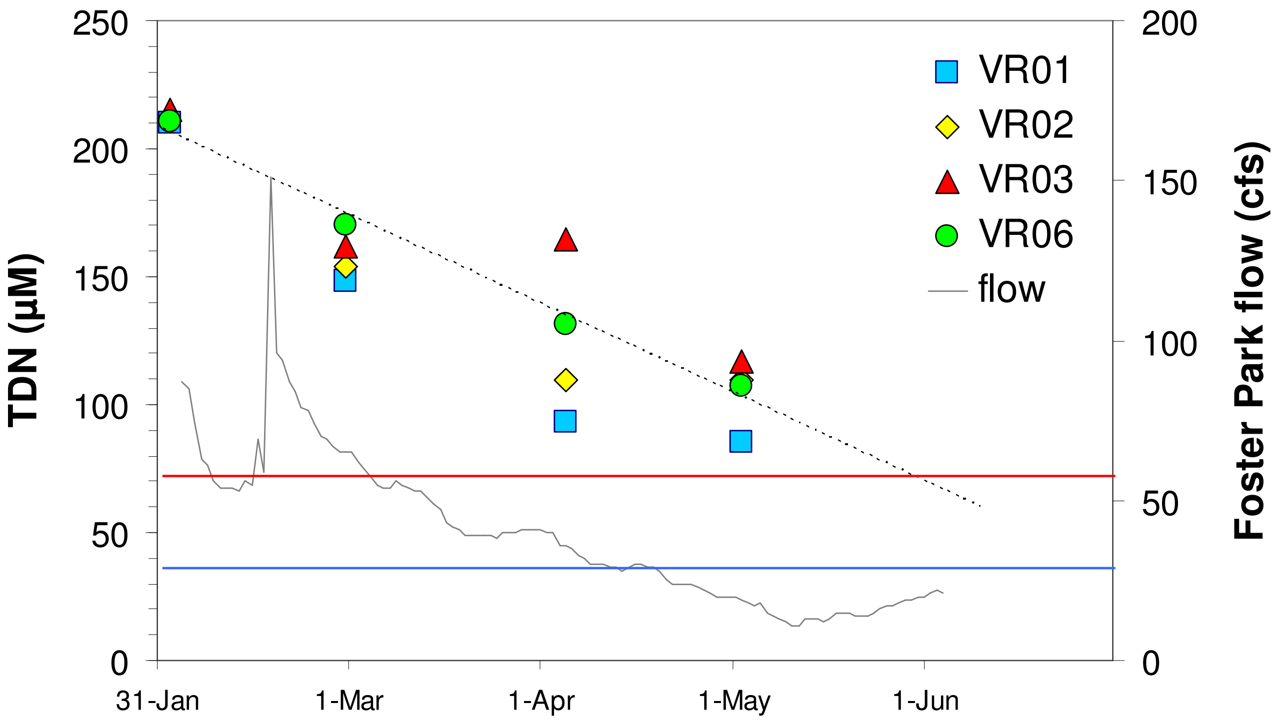
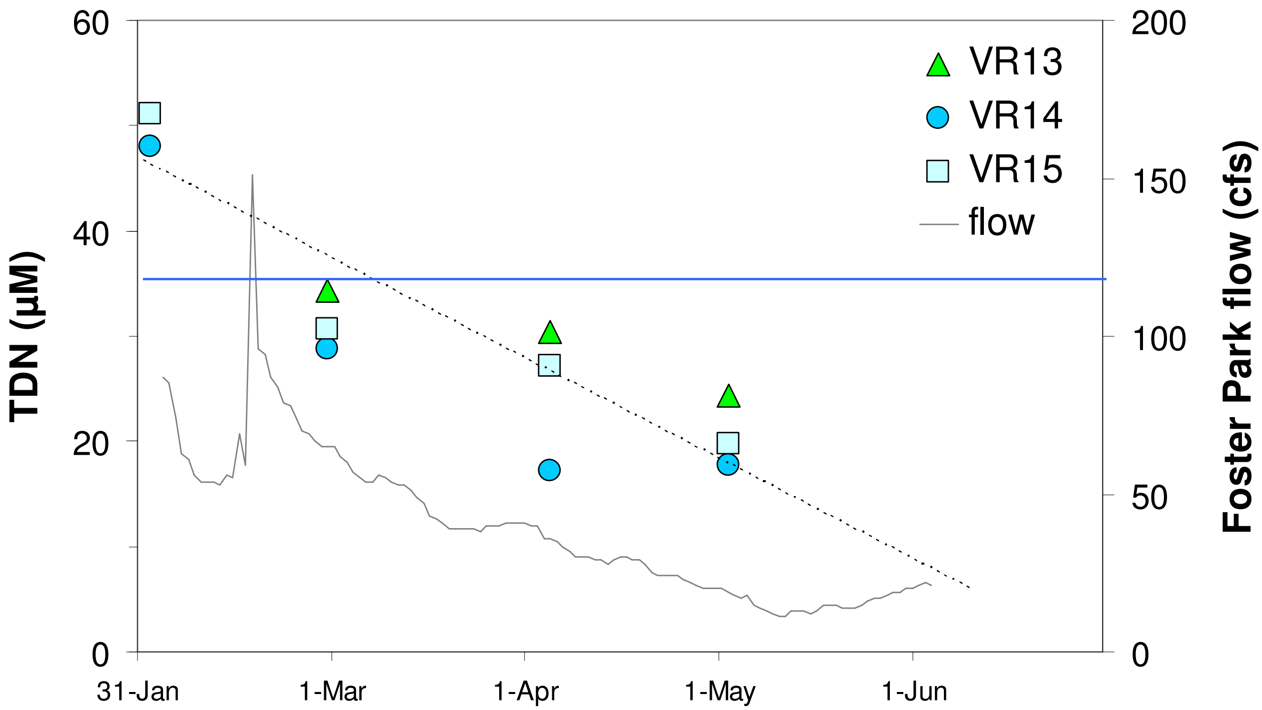


I think it's a good time to discuss the nutrient situation on the Ventura River now that Kristi and I have finished the first round of algal surveys under the UCSB/TMDL contract. As of this "think piece," Channelkeeper nutrient results are available only through May 3rd. When June data become available, including the samples Kristi collected during the algal survey, I'll add them and review the analysis -- I thought it might be instructive to construct a story at this point and then determine whether or not I might want to eat my words when later data become available.

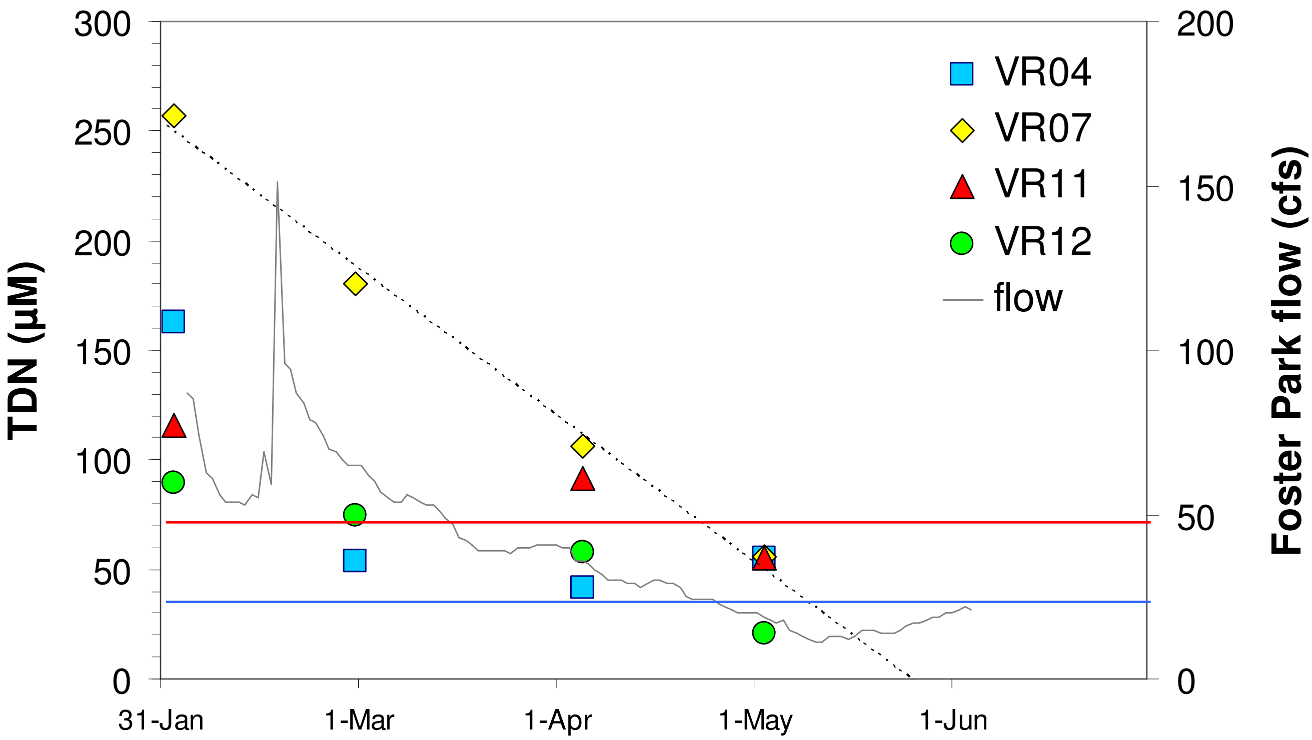
The first figure shows total dissolved nitrogen (TDN) from Feb. on (after the big January storm) at monthly sampled Channelkeeper sites on the lower river. VR03 is Shell Bridge, the nearest location below the treatment plant, VR06 is Foster Park, above the plant, VR01 is at Main Street, just above the tidal limit, and VR02 (Stanley Drain) is about a third of the way downstream between 03 and 01. Foster Park flow (USGS gauge) is shown to indicate relative changes in flow, as well as storm events (peaks in the hydrograph), at all these sites.

The red and blue lines mark the State of California TN criteria (from the 2006 SWAMP 305b Report) for streams of good quality (<0.5 mg/L) and those of poor quality (>1 mg/L), in µMs this translates into 36 and 71 µM, respectively; streams falling between these limits are considered of fair quality. I'll discuss overall patterns later, but N concentrations generally peak during winter and decrease throughout the remainder of the year and that's the pattern we see here. We can also see N uptake if concentrations at VR01 are compared with those at VR03. Note that N concentrations are more-or-less the same at 01, 02 and 03 in Feb., i.e., little to no uptake is taking place below the treatment plant. However, the difference appearing in March appreciably increases by the first week in April (ever increasing uptake, arguably almost totally by algae, as this earlier than usual growing season progressed), and then decreasing from April to May. To me, the May decline indicates a decrease in algal productivity between 03 & 01.

The decrease in May uptake is even more noteworthy if we consider it in terms of flux instead of concentration: throughout the period from March through May, flows, as well as concentrations, have been decreasing. I'm also struck by the linearity of the Foster Park (VR06) decrease as shown by the dashed regression line. If this trend continues, N at Foster Park should remain high enough to sustain algal growth, even though Foster Park will have crossed the boundary from a "poor" to a "fair" quality stream. (Below the treatment plant river water is a mix of relatively constant plant effluent and steadily diminishing flow from Foster Park, thus the absence of any consistent pattern at these locations.)

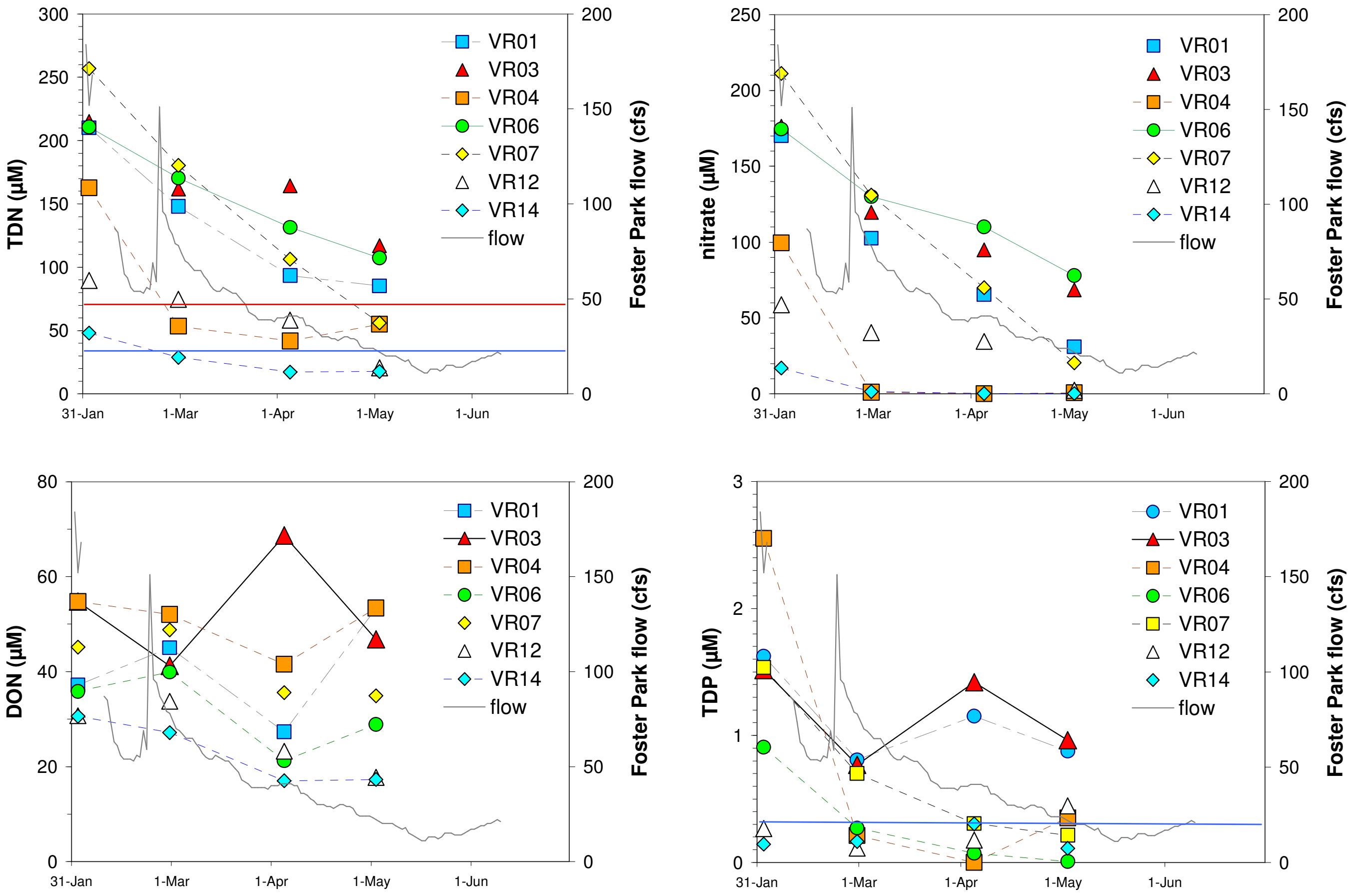


The next graph is similar to the first, but shows data from the Matilija sites: VR13 and VR15 are on Matilija Creek, respectively below and above the dam; VR14 is on the N. Fork of the Matilija. I again show Foster Park data as a general indicator of flow. Ventura County does maintain gauging stations at or near all of these sites (although calibration is often spotty), but data for the current year is not normally available. Again, as for the lower river, there is a general decrease in TDN concentrations as the growing season advances. Interestingly, a prolongation of the regression trend (for VR15) projects a scarcity of N by the beginning of June. Indeed, by mid-May cladophora at all these sites was either dead or in advanced decay, except for small patches in shallow and very swift areas of the stream. This accords with my theory that it's the nutrient flux – the supply per unit of time, and perhaps the penetrating power of rapid current in dense growth – instead of simply nutrient concentrations that determine the relative health and longevity of the initial algal bloom. Nitrate concentrations fell to below 1 µM at VR14 in March, at VR13 in April and in May at VR15. The increase in TDN concentrations from April to May at VR14 was most likely caused by the onset of algal decay – and represents an increase in dissolved organic nitrogen (DON). On average, all three locations meet the N requirement for "good" quality streams.



Again, the same graph but with data from Canada Larga (VR04), lower San Antonio Creek (VR07) and the middle reaches of the Ventura (VR11 at Santa Ana Road and VR12 at Highway 150). A linear decrease at VR07, similar to that seen at other sites, suggests N exhaustion by the end of May, and indeed, during Kristi's survey (May 16th) most of the algae at this site was on its last legs. The May upturn in TDN concentrations at Canada Larga probably, as at VR14, signifies cell lysis of dead and decaying algae; these processes were well advanced by this time.

Unlike the TDN decrease from algal uptake seen below the Ojai Sewage Treatment Plant, VR11 and 12 exhibit the opposite relationship: increasing TDN with downstream flow. There has to be a significant inflow of high nitrogen water into the river between these two points. It's unclear whether this might be from a relatively high ephemeral water table, nuisance waters from substantial suburban development on both sides of the river (but heavier on the west), or late season flows out of Devils Gulch (entering the river about half a kilometer above the Santa Ana Bridge). Since TDN concentrations on the Matilija branches are very low, the relatively high N content at VR12 indicates substantial high nitrogen inflows above, as well as below, this point. While TDN decreases over time at VR11 and 12, as at the other examined locations, the relatively flat trajectory of this decrease also points to substantial high-N inflows during the early part of the growing season. This is rather surprising since we are unused to seeing any water at all in this section of the river. In some years, e.g., 2002, 2004 and 2007, there was no flow at all. We should probably pay more attention to this section since what is happening here has directly affected reaches below; the confluence of the Ventura with San Antonio Creek lies less the 2.5 km below VR11, and the extravagant algal growth experienced over the last two years in this area is probably a consequence of N export from these middle reaches.



Rather than laboriously repeating this exercise for totally dissolved phosphate (TDP), dissolved organic nitrogen (DON) and nitrate, I've shown each of these species (along with TDN) in the above graphs for a range of sites that exhibit the gamut of variation. With TDN we saw a steady decrease at all sites since February, with the exception of an up tick or flattening out in May that I believe is caused by increasing DON due to algal decay and cell lysis. The slope of the decrease varies from steep (VR07) to relatively flat (VR14). Two distinct possibilities can cause a flat slope: (1) low or limited algal growth (reducing N uptake) or (2) additional N inputs sustaining extravagant algal development. VR14 is an example of the first, VR12 an example of the second.

The nitrate results are extremely surprising. Note that the site with the highest algal-season nitrate is VR06, *above the treatment plant*. I've never before thought of Foster Park as a high nitrate site; the overall mean monthly nitrate concentration at VR06 (2001-2007) was 0.62 mg/L, a third of the mean concentration seen below the plant at VR03: 1.80 mg/L. However, when I went back and looked more closely at the data, the mean growing season (May through Sept.) nitrate concentration has varied from 0.16 mg/L (2002) to 1.15 mg/L (2005), an almost order-of-magnitude difference. In 2005 average seasonal nitrate concentrations at VR06 did exceed those at VR03 (1.06 mg/L); and in 2001 they almost did (0.99 vs. 1.09 mg/L). Both of these years were high rainfall/high runoff years. Undoubtedly, this high nitrate is coming from both middle reach inputs (VR11 & 12) and San Antonio Creek (VR07), but the sustained nature of high nitrate values at VR06 indicates a more important wet-year role for the middle Ventura. Note the rapid die-off of VR07 nitrate concentrations vs. the sustained nature of those at VR12 – and that the slope of the VR12 March-to-May line bears a remarkable resemblance to that of VR06.

High TDN at VR06, and at VR11 &12, is mostly due to nitrate – also an indication of upstream land use as the pollution source. Nitrate makes up around 80 % of the TDN seen at Foster Park and was only slightly lower than this at VR12. These are higher than percentages usually seen below the treatment plant. A look at the DON graph shows that both VR06 and VR12 exhibit low DON concentrations, only the relatively pristine Matilija locations have lower values.

I find the see-saw DON pattern (up in March, down in April, up again in May) exhibited at most of these sites puzzling. The only possibility that occurs to me is a DON increase at the advent of algal growth – possibly from disruption by that late February storm shown in the Foster Park hydrograph or the competitive replacement of crustal algae by cladophora – followed by a decrease as algal competition for nitrogen intensifies at peak production, and then a final increase associated with algal decay. If this is so, the totally out of phase VR03 pattern is a real mystery; when concentrations at VR01 (and VR02, not shown) increase, DON at VR03 decreases – and visa versa. It may simply be that variations in treatment plant output, measurable at VR03, become masked at locations further downstream. If this is correct, however, it remains an open question whether these variations are of short, or of long, duration, i.e., does the higher DON (and TDN) concentration seen at VR03 on April 5^{th} indicate the situation on that day alone? Or is it indicative of a much longer period? A look at plant records – if effluent nitrogen is measured on a daily basis – will be needed to answer the question.

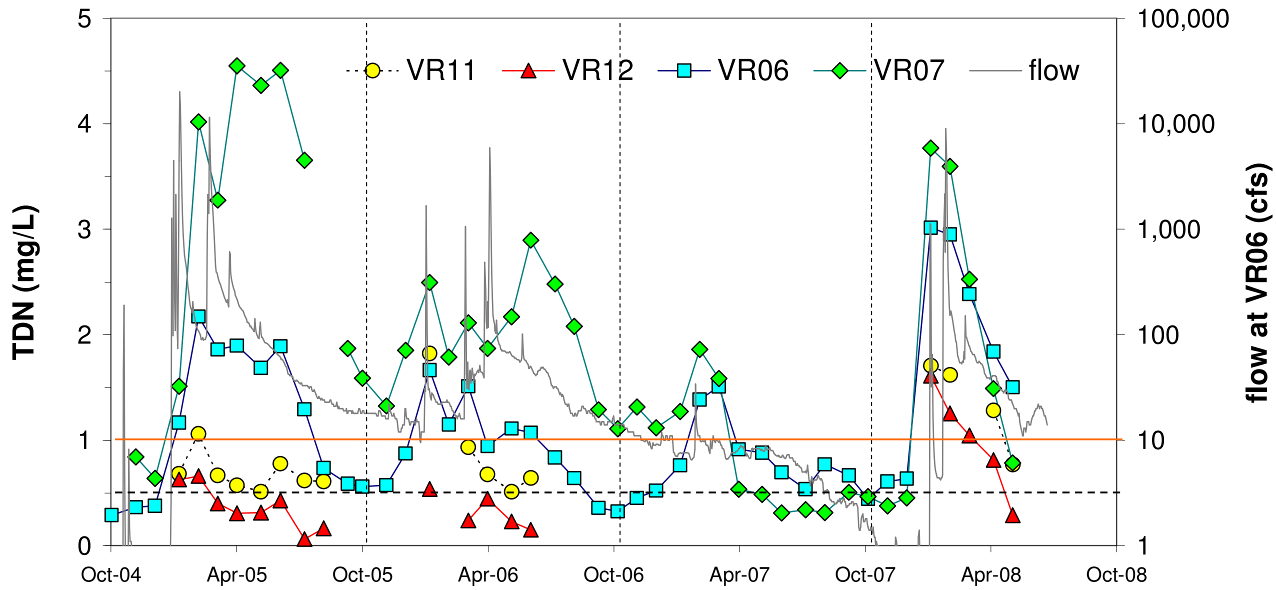
That the TDP variation at VR03 resembles that of DON (down-up-down) offers support to the idea that both are caused by variations in treatment plant effluent quality. Interestingly, the TDP variation seen at VR03, unlike that for DON, is mirrored further downstream at sites VR02 & 01. It may be that N-cycling by algae, in the various stages of growth encountered by downstream flows, more heavily influences DON than it does phosphorus concentrations. On it's face, given TDN to TDP molar ratios near, or in excess of, 100, it would appear that phosphorus rather than nitrogen was potentially limiting. However, from the level of both TDP and TDN concentrations in May at all sites below the treatment plant, it would appear that nutrient limitation is currently not an issue.

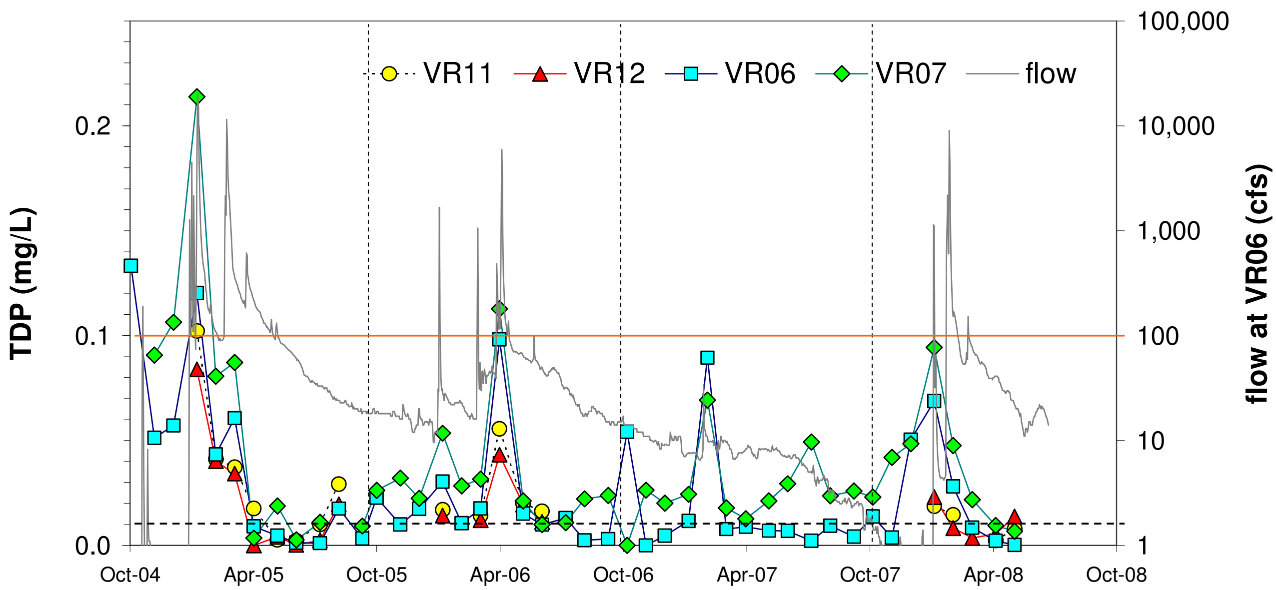
As in the TDN graphs, red and blue lines mark the State of California TP criteria (2006 SWAMP 305b Report) for streams of good quality (<0.01 mg/L) and those of poor quality (>0.1 mg/L), this translates into 0.3 and 3.2 µM, respectively; streams falling between these limits are considered in fair condition. I need to make two caveats about the TDP concentrations shown here. First, there is the unresolved problem as to why phosphate and TDP results from the UCSB-LTER lab showed an abrupt across-the-board decrease after the 2005 storms, i.e., results from 2001 to Dec. 2005 were generally (this encompasses thousands of samples taken by the LTER) 0.05 mg/L (1.6 µM – a rather significant difference) higher than those after March 2005. I'm unable to think of a reasonable natural explanation. Second, LTER phosphorus results often (up to 50% of the time) show TDP concentrations to be less than those of phosphate (more accurately, soluble reactive phosphorus, i.e., SRP) in the same sample. To somewhat counter-act this second problem the TDP shown here is what I call "modified" TDP, or TDP*. TDP* represents either the TDP result when TDP>phosphate, or phosphate when phosphate>TDP. The extent of the problem this year is as follows: 107 Channelkeeper Ventura samples have been analyzed since the start of the water-year (Oct. 2007). Of these, 26 had phosphate concentrations higher than TDP; in 22 of those samples the differences were slight – the median difference being 0.07 µM – and only 4 exhibited differences greater than 1 µM (two had differences of <10 %, the other two showed more egregious errors).

TDP* assumes that the great majority of samples with phosphate>TDP have little or no dissolved organic phosphorus (DOP) and that the analysis error is simply one of two separate procedures, done at different times, resulting in minor inaccuracies in measuring the same quantity; and these accuracies are, therefore, unimportant. Whether or not this is correct remains to be seen. Samples collected by Kristi have also been sent to both a lab at UC Davis and a different UCSB lab, and we hope that comparisons among all these results will resolve these open questions.

Aside from the three sites below the treatment plant, TDP concentrations at the other locations were typically high in February and then declined thereafter. Unlike the linear trend seen in the TDN decrease, that of TDP appears exponential. By April, TDP in these reaches had declined to near or below 0.01 mg/L – the "good condition" criterion. In May, concentrations continued their decline, except at VR04 and VR12. Since these locations had algae in advanced states of decay at that time it's tempting to assign the increase to cell lysis. However, given unanswered questions about the accuracy of the TDP analysis, this may be going too far.

I did go back and look at which locations experienced an increase in May nutrient concentrations to see if there was a discernable pattern. Four sites, 04, 11, 12 and 13 showed an increase in TDP from April to May, but only 04 and 14 had increased TDN (although 01, 02 and 06 did show increased DON). At VR04, where both N and P increased and algae was in a noticeable state of decay, cell lysis would appear to be a reasonable assumption as to cause. However, at locations exhibiting an increase in only a single nutrient we might expect that nutrient to be the one most abundant. Primary production in freshwater aquatic systems usually utilizes N and P in a molar ratio of 20-30 to 1. And since at all these sites nitrogen is far more plentiful than phosphorus (the ratios are very much greater than 30:1), algal decay appears far more likely to produce an increase in nitrogen concentrations than those of phosphorus. Unless, of course, something is utilizing the extra nitrogen, but finding an alternate source of phosphorus. June data may shed more light on this situation.





At this point I had planned to discuss the overall patterns of TDN and TDP variation on the Ventura using Channelkeeper results from the beginning of water-year 2005 (Oct. 2004) to the present. Using only the last 4 years of data allows a simpler story since it mostly concerns what has happened after the abrupt transition caused by the big 2005 winter storms – and I don't have to deal with the before-and-after 2005 part of the narrative. It also avoids problems with the dichotomy in phosphorus results mentioned earlier. I will get to the patterns of variation discussion, but first, I need to talk about the situation on the middle Ventura reaches, wherein lies the answer to this year's extravagant algal growth from around the San Antonio confluence to Foster Park.

The above graphs show the sampling locations tributary to this section: VR07 on lower San Antonio Creek, and VR11 & 12 on the middle Ventura. It also shows Foster Park (VR06); the flow is average daily flow (in cfs) at the USGS Foster Park gauging station.

The upper graph shows TDN, the lower TDP; the California nutrient criteria lines are also shown on both graphs. Note that data for VR11 & 12 are discontinuous; missing data, aside from occasional missed samples, indicates when these middle-reach sites were dry. Water flowed at these locations into August 2005, during January and from March into June 2006, and from January into June of this year. There was no flow in 2007. Nitrogen on the Ventura is typically mobilized by winter storms and usually peaks during this period, declining thereafter as discussed previously. Phosphorus has no such simple pattern. Phosphorus concentrations usually peak only during storms that mobilize significant amounts of sediment – phosphorus, unlike nitrogen, is tightly held by soil particles and absent water-borne sediment, concentrations are typically much lower. Note that most of the high TDP concentrations in the lower graph are associated with peaks in the hydrograph, and that high phosphorus values, unlike nitrogen, rarely carry over into the following month's sample.

The nitrogen pattern is one of increasing TDN concentrations with downstream flow: from VR12 to 11 to 06. San Antonio Creek enters the Ventura 2.5 km below VR11 (3.4 km above Foster Park) and VR07, on San Antonio Creek, is 0.8 km above the confluence. When flows on San Antonio are high (in winter and early spring) they influence concentrations at VR06 (note that during these times, and during 2007 when the middle Ventura reaches remained dry, the pattern of values at VR06 resembled, and concentrations were closer in value, to those of VR07). At other times, when the middle reaches are flowing, patterns and concentrations at VR06 more closely resemble those at VR11. Thus my first conclusion: *during years with enough rainfall to generate middle-reach flows, appreciable nitrogen (mostly nitrate) originates from these reaches and from the section of the river below VR11* (note the gain in TDN concentrations between VR11 and 06 when San Antonio flows are not an important factor).

Another thing that strikes me about TDN is the notable increase in concentrations seen this year: *2008 concentrations at VR06, VR11 and VR12 are the highest ever seen at these sites since sampling began in 2001.* TDN concentrations at VR06 at the beginning of the growing season were 1.9, 1.1, and 0.9 mg/L in 2005, 2006 and 2007, respectively; this year the concentration was 2.38 mg/L. Note that I cannot make this statement about VR07, nor can I make it for any other lower river or San Antonio location. The obvious question is why? The answer is also obvious: *we are experiencing increased nitrogen inputs from the middle reaches of the Ventura* (the question of increased flows, which would also mobilize increased amounts of nitrogen, also needs to be examined).

In contrast with TDN, TDP in 2008 doesn't look exceptional. Concentrations at VR06 generally resemble those at VR12 & 11 and when they don't Foster Park is obviously being influenced by San Antonio flows (from VR07). TDP concentrations at VR11 & 12 are generally low, as are, generally, those at VR06. And when phosphorus at VR06 is high it's usually because of meaningful flows from VR07 (during storms or in early spring, or when VR11 is dry). And there lies a rub. High nitrogen/low phosphorus is generally an indication of agricultural runoff – farmers and orchard growers usually care about how much, and what kind, of fertilizer is applied to their crops – using unnecessary fertilizer is like throwing money away. For home owners, gardeners, etc., money for fertilizer is not usually a consideration, so the more, the better, and the greater the amount and number of ingredients, better yet. High phosphorus is ordinarily an urban characteristic.

VR07 is a good example. San Antonio Creek is a high nitrogen/high phosphorus stream. The nitrogen generally comes from VR10, upper San Antonio Creek and other adjacent agricultural lands, the phosphorus from VR09 (Pirie Creek) which flows through central Ojai. Thus low phosphorus concentrations in the middle reaches presents something of a problem. There are plenty of agricultural lands above VR12, but, as noted earlier, between VR12 and VR11 residential land uses predominate. This situation continues down to Foster Park. Throw in a few horses and other animals (manure is high in P) and the expectation is an increase in both nitrogen and phosphorus, not nitrogen alone. Further investigation seems warranted. One possibility, mentioned earlier, is of relatively high, wet-year, groundwater inputs. These could be highly influenced by upstream agriculture. While I have no knowledge as to whether or not groundwater might actually play this role, the proximity of Lake Casitas to the west, and its potential impact on the local water table, lead me to suspect the possibility.

And now to patterns of variation at the other monitoring sites:

Figure 5 shows the monthly TDN variation since October 2004 at most of the Channelkeeper monitored locations. Mainly we see the pattern of "high winter concentrations followed by slow decline" discussed previously. However, there are exceptions. VR01, 02 and 03, sites below the Ojai treatment plant are three. Plant effluent, high in nitrogen, is superimposed on the normal nitrogen pattern as treated sewage is combined with flow out of Foster Park. As Foster Park flows diminish, typically in late summer and during the autumn, effluent dominates (furnishing up to 80 % of the total flow) and TDN concentrations appreciably rise. VR03, the location closest to the plant, attains its highest concentrations at these times, especially during drought years like 2007. These years also show the greatest decrease in concentrations between sites 03 and 01 from biological uptake (the removal of N for cell growth), mainly because very low flows magnify concentration changes as nitrogen is removed. At times, nitrate totally disappears at VR01 and TDN values drop below the "good" 0.5 mg/L benchmark.

Upper San Antonio Creek (VR10) is another exception. Here typically high TDN concentrations actually decrease in winter. Flows at VR10 consist mostly of high nitrate groundwaters, presumably from upstream agricultural operations. In winter, lower nitrogen stormflows, and storm-related flows, actually dilute in-stream concentrations. This is a normal pattern: stormflows generally increase pollutants found in low concentrations, but decrease those that are normally high. None of the San Antonio sites, nor those below the Ojai treatment plant, show anything unusual happening in 2008: concentrations are neither unusually high nor unusually low.

However, in the bottom Matilija panel, there is a noticeable trend of gradually increasing TDN concentrations since the end of water-year 2005. This trend is visible at all three locations and has persisted through both a reasonably wet year like 2006 and the drier 2007. And, as was true for VR06, 11 and 12, the highest concentrations of all were seen at the start of this growing season. Even more interestingly this increasing trend is almost solely due to increases in DON – not nitrate (Figure 7). Therefore the cause would appear to lie neither in increased pollution nor in groundwater changes. I've considered the possibly of a chicken/egg situation (as in "which came first, the chicken or the egg?"), more algae produces more DON, which fuels greater algal growth, etc. However, the gradual DON increase has not been limited to a specific time of year, but continues year-round. For now it remains a puzzlement.

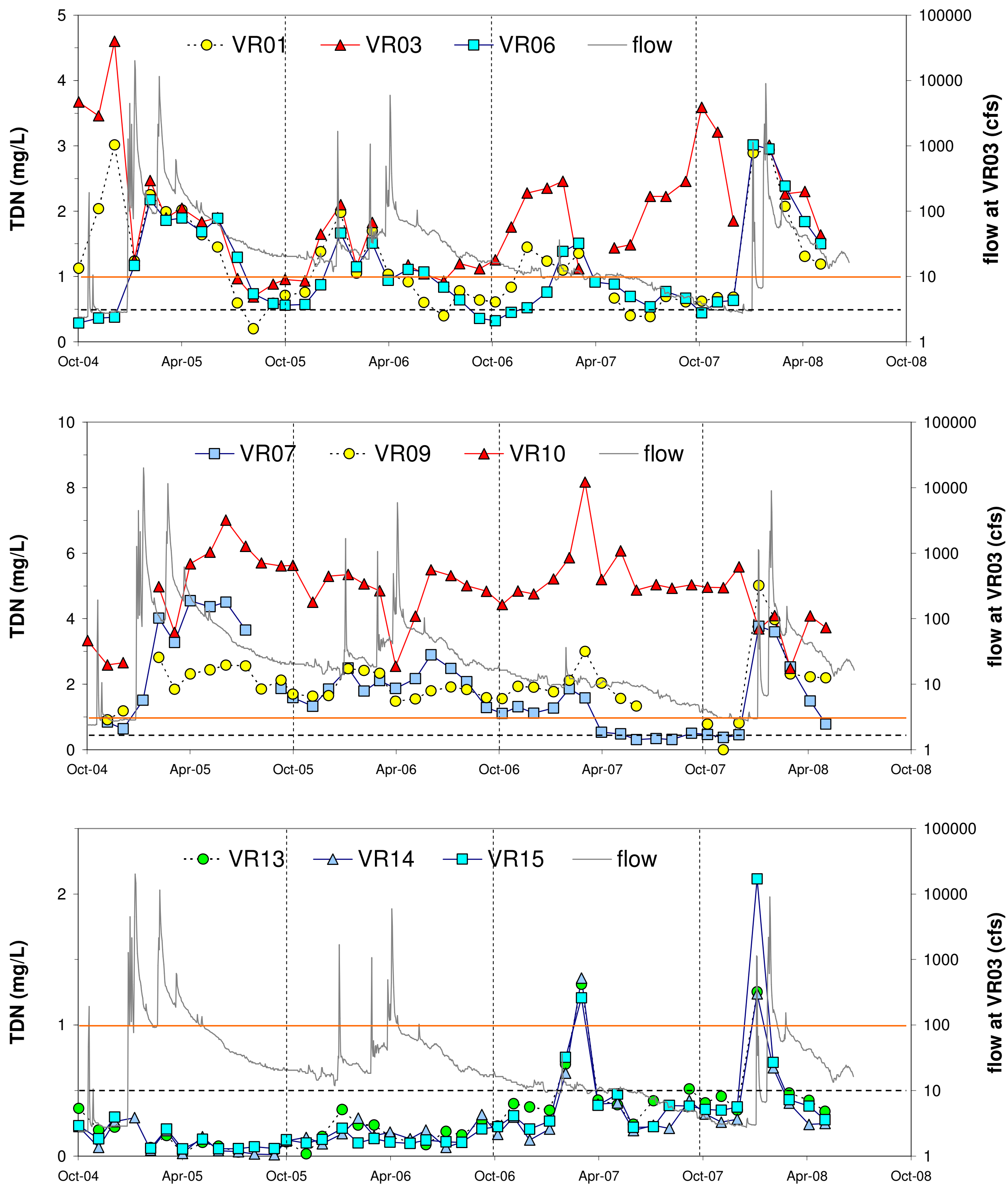


Figure 5. TDN variation since October 2004 at various Channelkeeper monitored locations in the Ventura watershed: lower river sites in the upper panel, San Antonio Creek in the middle, Matilija sites in the lower. Flow at VR03 (Shell Bridge, average daily flow at Foster Park plus average daily treatment plant output) is also shown as are the California TN stream nutrient "good" (<0.5 mg/L) and "poor" (>1.0 mg/L) criteria.

Figure 6 shows the same kinds of graphs, but for TDP. Phosphorus concentrations are never really low, local geology in the form of readily eroded, recently uplifted seabed deposits, sees to that, but they generally meet or come near to meeting the California 0.01 mg/L TP criterion for "good" conditions. As mentioned earlier, sediment generating storms mobilize phosphorus but this effect usually disappears as sediment levels decrease back to normal. This can best be seen in the middle San Antonio panel: where high TDP concentrations usually coincide with peaks (indicating stormflow) in the hydrograph. Again, the principal exceptions are sampling locations below the treatment plant where low flows from VR06 magnify the impact of high-phosphate effluent (as mentioned earlier, excrement, human or animal, is high in phosphorus). The highest TDP concentrations in the Ventura watershed are found at VR03, usually in the early fall of drought years (e.g., 2007). I find it interesting that whereas TDN concentrations at VR01 are often lower than those found at Foster Park, TDP concentrations almost never are. The other high-phosphorus exception is the previously mentioned Pirie Creek, flowing out of downtown Ojai (middle panel).

Finally, a look at nutrient status. Figure 8 shows the monthly variation in molar N/P (TDN divided by TDP with concentrations expressed in μM) ratios for most of the monitored Channelkeeper locations. Oceanic primary producers (organisms that fix carbon from carbon dioxide using sunlight and form the base of the oceanic food chain) utilize N to P in a ratio of 16:1 (often called the *Redfield* ratio). In freshwater aquatic systems this ratio has often been found to lie between 20:1 and 30:1 and I've indicated this range on the graphs with a green band. When the actual ratio falls above the band it indicates that phosphorus is potentially limiting, i.e., it's much less readily available than nitrogen; below the green band nitrogen is in shorter supply and potentially limiting. I stress the word *potentially*. Although one nutrient may be relatively scarcer than another, both may be present in quantities adequate enough for all the primary production taking place – thus neither nutrient would actually limit growth.

Note that at most of the sites nitrogen is usually more plentiful than phosphorus, and if productivity were to be limited it would be by the lack of phosphorus. There are exceptions, mainly below the treatment plant: the plant puts out lot of both, but when plant effluent dominates flow (summer and fall) there is no lack of phosphorus. (Note that while the treatment plant exports far more nitrogen than phosphate, primary producers like algae need 20 to 30 times more nitrogen than phosphorus, and treated effluent has proportionally less nitrogen than this.)

There seems to have been a curious reversal in Matilija nutrient status. Prior to the fall of 2006, nitrogen was usually potentially limiting, since then, phosphorus. This matches the gradual increase in DON noted earlier. Increasing DON (thus TDN) while TDP remains relatively constant (or even slightly decreases) has led to a gradually increasing N/P ratio.

Currently all sites exhibit an excess of nitrogen, and if a nutrient is now limiting it is most likely phosphorus. This said, I repeat my point that nutrient concentrations, as such, may not adequately address the limitation issue. I believe the delivery of nutrients, or flux (concentration multiplied by velocity), to be the most important factor. What may seem to be available in the river reach – concentration – may not be deliverable, or deliverable in sufficient quantities, to micro-sites inhabited by algae. Local current speed, stream depth and algal density itself, may play equally if not more important roles in determining nutrient availability and algal growth.

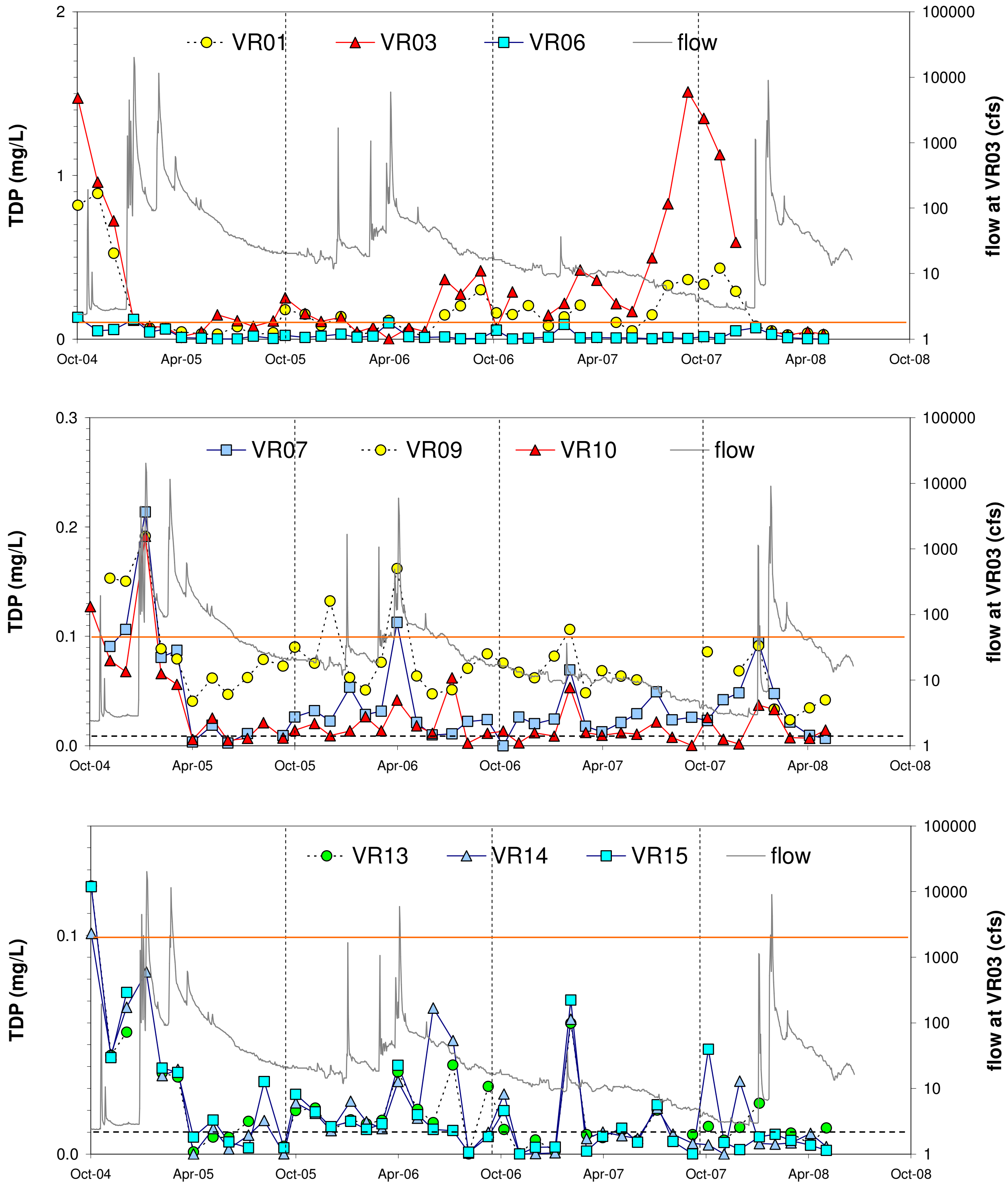


Figure 6. TDP variation since October 2004 at various Channelkeeper monitored locations in the Ventura watershed: lower river sites in the upper panel, San Antonio Creek in the middle, Matilija sites in the lower. Flow at VR03 (Shell Bridge, average daily flow at Foster Park plus average daily treatment plant output) is also shown as are the California TP stream nutrient “good” (<0.01 mg/L) and “poor” (>0.1 mg/L) criteria.

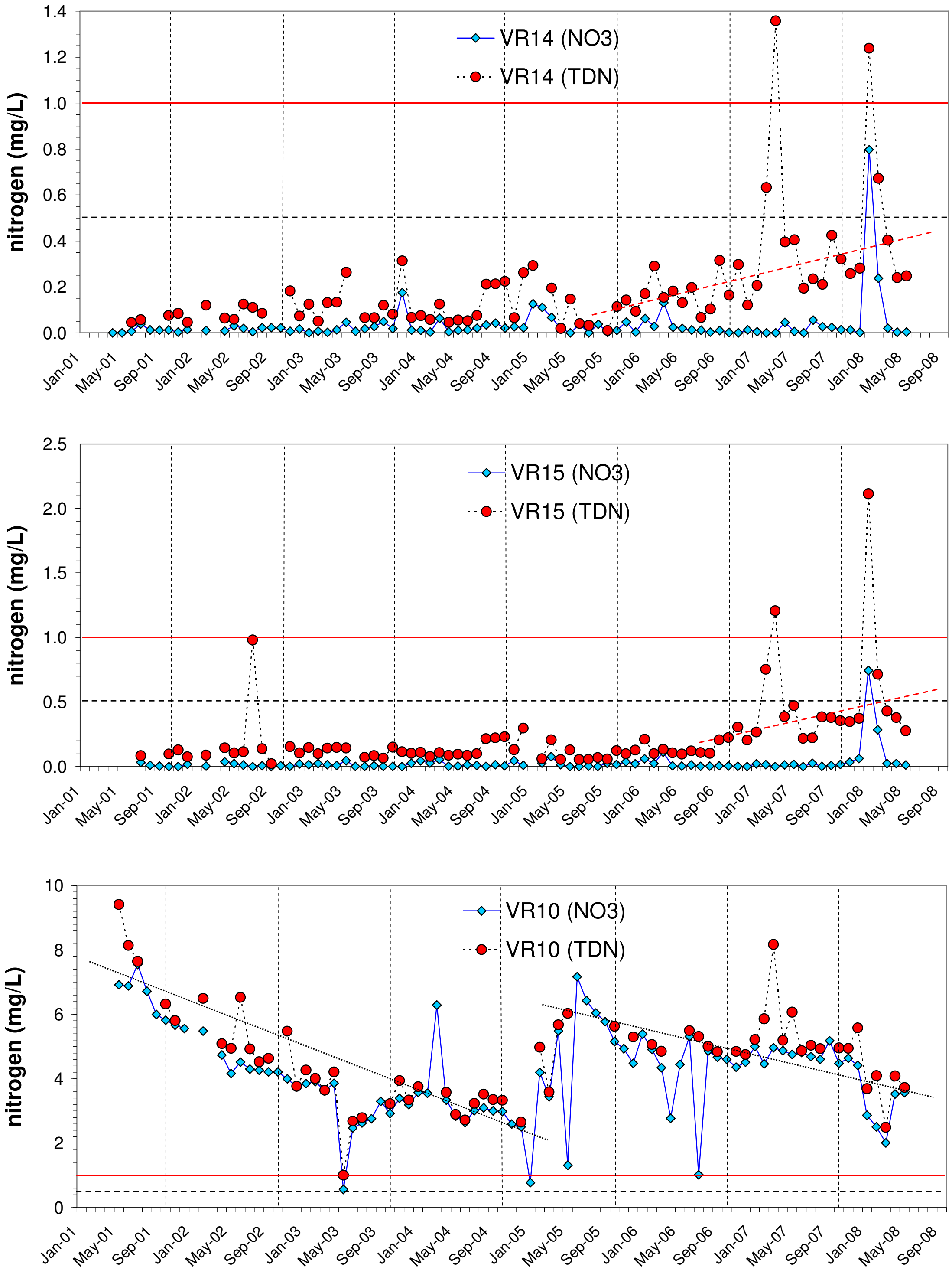


Figure 7. TDN and nitrate concentrations since 2001 at the N.F. of the Matilija (VR14), Matilija Creek (VR15) and upper San Antonio Creek (VR10). The first two panels show the increase in DON on the Matilija branches since the fall of 2005 (red dashed lines). The cause of the DON increase remains a mystery. The last panel exhibits the expected pattern from high nitrate groundwaters. The dashed black lines show the loss of nitrate as groundwaters age – and the break, and recharge, caused by the big 2005 storms. The California TN stream nutrient "good" (<0.5 mg/L) and "poor" (>1.0 mg/L) criteria are also shown.

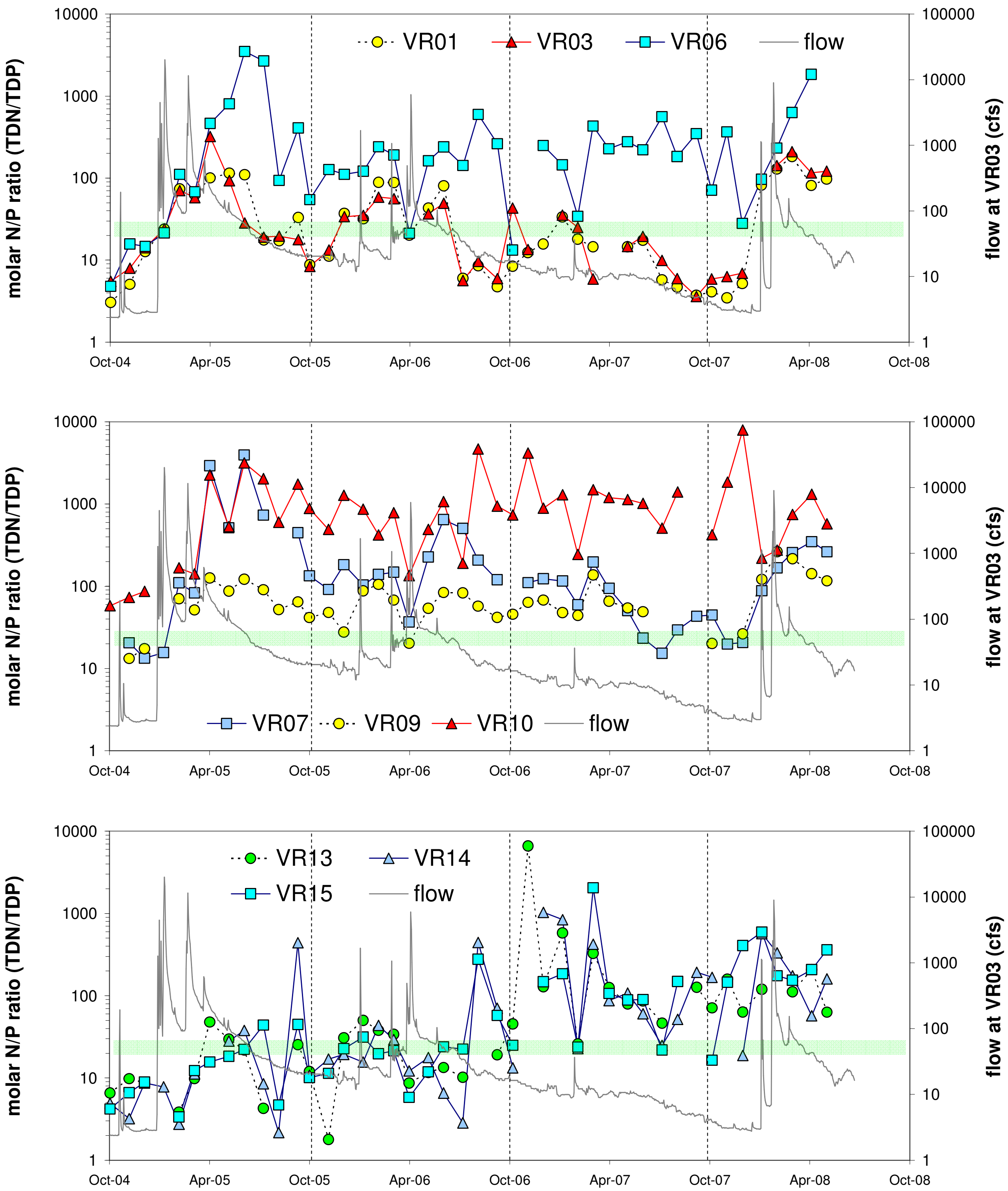


Figure 8. Variations in the molar N/P ratio since October 2004 at Channelkeeper monitored sites in the Ventura watershed: lower river sites in the upper panel, San Antonio Creek in the middle, Matilija sites in the lower. Flow at VR03 (Shell Bridge, average daily flow at Foster Park plus average daily treatment plant output) is also shown. The green band indicates the 20-30:1 ratio typically utilized by freshwater primary production; values above the band indicate a surplus of nitrogen.