

Don't be afraid. It's not as bad as it looks. There will be lots of pictures, but first we need to get through the hard part. This is a graph of minimum dissolved oxygen levels (min. DO) on the Ventura River derived from Channelkeeper pre-dawn/mid-afternoon DO and flow (Q) measurements and UCSB chlorophyll $a$ results (Chla, a measure of the active photosynthesizing agent in algae, thus an indirect measure of the amount of algae). Scientists call a series of mathematical equations a model, so this graph represents a model which predicts min. DO given Chla density and flow. As an example, the dashed black lines show how a min. DO level of 7.5 $\mathrm{mg} / \mathrm{L}$ would result from a Chla density of $500 \mathrm{mg} / \mathrm{sq}-\mathrm{m}$ and a flow of 20 cfs . While this is not a very precise model, and one that includes a number of simplifying assumptions, it does fit the limited data (the colored circles, numbers next to these points represent Channelkeeper site codes) surprisingly well. The dashed red line represents the Regional Board's minimum acceptable DO level of $5 \mathrm{mg} / \mathrm{L}$.

The model predicts that min. DO concentrations will decrease as algal density (Chla) increases, , but conversely, min. DO will increase as flow increases - i.e. the lower the flow, the greater the danger of depressing dissolved oxygen levels to the point were they present a threat to aquatic life.

This past winter (2008-9) there has been little rainfall: as of April 1, 9.1 inches in Goleta,
10.3 in Ojai, 9.1 in Santa Barbara; these numbers represent 50-60 \% of average annual totals (data from USWS and Calif. state sources, the County of Santa Barbara reports rainfall, at the end of the first week in April, at 11.4 inches or $68 \%$ of average). River flows are also down. At Foster Park today's flow (April 12) is 13 cfs , compared with 33 cfs on this same day last year. The average April $12^{\text {th }}$ Foster Park flow is 66 cfs. But before getting too excited, recall that flow on the Ventura is a matter of extremes, and the median flow, a better measure since half the April $12^{\text {th }}$ s have had flows less than this value, is 15 cfs . So we are on the low side, but not by much - and we've been there many times before.

But low flows, combined with high levels of algae (and, as an example, UCSB measured algal densities from 600-1000 mg/sq-m Chla at Main Street last year), may present a low oxygen threat. A look at the model shows that densities this high, combined with flows this low, will produce minimum DO concentrations below the $5 \mathrm{mg} / \mathrm{l}$ basin plan limit. So should we be worried?

The short answer is "No."
Or at least, not in the locations where we usually worry about algae. There's a reason why, in the past, we've only bothered to measure the algal impact on pre-dawn DO in years like 2005 and 2008 big rainfall years, years with dry seasons following winters with lots of rainfall - and not during drought years or in summers following low rainfall winters. The reason being aquatic plants and fine sediment.

Aquatic plants out-compete algae by over-shadowing the water surface and hogging sunlight, and fine sediment covers the bottom gravels and cobbles that provide preferred habitat for the algal species that usually dominate the Ventura watershed. In a dry year, the lack of big, riverbed-clearing, storms, leaves plants and sediment from the previous fall in place, depriving algae of its usual head start at the end of winter. Think of it as a symbiotic process, increasing amounts of sediment on the bottom allows aquatic plants to expand across the riverbed, which, in turn, increases the efficiency of sediment capture. Low flows also shrink river widths, intensifying competition, and in that competition algae loses. Figures 1, 2 and 3 show this progression in past years at Main Street (Figure 1), Shell Road (Figure 2) and Foster Park (Figure 3). So, observing this process, we've never worried about algal problems during dry seasons following low rainfall winters.

Yet, Channelkeeper has decided to continue last year's program of pre-dawn/mid-afternoon DO and $p \mathrm{H}$ measurements in the coming dry-season, starting this April. Why? One reason is, in spite of the evidence shown by these photos, it appears that the claim of no, or greatly lessened, algal problems in a dry-year may not be taken seriously during the developing algal TMDL process. After all, it's logical that algal problems should be greater when flows are lower - even my own model, with which I began this discourse, says so. And if the only year you actually studied the algal problem happened to be following a wet winter why would you think differently? After all, the Regional Board's view of the problem is centered around nutrients and algae - high nutrients causing lots of algae - and no one has ever mentioned aquatic plants. Much less that over-enrichment of the river by nutrients has produced periodic explosions of aquatic plant growth. The fact that Channelkeeper has never bothered to measure the diel DO cycle in a dry-year, because it never appeared that algae might be a problem, has come home to bite us in the ass.

The second reason is that we've never really looked to see if there might be a problem in other locations. We focused on places where there were wet-year problems, and since these same locations


Figure 1. Looking upstream from the Main Street Bridge : left to right, top: June 2004 (plant dominated reach following a dry winter), June 2005 (algal takeoff after a big wet winter); middle: Oct. 2006 (aquatic plant dominance in the fall of a wet year), Sept. 2007 (plant dominance throughout the dry-season following a dry winter); bottom: May 2009 (algae following the wet winter), Nov. 2009 (aquatic plants dominating by fall). A wet winter with large stoms = algal dominance; the absence of large stoms = dominance by aquatic plants. The aquatic plants at Main Street being watercress and Ludwigia.


Figure 2. Looking upstream from the Shell Road Bridge: left to right, top: July 2001 (algae following the wet winter of 2001), Aug. 2002 (dry year plant dominance), March 2003 (open environment following a large storm); bottom: Oct. 2003 (aquatic plants succeeding algae by year's end), Sept. 2004 (total plant dominance at the end of another dry year), May 2005 (a big winter clears the riverbed and algae dominate). The photcs document extreme changes caused by wet-winter/drywinter rainfall differences on the lower Ventura River: large storms = algal dominance; the absence of large stoms = dominance by aquatic plants. And a winter with a moderately large stom results in algae at the beginning of the dry-season being replaced by aquatic plants during later months.


Figure 3. Looking upstream from the bridge be low Foster Park: left to right, top: Sept. 2002, May 2003; middle: Sept. 2003, Sept. 2004; bottom: May 2005, Oct. 2006 . Winter rainfall and storm intensity influence dry-season flows at Foster Park, and cause a shift between the relative densities of aquatic plants (watercress) and algae but not to the extent seen on the lower river. In this open reach, with high surlight exposure, algae are always a problem. (The change in perspective in the lower photos was due to river re-aligument from its west to east bank by Courty flood repairs in the spring of 2005.
obviously didn't have dry-year problems we never really looked further. And perhaps we should have.

In 2005 we were unaware of the serious algal problem above the San Antonio confluence. My first (and probably Ben's also) visit to this location was in the summer of 2007 - a drought year - and a surprising amount of algae were present. On the same day (we were collecting samples for the Regional Board) we also saw appreciable blooms on Matilija Creek (Figures 4 and 5) and on the Ventura River at Camino Cielo. In a way, I've been wearing blinders by simply assuming that if there is no dry-year algae problem on the lower river, there must not be a problem elsewhere. Along with this mind-set was the thought if sites elsewhere on the river do not have a serious algae problem in a big algae year (a wet year like 2005 or 2008), they will probably not have one in a dry-year.

Helping this along is the simple fact that in a dry-year sites that have a wet-year algae problem, like lower San Antonio Creek, Lion Canyon and Canada Larga, go dry (by definition, no water = no algae) or may never have water at all (like the middle Ventura reaches circa Highway 150 and Santa Ana Blvd.). We have also been hampered in that little time is spent on these streams in locations other than the sampling sites. And, particularly on San Antonio Creek, some of these sites are in shady locations (the N.F. Matilija is another example) which generally don't present problems with dense algae.

Channelkeeper's past dissolved oxygen data offers clues as to which locations might be candidates for dry-year algal problems. Although DO measurements typically take place between the hours of 9:45 AM and 12 noon, and not before dawn nor at mid-afternoon, they usually are made around the same hour each and every monthly sampling day. As such, comparing relative differences in DO concentrations in wet-years with those of dry-years will indicate which years (dry or wet) have the elevated DO levels indicative of a substantial algal problem. For this purpose DO measured in percent saturation is of greater use than concentrations expressed in $\mathrm{mg} / \mathrm{L}$ since $\%$ saturation excludes the influence of altitude and stream temperature from the data.

I've plotted this data for four locations, from April through September (the prime algal months) in Figure 6. My wet-years include 2001, 2003, 2005, 2006 and 2008, the dry-years 2002, 2004 and 2007. The graphs show a red line at $120 \%$ of saturation - DO above this level is usually a good indicator of serious algal problems. Keep in mind that all these measurements were made before noon and do not represent the true algal situation; peak saturation probably occurred between 2 and 3 PM and Channelkeeper concentrations do not show these locations at their worst. A noticeable difference in dry- vs. wet-year values indicates which years have a serious algal problem and which don't; Main Street has a very serious wet-year problem (average saturation circa $150 \%$ ), but not a dry-year problem. I've only shown Main Street, but all locations below the OVSD treatment plant show similar characteristics, as does lower San Antonio Creek.

No noticeable difference between wet- and dry-years indicates a possible dry-year algal problem, if concentrations are high enough. Note that these are average values, the error bars, which represent twice the standard error of the mean ( $\sim$ the $95 \%$ confidence interval for the mean), indicate the likelihood of this happening (dashed error bars apply to dry-years, solid to wet). Both Foster Park and upper San Antonio Creek are likely candidates for serious algal problems this dry-season, as is the upper basin (although not shown, Matilija Creek, both below and above the dam, as you might expect from Figures 4 and 5, exhibits the same DO saturation characteristics as upper San Antonio).


Sept. 2007
Figure 4. WY 2007 was a drought year, yet Matilija Creek, above the dam, had a substantial algal bloom. In June this bloom extended down below the N.F. confluence, to Camino Cielo. We saw a similar bloom in September 2008.

## July 2007



Figure 5. Matilija Creek below the dam: August 2007. For some reason (altitude, diel temperature fluctuations, lower nutrient levels, etc.) aquatic plants are not as prevalent in the upper basin. And with low, drought-year, flows, algal problems may have more severe consequences than heretofore realized.


Figure 6. Average wet-year (water-years 2001, 2003, 2005, 2006 and 2008) and dry-year (2002, 2004 and 2007) dissolved oxygen concentration (\% saturation) for the months of April through September. Measurements for 2008 are also shown separately for comparison. The error bars indicate 2-times the standard error of the mean. The red dashed line indicates $120 \%$ of saturation; concentrations above this limit are usually a good indicator of algal problems. These measurements were all made before noon (generally earlier at Foster Park and upper San Antonio, later at Main Street and lower San Antonio) and are not indicative of peak saturation which typically occurred circa 2-3:00 PM.

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Figure 7. Percent DO saturation, April through September, for the sites shown. White symbols identify dry-years, black big wet-years, and grey plain wet years. The red dashed line indicates $120 \%$ of saturation; concentrations above this limit are usually a good indicator of algal problems.

Figure 7 shows year by year algal season DO saturation for 3 locations. Since each graph displays 8 years of data I've tried to make them easier to comprehend by color coding the symbols: white indicates a dry-year, black a big wet-year (2001 and 2005), and grey a more "typical" wet year (2003, 2006 and 2008). Note that, while the white symbols often denote the highest DO levels, results are somewhat mixed: 2002 often appears anomalous when compared with 2004 or 2007. Why this might be so is a good question. Perhaps changing circumstance (e.g. less nutrient availability back then), or changes in stream topography at the sampling site, or small variations in flow (Foster Park flows in 2007 were almost twice those of either 2002 or 2004). My best guess is that 2009 will most resemble 2007 since it's closest in time and, at present, has similar flows.


Let's consider nutrients. And whether or not there is enough nutrient availability to foster a significant bloom, especially in the upper basin. One of the conclusions of the past year's UCSB study is that there exists a positive relationship between increasing concentrations of total nitrogen (TN) and algal density (Chla). This relationship, a model predicting Chla from TN if you will, and the data it's based on, is shown in the graph (Chla density in $\mathrm{mg} / \mathrm{sq}-$ meter and TN conc. from samples collected in June and September 2008; the Channelkeeper site number is shown alongside each point). The equation (represented as a solid black line) indicates that TN can explain $65 \%$ of the variation in Chla (the dashed lines indicate the $95 \%$ confidence interval for a mean estimate based on the model -- the equation is exponential since it was developed from logarithmic data values for statistical reasons that need not concern us). Among the recommendations of the draft report is that unimpaired streams have Chla densities $<50 \mathrm{mg} / \mathrm{sq}$-meter and TN concentrations of $<200 \mu \mathrm{~g} / \mathrm{L}(0.20 \mathrm{mg} / \mathrm{L}$ or $14 \mu \mathrm{M})$ while those impaired for human use have respective values of $>$ $200 \mathrm{mg} / \mathrm{sq}$-meter and $450 \mu \mathrm{~g} / \mathrm{L}(0.45 \mathrm{mg} / \mathrm{L}$ or $32 \mu \mathrm{M})$.

For unimpaired think "Matilija;" for impaired think "lower Ventura and lower San Antonio Creek." I've colored the space bounded by these respective standards on the graph: yellow for impaired, blue for unimpaired; the un-shaded portion representing a region of increased algal densities but no serious impairment. These are not meant to be hard-and-fast values and if you examine at the site numbers you'll see that a lot of locations move between yellow and white, and more to the point since I want to consider the likelihood of a serious algal bloom on the Matilija, between blue and white.


This next chart shows average seasonal (May through September) nitrate and TDN (total dissolved nitrogen, shown as grey bars in the background) concentrations from 2001-2008 at most of the sites we've been considering as possible candidates for serious algal blooms this year. The dashed red and black lines represent the impaired for human use ( $>450 \mu \mathrm{~g} / \mathrm{L}$ ) and unimpaired ( $<200 \mu \mathrm{~g} / \mathrm{L}$ ) limits mentioned previously (keep in mind that concentrations are shown on a logarithmic scale and small visual differences represent big changes in value). On San Antonio and the lower Ventura big years produce the highest TN and nitrate concentrations, while the lowest are seen in drought years.

However, at the Matilija sites a opposite pattern appears to prevail: the biggest TN year being 2007, with the other drought years, 2002 and 2004, not far behind. A number of other factors may play a role: (1) that these data represent concentrations and not the amount (i.e. flow $\times$ concentration) of available nitrogen, and (2) this may be somewhat of a chicken or egg situation - are concentrations low because of low nitrogen availability or are they low because a lot of the available nitrogen has been already tied up in algal productivity? These considerations preclude a simplistic conclusion, but as a first approximation there would appear to be enough nitrogen to fuel a substantial bloom at all these locations.

It's interesting that for the Matilija sites there appears to have been a noticeable increase in TDN concentrations since 2001. The increase is due to a steady rise in organic nitrogen since nitrate, while fluctuating considerably, has remained rather consistent. In fact, on Matilija Creek the highest concentrations of DON (dissolved organic nitrogen) have occurred during drought years (2002, 2004 and 2007), implying a high degree of biological productivity.

Sufficient nitrogen, lower flows and warmer temperatures (a direct consequence of lower flow) all indicate the possibility of a significant upper-basin bloom this year. That a late bloom, featuring algal groups seemingly adapted to low nutrient conditions (Chara and Mougeotia, see also Figure 11), occurred in September of 2008, reinforces this conclusion.


I want to end this piece the same way I began: with a model. This model estimates minimum DO based on delta-DO (the diel DO fluctuation, e.g. mid-afternoon - pre-dawn) and flow. The chart works just like the first one - move vertically from a given delta-DO (x-axis) until you intersect the correct flow (solid black lines with red numbers indicating flow in cfs), and then horizontally to select the estimated minimum DO. It's based on last year's Channelkeeper measurements which are shown as color-coded dots (the colors representing different sampling dates). It's a pretty good model as models go, explaining $2 / 3$ of the variation in measured minimum DO.


Figure 8. Looking upstream from the Main Street Bridge : April 9, 2008 above, April 4, 2009 below. In which year does a substantial algal bloom appear more likely?


Figure 9. Looking upstream from the Foster Park Bridge: April9, 2008 above, April 4, 2009 be low. Again, which year seems more likely to have a substantial bloom, and at which location, Main St. or here, is it likely to be more severe?


Figure 10. Looking upstream from the Canada Larga confluence (just below the OVSD plant): May 20,2008 above, April 4, 2009 below (unfortunately, there is no matching April 2008 photo). The same two questions still apply, assuming, of course, that we've seen the last major rainfall in 2009.

And the data points roughly coincide with the black lines calculated from the model's equation.
Of course, as a practical tool, it's a little silly since one would have to actually measure minimum DO to calculate delta-DO, but bear with me. I want to consider the $1 / 3$ of the variation in minimum DO that the model can't explain. The numbers next to the data points are stream flows measured at those sites on the same day. If you look closely you'll see that a lot of 'em don't match up very well; and then there are all those points that fall above or below the lines of the model.

One of the problems is that other things, besides algae, are affecting DO levels. Some of them can probably be identified. The points above are green, measurements made early in April when flows were high and water temperatures cold. Conditions that lead to greater physical entrainment of oxygen, especially at night when differentials between concentrations in the atmosphere and those in water are reduced (because algae are removing instead of generating oxygen). The points below represent late-season measurements when other oxygen devouring processes like aerobic decay become magnified by low flows. But reasons for a lot of the variation can not be identified, and might not even be presently imagined.

And, of course, there is error. Error in measurement of DO or flow, or both. Or possible error in assuming that minimum DO occurred at pre-dawn, or that it was reasonably close to the value we just happened to measure at the hour we happened to measured it. Not to mention that we picked the right spot.

All models, and all conclusions, standards, limits, whatever, suffer from similar problems. Which is why, in the end, we should keep on measuring and checking. Lots of times we simply don't know. And even when we think we know we are going to be periodically surprised. Especially when circumstances have changed. And they have changed, particularly on the lower river (which is the reason I've included Figures 8, 9 and 10). The Ventura is a very changeable system and we need to keep that in mind. To quote Hamlet, "There are more things in heaven and earth, Horatio, Than are dreamt of in your philosophy." Words to live by or, in Hamlet's case, die by.


Figure 11. Scott (or Kristie) cleared up a small question bothering me last summer. In my simplistic view of algal identific ation I'd been equating slimy = spirogyra, and wondering why some spirogyra was dark green (upper photo, Camino Cielo; spirogyra is usually this color throughout the lower basin) while others (most commonly in the upper basin) had the light green color seen in the lower photo (same location, same day). I'd been hypothesizing that the color difference might be related to nutrient availability and thinking about neat experiments that might test this out. Alas, there are more than one group of slimy algae, and the light green, upper-basin, stuff is called Mougeotia (a group that generally does better in low nutrient and low velocity ervironments). However, upper basin cladophora is also lighter green than the stuff lower down, so I'm still holding on to my, now slightly revised, theory.

