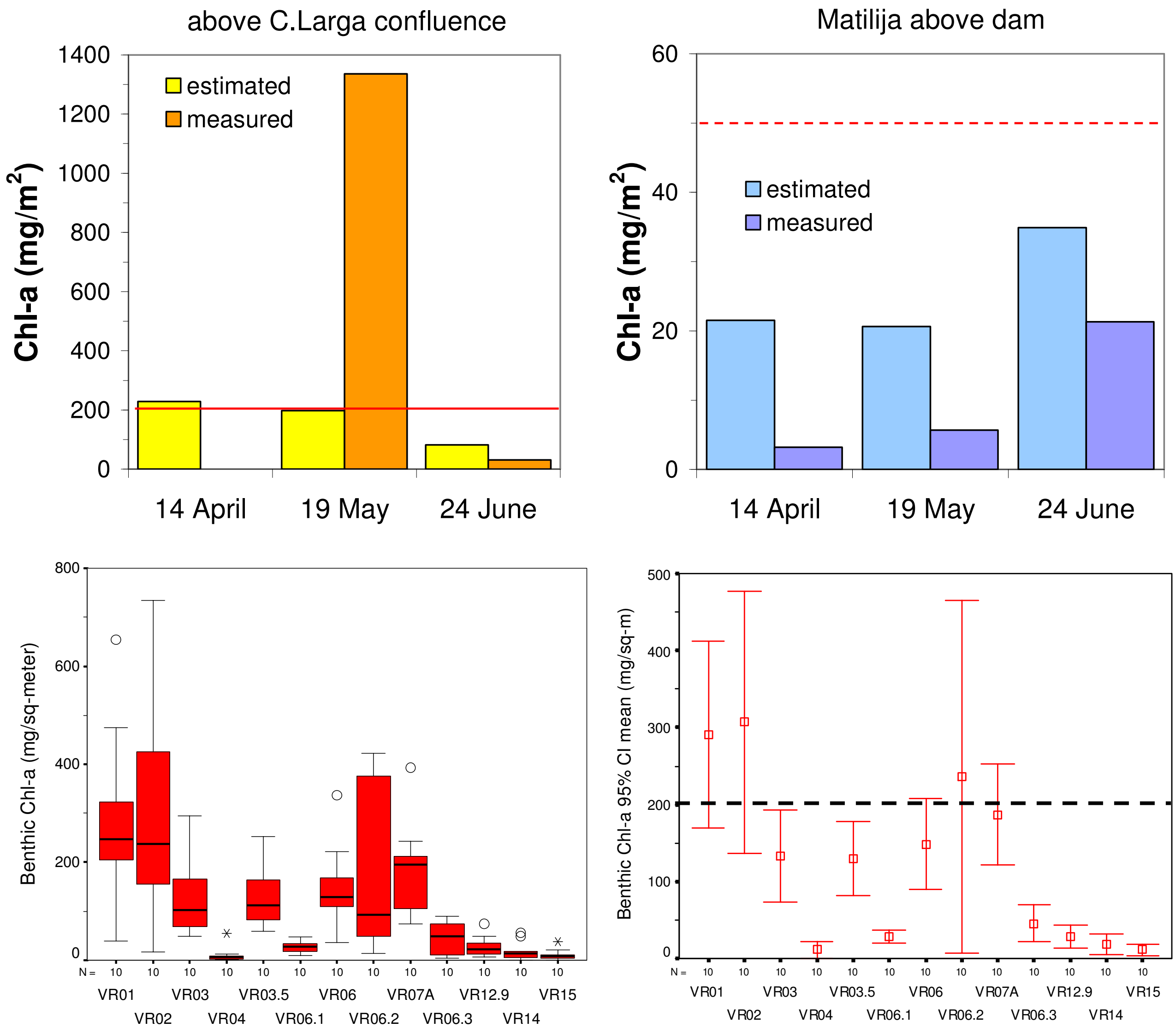


Figure 6: (top) Comparing measured vs. modeled estimates of Chl-a at two Ventura watershed locations. Modeled estimates are calculated from flow and delta-DO.

(bottom left) Box plots for each of the locations sampled during the May/June 2008 UCSB algal density survey. Ten transects were sampled at each location, and the individual transect means (n = 10) were used for each box plot. The heavy line across each box represents the median (the 50 % value). The length of the box represents the inter-quartile range, i.e., 50 % of the individual transect means lie within the box. The whiskers represent the highest and lowest transect means that fall within what might be considered a reasonable range of variation (one and a half times their respective inter-quartile ranges). Dots represent outliers (points falling between the whiskers and 3 box lengths further away) and stars extremes (greater than 3 box lengths away), i.e., out of the ordinary results. For example, at Main Street (VR01) the median was 247 (mean = 290); the box length extended from 208 to 322 (the 25 to 75% range); the whiskers are at 39 and 474; and there was one outlier at 655 mg/m^2.

(bottom right) The May/June 2008 mean for each surveyed location; error bars represent the 95% confidence interval.

accurately measure some characteristic of a population, is that it be a random sample. The algal protocol, of course, requires a fixed sampling pattern that is anything but random: ten transects. each a fixed distance apart, with samples taken at the quarter and half points on each transect. We see many examples of locations, during the dry-season, where algal species that prefer quiet-water conditions begin their growth near the stream-edge. And other examples where floating and detached algae are similarly concentrated along the edge. The protocol, I would point out, does not include the collection of any samples from these areas.

There are problems beyond statistical concerns, problems with the actual collection of algal samples: subjective decisions, producing not so subtle differences, are consistently made by every sampler; differences in technique and diligence are also certain to produce varying results; and special problems arise when aquatic plants are also present – which they often are in the Ventura watershed, etc., etc. But I'll stop here.

I think these are valid concerns. But I can have my mind changed by research data showing that different individuals surveying the same reach, or even the same individual repeating a survey, would end up with similar Chl-a density values. If that evidence is out there I would sure like to see it.

Aside from these technical criticisms, my basic problem with mandating a Chl-a TMDL standard is as follows: Let's say the TMDL criterion is established at 200 mg/m^2 of Chl-a. What happens if whoever samples a suspected non-compliant reach comes up with a value of 190? How about if it's 220? Is one acceptable and the other not? And what might happen if it ends up before a judge? Determining algal density by measuring Chl-a is a very difficult, time-consuming and expensive enterprise – more so than almost any other standard aquatic measurement. The end result, again, more so than other measurements, will be open to question and fraught with problems. And if an appreciable financial risk attaches to some group or agency based on this number, questioned it will be.

For the algal measurements Kristie made in 2008, samples were collected along 10 separate transects, and each transect was analyzed separately. Thus we are able to see how each of the 10 transects varied, and to calculate the confidence interval of the mean algal density calculated from the combined data. I'm still in the process of looking at those results, but Figure 6 shows the distributions of the 2008 end-of-May/beginning-of-June data. I've drawn a line at the 200 mg/sq-m standard; decide for yourself how much confidence you're willing to put into a 5-transect, lumped-sample, measurement.

A final comment: If not Chl-a, what then? Well, I think the Central Coast RWQCB offers a good answer: a maximum oxygen deficit standard to determine which stream reaches do, or do not, meet objectives for excessive biostimulatory substances. After all, regulating nutrients is what this "algal" TMDL is really all about.

As usual, photos taken on diel sampling days (and on other Channelkeeper sampling days) can be downloaded at:
http://sbc.lternet.edu/~leydecke/Al's_stuff/Recent%20Stream-Team%20Photos/

Posted PDF copies of all my previous Ventura Nutrient TMDL reports can be found at:
http://sbc.lternet.edu/~leydecke/Al's_stuff/Ventura%20Nutrient%20TMDL/My%20PDF%20files%20on%20algae%20&%20nutrients/

For additional information or questions, or comments and opinions, or even hate mail, please feel free to email me at: al.leydecker@cox.net

Photo 1: Winter flood flows were strong enough to cut a new river mouth, shortening the path from RR Bridge to the channel. Top left, April 14, 2010; top right, May 6; bottom left, June 5; bottom right, looking upstream towards the RR on June 5. River flows in April and May were high enough to keep water in this reach fresh – the dark-green color from freshwater algae can be seen in the May photo. By June, the water varied from brackish to highly brackish and these algae had disappeared, replaced by Enteromorpha (also called Ulva); this is the tidally stranded algae shown in the June photo.

Photo 2: The previous river channel and old mouth formed a, now semi-isolated, lagoon (which I'm calling "cutoff-lagoon"). The upper left photo shows this lagoon on April 10; upper right on May 6; the two lower photos on June 5. Water in the cutoff-lagoon tended to be more brackish than in the main channel (the May photo shows it to have been highly affected by tidal flows) and the algae present in these photos is predominantly Enteromorpha (Ulva). Although we suspected that this lagoon might be subject to anoxia, our lowest pre-dawn oxygen concentration was 5.69 mg/L.

Photo 3: Looking directly down from the upstream side of the Main Street Bridge (VR01): top left, March 6, 2010; top right, April 10; middle left, May 6; middle right, May 19; lower left, June 5; lower right, July 21. The very dark green color of the water in the top left photo indicates benthic growth of Cladophora prior to March 6. Growth here may have peaked in early April. Strands of Ludwiga can be seen growing beneath the flow in the April photo. Benthic algae became relatively sparse from May on. The photos also show the gradual encroachment of Ludwiga into even fast-moving current. The deposition of fine sediment over bottom cobbles – with an appreciable contribution from agricultural operations on the east side of the river above this point – may have retarded algal growth in this reach.

Photo 4: Looking upstream from the Main Street Bridge (VR01): top, March 6, 2010; middle, April 10; bottom, June 5

These photos show the encroachment of aquatic plants and riparian vegetation into the waterway. Winter flood flows removed neither riparian brush nor Ludwigia root systems, and early in the Spring aquatic plants began their encroachment

– first watercress, followed by Ludwigia which soon became dominant. The dark-green water color of the March and April photos show a substantial Cladophora bloom, which peaked early. By May algal density had greatly diminished.

Photo 5: Just above the Canada Larga confluence, a short distance below the WWTP outfall (VR03.5): top left, March 6, 2010; top right, April 14; middle left, May 19; middle right, June 5; both lower photos are from July 21. Benthic Cladophora was well established by the beginning of March and probably reached its peak in May. By July little remained, except for the presence of decaying mats on the river bottom.

Photo 6: An overview of site VR03.5, located just above the Canada Larga confluence, a short distance below the WWTP outfall: top left, March 6, 2010; top right, April 14; middle left, May 19; middle right, July 28. The lower photos show close-ups of the sampling location: April 14 on the left; May 19 on the right. This bottleneck creates a fast current and the WWTP provides lots of nitrate – an almost perfect situation for Cladophora. Results from the Chl-a model show algal density in April slightly higher in April than in May (229 vs. 198 mg/sq-meter) followed by a rapid decrease in June and July (to 82 and then 36 mg/sq-meter).

Photo 7: Adjacent to the Ojai Wastewater Treatment Plant and above the outfall (VR06.1), on the left looking downstream, on the right looking upstream: top, April 14, 2010; middle, May 18; bottom, July 21. As in 2009, there was a heavy growth of Cladophora at this location. Although the photos don't quite show it, dissolved oxygen and flow measurements indicate that peak density occurred sometime in April. By July the algal mats had almost completely decayed; in the downstream July photo Spirogyra growth can be seen beginning along the east edge.

Photo 8: Foster Park, looking upstream from the bridge: top left, March 6, 2010; top right, April 10; middle left, June 5; middle right, July 21. The two bottom photos show close-ups of the Arundo patch seen near the center of flow in the other photos: bottom right, March 6; bottom left, May 19. The Cladophora bloom began before March (note the green patches under the flow) and by May it had pretty much run it's course (although dying elsewhere, Cladophora still remained healthy underneath the center of flow on the far right). The bloom peaked in April. Algal growth never approached the density seen in 2008, and although results are not yet in I expect to find that nitrate concentrations were much diminished. Winter flows did not remove larger vegetation from the stream bed, and thus allowed the rapid dry-season growth seen in these photos.

Photo 9: (top) Canada Larga, about 50m above the confluence, on May 19, 2010 (VR04): looking downstream on left, upstream on right; top left, April 14, 2010; top right, May 19. This stream was dry during the April 10 sampling and the algal growth, shown decayed here, must have occurred sometime after the rainstorm of April 12 (~ 1.4 inches); the algal peak probably occurred in early May. (bottom) San Antonio Creek, about 30m above its confluence (VR07a), on April 10. The April 12 storm may well have wiped out this developing bloom since only sparse algal growth was seen on April 14.

Photo 10: Looking upstream from the ranch access road (VR17): top left, April 10; top right, April 14; bottom left, May 18; bottom right, July 21. The algae present in the April 10 photo are crustal algae. These are usually the first algae making their appearance in the Ventura watershed, as they are adapted to very rapid flows. Note that four days later they had almost disappeared, replaced by the beginning of Cladophora growth. Scouring from a storm on April 12 (1.55 inches) probably explains the rapid transformation, but why Chadophora got such a late start on this section of San Antonio remains an interesting question. By May, however, Cladophora was doing well, and some patches remained vibrant through July – although decaying mats stranded by deceasing flows are visible in both lower photos.

Photo 11: Pirie Creek (top) and upper San Antonio Creek (bottom) on April 10, 2010 (VR09 & VR10). Although we don't usually show these locations, they have appreciable algal growth in early Spring. However, narrow stream widths, overhanging riparian vegetation restricting sunlight, and decreasing flows usually bring an early end to much of the S. Antonio bloom in spite of very high nitrate concentrations. The April 12 storm also cut this bloom short; algal density was much reduced when these sites were visited for pre-dawn sampling on April 14.

Photo 12: Just above the San Antonio Creek confluence (VR06.3): top left, March 6, 2010; top right, April 10; middle left, May 18; middle right, June 9; lower left, June 24; lower right, July 21. The very dark green color of the water in the upper photos indicates the heavy growth of benthic Cladophora. The algae seen floating on the surface are Enteromorpha; these algae floated down from further upstream – it typically grows along stream edges in quiet sections – and became trapped on the boulders shown in the photos. Algal growth at this location peaked in May (estimated at 208 mg/sq-meter). The bottom photos show Cladophora's gradual disappearance throughout June and July.

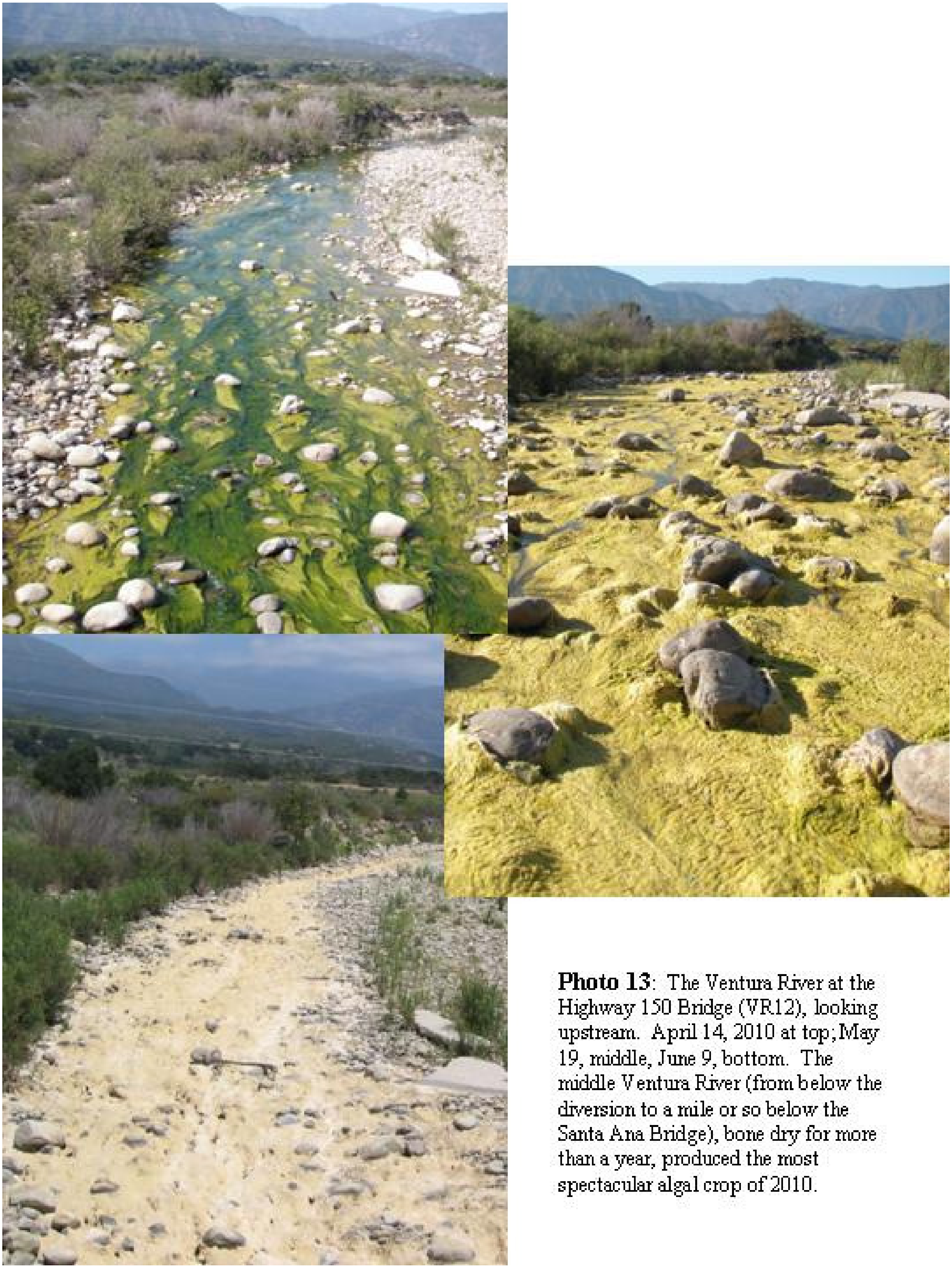


Photo 13: The Ventura River at the Highway 150 Bridge (VR12), looking upstream. April 14, 2010 at top; May 19, middle, June 9, bottom. The middle Ventura River (from below the diversion to a mile or so below the Santa Ana Bridge), bone dry for more than a year, produced the most spectacular algal crop of 2010.

Photo 14: The Ventura River at the Highway 150 Bridge (VR12), looking downstream. Top left, April 14, 2010; top right, May 19; bottom left, June 9. The view on the bottom right is from the Santa Ana Bridge on May 19. After the secession of winter runoff, groundwater becomes the sole source of flow to this reach and it rapidly dries out from the top down.

Photo 15: Matilija Creek above the dam (VR15): top left, April 10, 2010; top right, May 18; middle left, June 9; middle right, June 24; lower left, July 21; lower right, July 28. Absent a photo with the right perspective, the top left photo shows the appreciable algal growth seen on April 10. Note that the algal color shows the Cladophora here in its declining phase. The storm two days later pretty much cleaned out all the upper basin streams (3 inches of rain in Matilija Canyon). Algal density remained very low in May, but Mougeotia began growing in slack water by the beginning of June. The July photos show the development of this Mougeotia bloom. Modeled algal density on July 21 was 87 mg/sq-meter vs. 22 on April 10; we have no idea what it might have been prior to the April 12 storm.