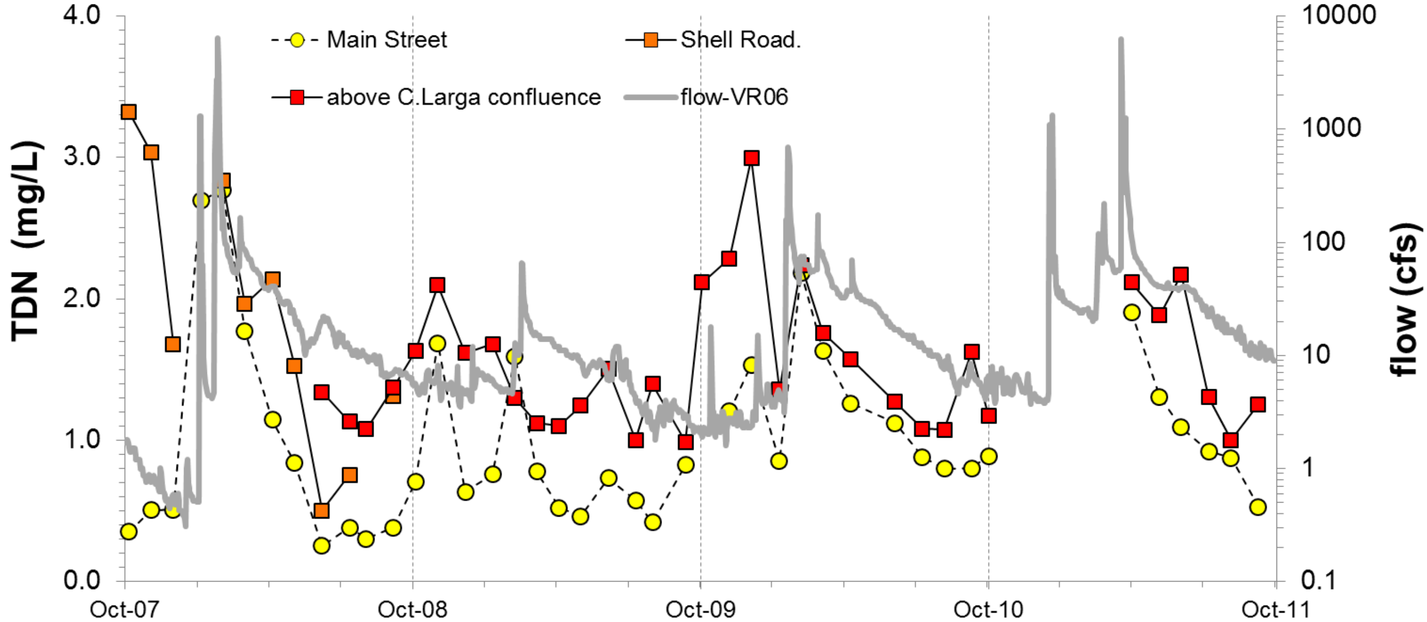
Nitrogen: The Lower River



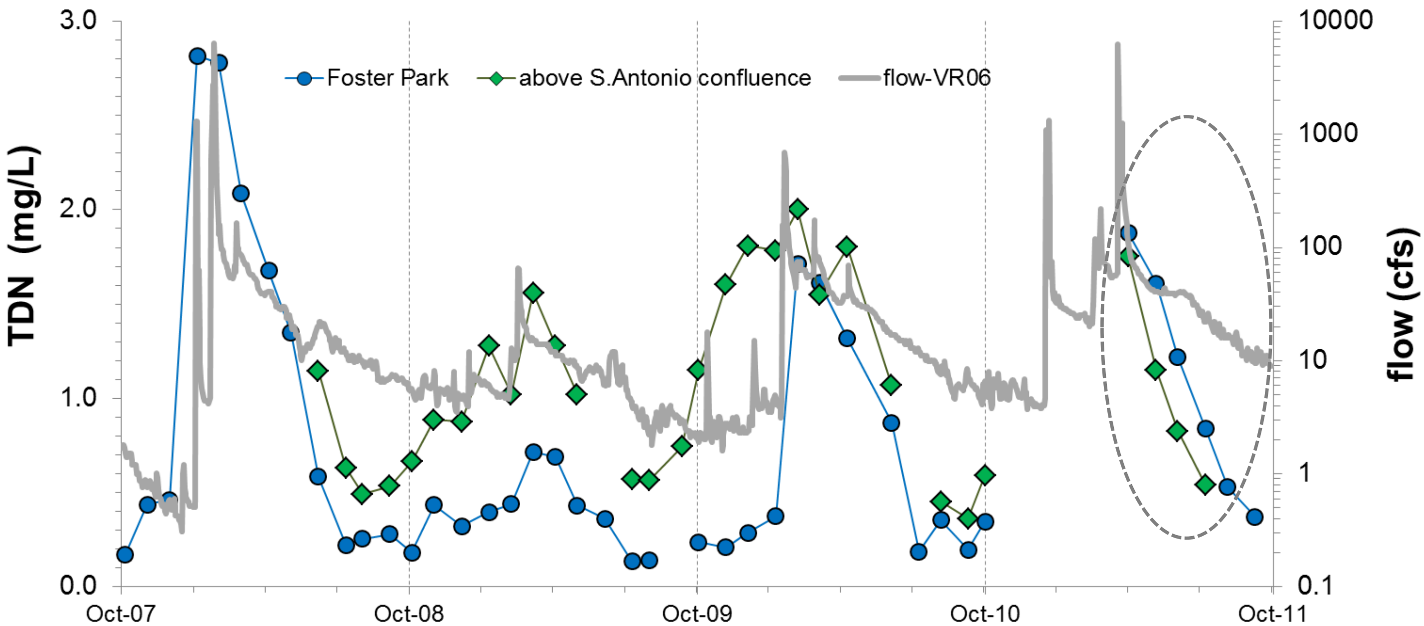


Figure 1. Monthly TDN (total dissolved nitrogen) for Santa Barbara Channelkeeper (SBCK) monitoring sites on the lower Ventura River from water-years 2008 through 2011: (top) Main Street and above the Canada Larga confluence, i.e., just below the wastewater treatment plant; (bottom) Foster Park and just above the San Antonio Creek confluence.   Flow at Foster Park is also shown.

I've shown TDN in mg/L and included 2008 data for Shell Road since sampling had not begun at either "above the confluence" site until late in the water-year. The data show (more-or-less) what we might have expected: Nitrogen – and nitrogen is mostly nitrate at these sites – is mobilized by winter storms (lower rainfall winters mobilizing less nitrogen, e.g., 2009 less than 2010, and 2010 less than 2008; the picture for 2011 is incomplete since sampling didn't begin until April of that year). After the winter rainfall peak there is a continual decrease in concentration throughout the remainder of the water-year due to increasing uptake by plants and algae. (There is also a decrease brought on by decreasing flow – the amount (also called *flux*, flux is calculated by multiplying concentration by flow) of nitrogen is as important as concentration, if not more so, and the amount of nitrogen decreases as flow decreases even if concentrations remain the same. Decreasing flow means decreasing amounts of nitrogen flowing down the river and the same amount of uptake removes proportionally greater and greater amounts of N). The summer decrease in N is usually followed by an autumn increase as uptake declines with the ending of the growing season and the start of colder weather, and as nitrogen inputs from groundwater and early storms increase.

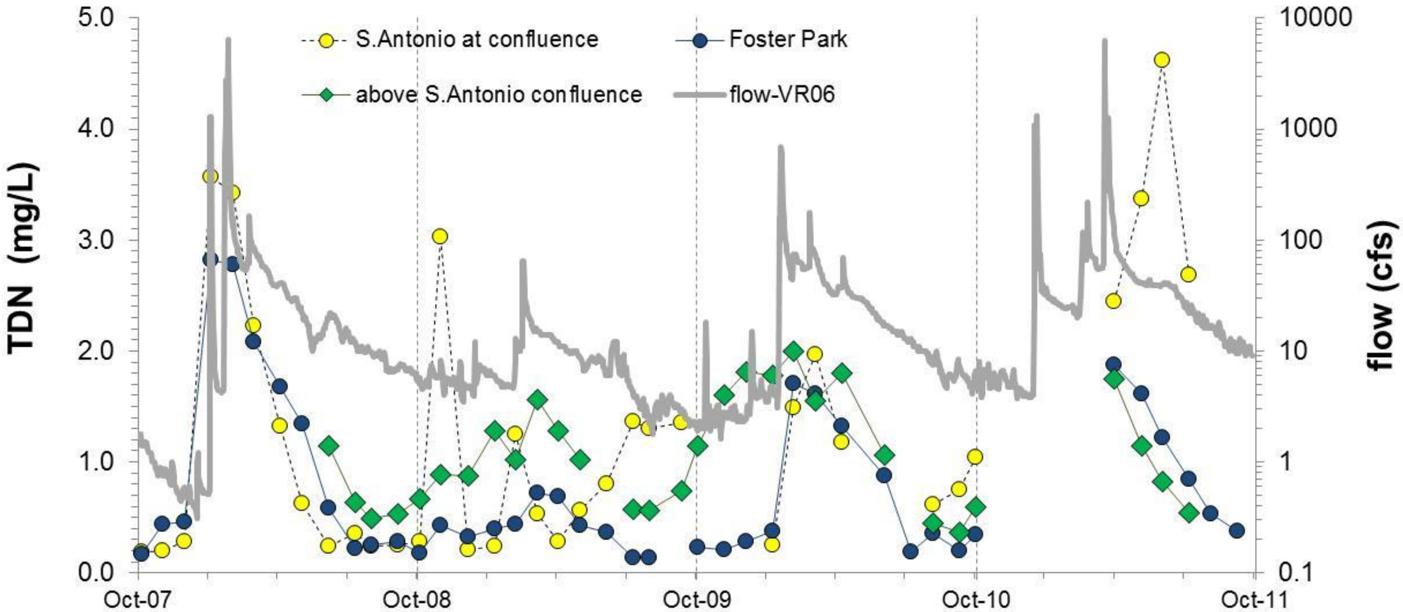
Also expected would be a decrease in TDN – again because of continual uptake by plants, algae and riparian vegetation – as flow moves downstream from high-nitrogen locations (as long as no new major inputs are encountered). The major dry-season sources of N on the lower Ventura are (1) effluent from the wastewater treatment plant (WWTP) and (2) high nitrate groundwater surfacing in the river above the San Antonio confluence. The top panel of Figure 1 shows this expected decrease from below the WWTP to Main Street (one might also note that the decrease was greater in 2008 than in subsequent years, probably an indication that that year's algae removed a greater amount of nitrogen than is normally removed during years when aquatic-plants are dominant). In the lower panel, nitrogen concentrations on the river above the San Antonio confluence were higher than those at Foster Park in 2008-2010, as we would normally expect, but in 2011 an unusual reverse occurred: Foster Park concentrations were higher than those above the confluence.

I've circled this section on the lower graph. Since this situation continued for 4 months (unfortunately, the confluence site was not sampled in August or September), and since the general range and sequential pattern of the TDN results at each of these sites is exactly what we might expect, there seems little chance of sample collection or analysis error.

The most plausible cause for this reversal (along with TDN, nitrate concentrations at Foster Park were also greater than those above the confluence) would appear to have been increased nitrogen input from San Antonio Creek. Usually, as Figure 2 shows, TDN concentrations entering the Ventura River from San Antonio Creek are not all that different from those above the confluence. And flows from San Antonio into the Ventura are usually too small to cause much of a change either; this is especially true as we get further into the dry-season when San Antonio Creek either slows to a trickle or dries up completely.

However, in 2011, San Antonio TDN concentrations were abnormally high, and flows, as a result of above average rainfall (29 inches vs. a water-year median of 18 at Ojai), were also higher than usual. The combination of high flow and high TDN concentration produced an unusually high flux of nitrogen from San Antonio Creek into the river. Flux calculations allow us to check that this was indeed the cause. The Ventura County gauge on San Antonio Creek at Casitas Springs functioned until July 11, 2011, and the flow record verifies that the amount of nitrogen coming out of San Antonio Creek was enough to account for the higher Foster Park concentrations. (Fluxes at all 3 points were calculated from TDN concentrations and measured flows at Foster Park and Casitas Springs – with flow above the confluence estimated as the difference between Foster Park and Casitas. The combined *below* the confluence flux exceeded that measured at Foster Park on all four sampling dates.)

Not only was the flux of TDN coming from San Antonio Creek substantial, it exceeded that coming from the Ventura River above the confluence from mid-April on. The cause of the high San Antonio TDN concentrations in 2011, and the rather unusual increase that took place from April to June (Figure 2), is addressed next.



Nitrogen: San Antonio Creek

Figure 2. TDN concentrations, WY2008-2011, circa the San Antonio/Ventura confluence. Flow at Foster Park is included to give some idea of seasonality and flow conditions.

Figure 3 shows TDN results for the four SBCK sampling locations on San Antonio Creek from 2008 through 2011. The blue (Pirie) and red (upper San Antonio) data points represent measurements on separate tributaries that combine a short distance downstream. Of the two, upper S. Antonio Creek, flowing out of agricultural lands, has far higher nitrogen concentrations. The now combined creek flows downstream to the middle S. Antonio sampling point and thence down to the confluence. The obvious expectation, absent any major new contributions, would be a decrease in TDN as we move downstream (concentrations being reduced by the same biological uptake mentioned earlier). This is generally what we see.

Upper San Antonio Creek flows at three or four times the rate of Pirie Creek and is the dominant influence in defining TDN concentration and other chemical characteristics below the point where they join. It also has the highest nitrogen concentrations in the Ventura watershed, roughly double those measured below the WWTP. Figure 3 does show the expected decrease in nitrogen concentrations as we move downstream except, perhaps, in 2010 when similar concentrations at the middle and Ventura confluence sampling sites occurred.

I'm not sure why this particular year was different except that very small flows can be drastically changed by what might ordinarily be considered minor contributions. Flows above the confluence were very low during this period (typically around 1 cfs during the first part of the dry-season and about half that later on). Extensive horse corrals are located above and just upstream of the confluence sampling point, and seepage or runoff from these may have substantially modified TDN concentrations.

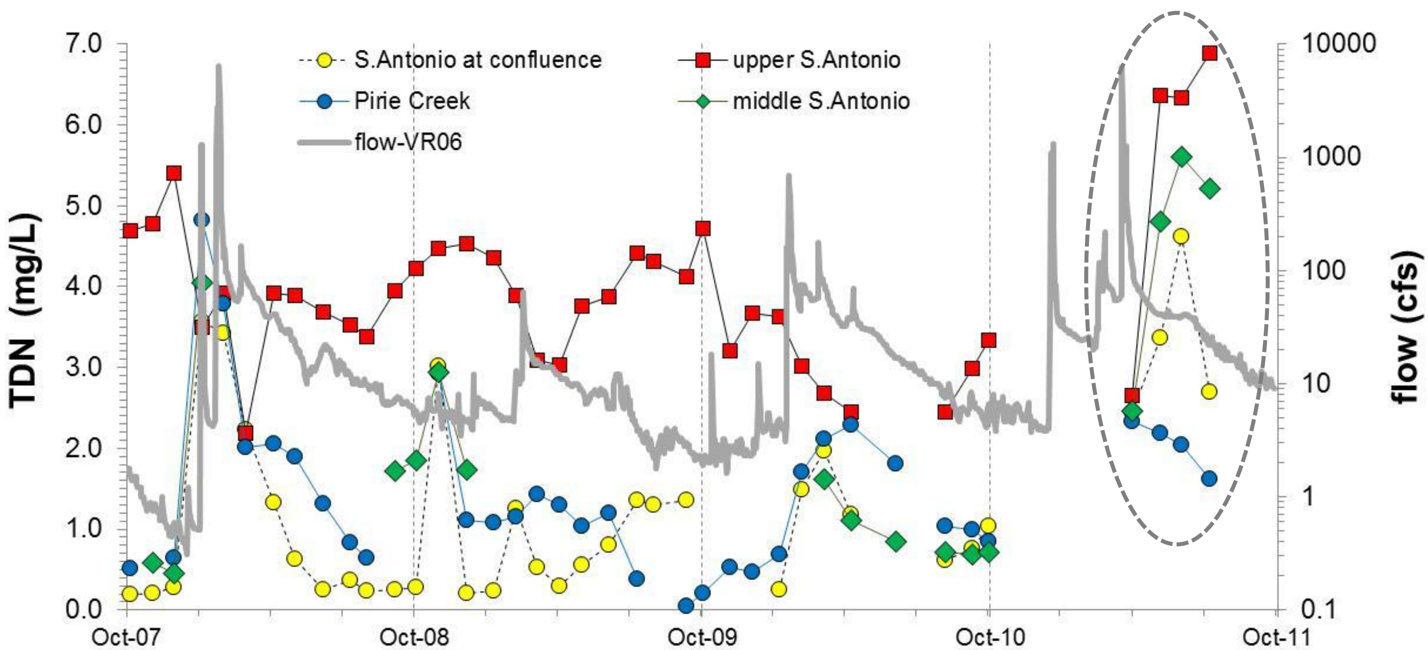


Figure 3. Monthly TDN (total dissolved nitrogen) for SBCK monitoring sites on San Antonio Creek from water-years 2008 through 2011: Pirie Creek comes out of Ojai and upper San Antonio flows mainly from agricultural lands further to the east; both are sampled just upstream of their confluence. Flow at Foster Park is also shown to reflect seasonality and provide a rough estimate of comparative flow.

I've circled the most interesting part of the data set: the 2011 dry-season. Note again the high "San Antonio at the confluence" TDN concentrations, and the rise in these values through May and June mentioned earlier (Figure 2). But note that the upstream sampling sites also show substantial increases – middle S. Antonio higher than lower S. Antonio and upper S. Antonio higher yet – indicating that the change was indeed real.

Notice that there are no winter-rainfall peaks in TDN concentration on upper San Antonio Creek. As a general rule stormflows *increase* pollutant concentrations in relatively clean waters, but they *decrease* pollutant concentrations in streams high in that particular contaminant. TDN and nitrate concentrations are very high (anything over 1 mg/L can be considered high) at this location and storm runoff dilutes instead of increasing the normally observed values. Where concentrations are lower, as in the other sampling locations, a stormflow peak in concentration is observed.

In contrast with the other sites during the 2011 dry-season, Pirie Creek exhibits the expected gradual dry-season decline seen in earlier years (and on the lower Ventura in Figure 1). So sometime starting in April 2011, after the rains had ended, there was an inflow of high nitrate groundwater into upper San Antonio Creek (TDN concentrations in May jumped to 6.37 mg/L, nitrate to 6.13 mg/L). This inflow was undoubtedly agricultural in origin (I would include golf course irrigation as "agricultural"), but since no sampling was conducted above the SBCK monitoring site the exact origin cannot be pinned down. This new source of nitrate was higher than the concentrations seen in most years at this location and affected the river down as far as the WWTP.

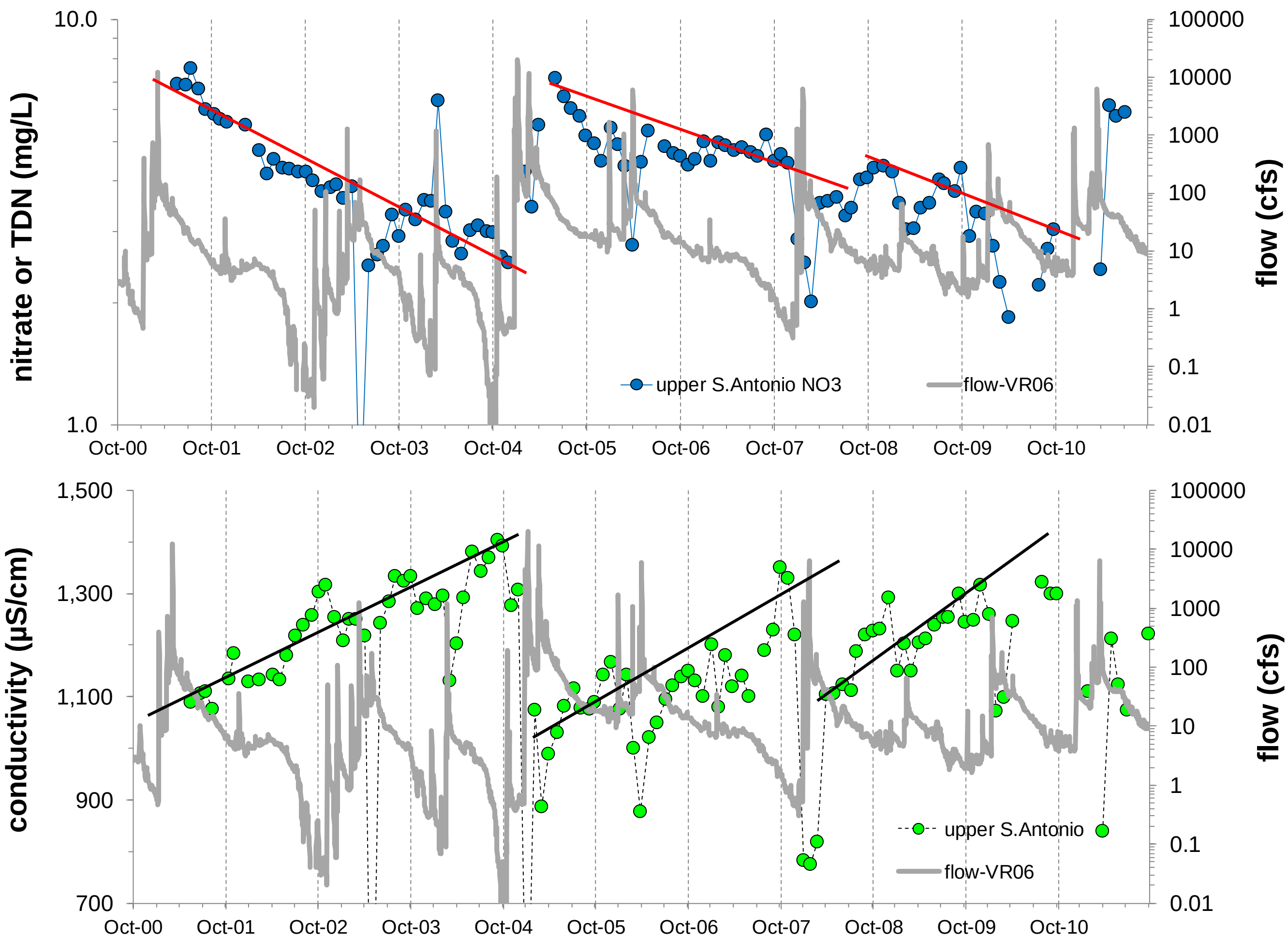


Figure 4. (top) Monthly nitrate concentrations on upper San Antonio Creek from water-years 2001 through 2011. (bottom) Monthly specific conductivity measurements for the same location. Flow at Foster Park is included in each graph to show seasonality and comparative flow. Lines have been drawn on the graphs to show the multi-year trends of nitrate decrease and conductivity increase that take place between winters of significant groundwater recharge.

We've seen this sort of N increase before: in 2001, 2005, and, to a lesser extent, in 2008 (Figure 4 (top)). All were years of significant groundwater recharge in the upper San Antonio drainage, recharge with high nitrate waters originating from agricultural land uses. Only in high rainfall years does significant recharge of this aquifer take place: precipitation in 2001, 2005, and 2011, was 27.6, 43.8, and 29.3 inches, respectively (Ojai rainfall data). The evidence for the episodic nature of these major recharge events is threefold: First, summer stream flows, which rely almost totally on groundwater inflows (WWTP effluent being almost the sole exception) and therefore reflect the status of the underlying aquifer, show an almost continual decrease during periods between these significant recharge episodes, i.e., water table levels are continually dropping (Figure 4). Dropping water tables, in turn, indicate lack of significant recharge and the aging of the groundwater resource. (There are no stream gauge data available for the upper S. Antonio and I'm using Foster Park as a stand in; although imperfect, in that it measures flow in another part of the watershed and is fed from a different aquifer, summer flows at Foster Park generally reflect what is happening in *all* the other small aquifers that underlie the Ventura watershed.)

Second, aging groundwaters, especially in the upper levels of the water table, lose nitrate, mostly via biological uptake (in this case, by bacteria), and we see this loss in declining nitrate concentrations between major recharge episodes (Figure 4 (top)). Third, although nitrate concentrations decline as groundwater ages, the overall ionic strength (ions or minerals that enter into solution) increases because of longer periods of contact between groundwater and its containing geologic strata. This increased ionic strength between major rainfall winters is captured in the increased specific conductivity shown in Figure 4 (bottom).

I'm simplifying, of course. Some recharge undoubtedly occurs in drier years and not all areas of the S. Antonio watershed contribute equally. And I've left out any consideration of time – movement of groundwater downslope is not like flow in a channel and takes considerably greater amounts of time. Note that late in the summer of 2010 nitrate values began to rise and conductivity to fall. This was probably related to the delayed arrival of recharge from the preceding winter's rainfall – recharge that took place in more remote parts of the watershed. Water-year 2010 had above normal precipitation (24.1 vs. the Ojai median of 18 inches) which resulted in some degree of recharge (as evidenced by the increased dry-season flows of 2010 over those of 2009). The early spike in 2011 nitrate concentrations (soon after the last major storm) is most probably related to the combined recharge of both 2010 and 2011: very recent 2011 recharge hurrying prior 2010 recharge on its way to the stream.

To reiterate, the wet winter of 2011 (with some help from 2010's rainfall) allowed major recharge of the upper San Antonio aquifer. This recharge contributed both increased nitrate concentrations (because the aquifer underlies extensive agricultural lands) and dry-season flows that, in turn, increased nitrogen concentrations all the way to the treatment plant.

Nitrogen: The Upper Basin

SBCK nutrient sampling in the upper Ventura watershed was relatively sparse (some of this was due to the loss of TDN samples from the latter part of the 2009 and early 2010 dry-seasons at UCSB), but I've shown the available data in Figure 5 to indicate that TDN concentrations remained low (as concentrations above 1 mg/L can be considered high, anything below 0.5 can be considered low). The data show the expected 2008 rainy-season peak normally associated with appreciable rainfall (high rainfall winters are typically followed by substantial algal blooms), but no TDN increase at all in 2009, a dry year with no major storms (and no readily visible algal bloom, also typical). Nitrate data (not shown) indicate very little increase during the winter of 2010 (although there was a substantial increase in TDN), and, looking at Figure 5, there seems even less chance that there had been an increase in 2011 (both nitrate and TDN concentrations were lower during the 2011 dry-season than in 2010).

Why this is so remains puzzling. We had a respectable winter in 2010, and 2011 had even greater rainfall (the Ojai rainfall totals for 2008-2011 were 20.6, 12.9, 24.1 and 29.3 inches, respectively). The 2011 rainfall came in the form of appreciable storms – storms roughly the same size as those of 2008 – and it would seem reasonable to expect a mobilized nitrogen pulse similar to that of 2008.

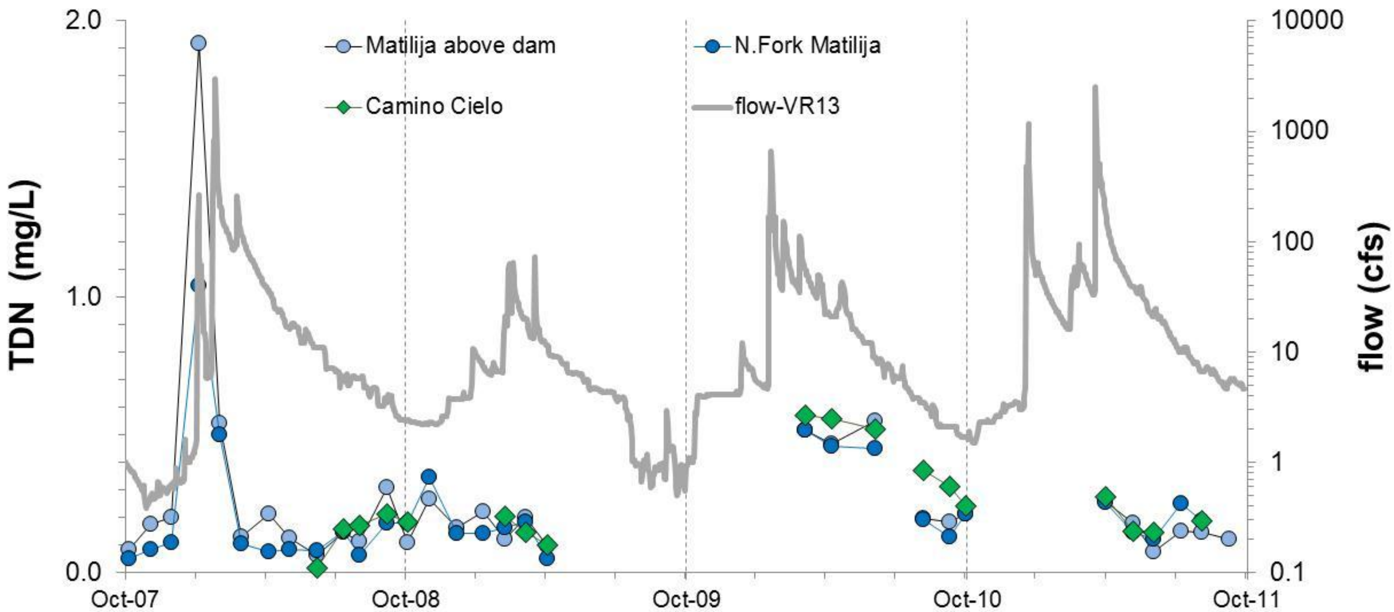


Figure 5. Monthly TDN (total dissolved nitrogen) for Santa Barbara Channelkeeper (SBCK) monitoring sites in the Matilija/upper Ventura River area from water-years 2008 through 2011: Camino Cielo is below the point where the Matilija and its North Fork join. Flow on Matilija Creek, just below the dam, is shown to reflect seasonality and provide a estimate of relative flow at these sites.

One possibility is that a 2011 pulse *did* occur, but earlier in the season, around the time of the first major storm (December 2010), and during the interval when no nutrient samples were collected. In spite of this "missing pulse" puzzle more nitrogen *was* made available as evidenced by substantial initial algal blooms in both years – these early dry-season blooms featured the alga Cladophora, an alga highly dependent on lots of nitrogen. However, these early blooms were in themselves rather strange . . .

The photo in Figure 6(a) shows the Matilija (above the dam) sampling site in early April 2009: note the very low flow and the absence of algae mentioned above. Figure 6(b), in April 2010, shows a much higher water level and plentiful algae – but algae at the end of its bloom; senescence is indicated by its pale yellow-green color. The big storm of 2010 occurred near the end of January and there was a smaller subsequent storm near the end of February, very much like what happened in 2008 but with much less intensity. However the bloom in 2008, while equally early, was far more substantial and lasting. Perhaps – and I'm just guessing here – the lower intensity of the major (comparatively speaking) January storm mobilized much less nitrate, and the multiplicity of the series of small storms thereafter (note the number of runoff pulses in the 2010

Figure 6. Matilija Creek above the dam sampling location: (a) April 4, 2009; (b) April 10, 2010, (c) May 2, 2010, and (d) July 21, 2010. Camino Cielo ford: (e) looking downstream and (f) looking upstream on June 4, 2011.

hydrograph – Figure 6 – that follow the January storm) may have further limited nitrogen availability when the algal bloom did finally take off. A multiplicity of small winter storms may have an as yet unrecognized impact on nitrate availability, perhaps simply by delaying the start of the algal season; the devil may lie in the details.

What is much less of a guess is that a small storm on April 12, two days after photo 6(b) was taken, swept a lot of this dying algae from the creek, leaving the relatively algal-free stream shown in 6(c) (May 2, 2010). (The removal of dying algae by a late storm also removes a significant source of nitrogen – flushing it downstream – which makes the high 2010 dry-season TDN concentrations even more surprising.) Figure 6(d) shows the site on July 21, 2010, when a second bloom occurred; this is a different alga – Mougeotia – which prefers very low water velocities and can thrive in low nutrient environments (this kind of bloom, occurring near the end of the dry-season, is typical of sun-lit stream reaches in the upper basin and occurs nearly every year).

The 2011 Cladophora bloom in the upper basin was equally strange: in being both sparse and occurring very late in the dry-season. The 6(e) and (f) photos show conditions at Camino Cielo on June 4, 2011. Camino Cielo is about a kilometer below where the Matilija and its North Fork join. Note from the photos, and the hydrograph in Figure 5, the rapid flow and high water level on this date (flow was approximately 28 cfs, compared with 14, 5, and 12 cfs on the same date in 2008-2010, respectively, i.e., it was more than twice that of the year before). Cladophora like fast moving water (the flux business again: high velocities can deliver a substantial flux of nitrogen even with the very low concentrations typical of the upper basin; Cladophora densities are often highest in areas with the fastest current), but there can also be too much of a good thing. Too high a water velocity and algae can't get enough of a foot-hold to withstand the current. Flows above a certain threshold value reduce the availability of suitable Cladophora habitat, and cause an extended delay to any potential algal peak.

And delay is important because the upper Ventura basin, unlike upper San Antonio Creek, has low nitrate groundwater (as evidenced by very low nitrate concentrations late in the dry-season when groundwater is the sole source of flow). The major source of nitrogen from the relatively pristine National Forest lands tributary to these streams is accumulated deposition from air pollution. Only in big rainfall years is this often multi-year accumulation washed into the stream and its riparian areas giving the kind of relatively short lived pulse seen in 2008. Absent this new nitrate there cannot be an early season Cladophora bloom.

So we can probably conclude that the large storm of December 22, 2010 was probably accompanied by a significant pulse in nitrate concentration, but by the time the very high flows caused by an even larger late storm around March 20, subsided enough to allow appreciable algal growth, there was insufficient available nitrogen to fuel it. So not only must the nitrogen come, but other conditions must be such that it can be utilized within a relatively short time frame.

Nitrogen: Dissolved Organic Nitrogen (DON)

I've used TDN data instead of nitrate in the above nitrogen discussion because the upcoming TMDL is expected to use total nitrogen (and not nitrate) in any mandated standard. Typically, much of the total nitrogen consists mainly of nitrate. This is especially true at the more nutrient-contaminated sites on the lower Ventura and along San Antonio Creek (it varies from near 90 % on the upper S. Antonio, to 77 % below the WWTP, to ~ 60 % at Foster Park and Main Street). Locations in the upper Ventura basin (as well as most other relatively pristine environments), usually have much lower proportions of their nitrogen in the form of nitrate (averaging about 22 % on the North Fork and 14 % on Matilija Creek above the dam). The difference between TDN and nitrate concentrations measured at a given point and time is considered organic nitrogen – complex organic molecules containing nitrogen which are usually not as easily assimilated by aquatic organisms as the more "digestible" nitrate molecule. (The two other, more reduced, species of nitrogen, nitrite and ammonium, are not usually found in meaningful concentrations in Ventura watershed waters.)

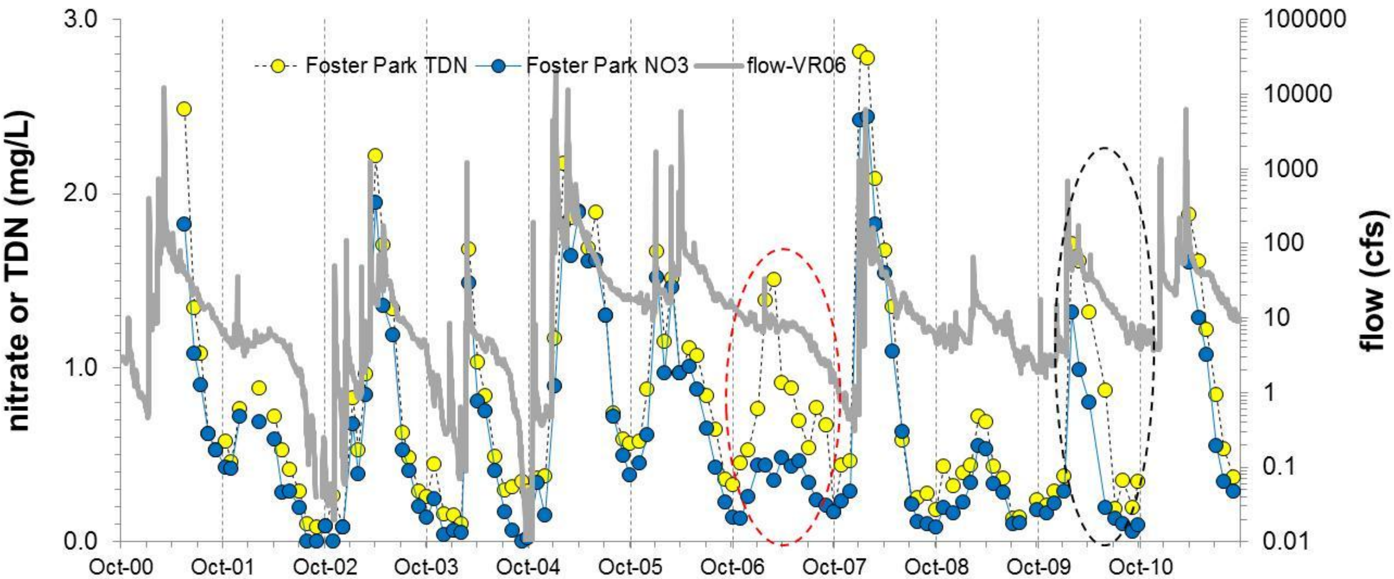


Figure 7. TDN and nitrate concentrations at Foster Park: WY2001-2011. Flow at Foster Park is also shown.

Figure 7 is a plot of both nitrate and TDN at Foster Park over the last eleven years. Note that in water-year 2010 the gap between the two is much greater than that shown for the other years (2010 data is circled in black) with but one exception, i.e., it appears that we had much more organic nitrogen during the dry-season of 2010 than in almost any other year. The exception is 2007 (circled in red) in which we had even greater concentrations of organic nitrogen. Although I've shown only Foster Park data the same statement can be made for every monitored location: higher dissolved organic nitrogen (DON) in 2007 and 2010 than in the other years. I don't know why we are seeing this at every monitored location.

Ordinarily we see higher concentrations of DON during drought years, years without a substantial winter nitrate pulse. Less available nitrate usually means greater reliance by a steam's biota on organic nitrogen – new growth being fueled by organic compounds released from dead and dying earlier growth in the relative absence of inorganic resources. But even in drought or low-rainfall years we don't usually see this happening at *every* location. Except in 2007 (a drought year, but one not as severe as 2009 or 2002). But 2010 was not a dry year (note the flow data in Figure 7), but a year with substantial rainfall and a well-defined rainy season nitrate pulse. The preceding year, 2009, was the most recent dry year but, alas, one with no noticeable increase in DON. Since the only commonality between 2007 and 2010 would seem to be a similar two year gap since the last significant algal bloom (2005 and 2008, both with major rainy season nitrate pulses) I'm at a loss for any reasonable explanation.

Phosphorus

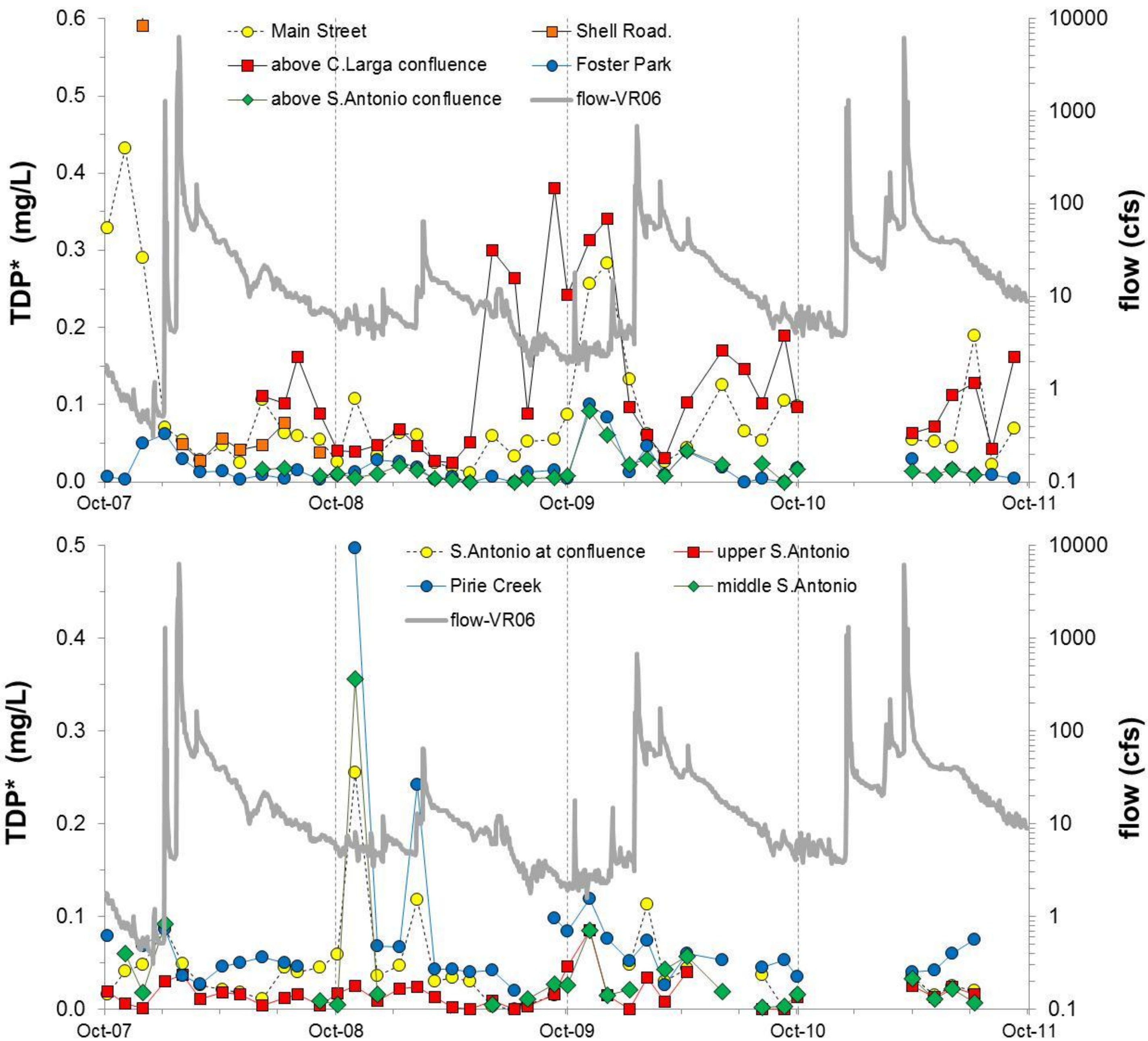


Figure 8. Monthly TDP* (total dissolved phosphorus) for water-years 2008 through 2011: the lower Ventura River (top); San Antonio Creek (bottom). Flow at Foster Park is also shown.

TDP* is total dissolved phosphorus; the asterisk indicates that I've made adjustments to the UCSB analysis results; these results are, unfortunately, often less than perfect. For some as yet undiscovered cause (and it has now been over 10 years) not all the phosphorus in some samples is captured during analysis. Without going into the various reasons (analysis of phosphate and phosphorus is a very complicated subject – and it's even more complicated to figure out what even accurate results might mean biologically) total phosphorus concentrations often exceed those of phosphate in a relatively high percentage of samples. This, of course, is impossible and thus unacceptable. Phosphate is the major constituent in total phosphorus (the difference, as with nitrogen, is considered to be organic phosphorus), but it can never be more than 100 % of any sample: one part can never be larger than the whole. In the Ventura watershed the percentage of phosphate in total dissolved phosphorus varies from around 80 % in Pirie Creek and below the WWTP, to 50 % at Foster Park and San Antonio Creek, to 35 % in the upper basin.

In order to avoid throwing out all the questionable results, whenever phosphate concentrations exceed those of total phosphorus I've simply substituted the phosphate result in place of the underestimated total phosphorus concentration (thus the asterisk). The upside is that somewhere around 30-40 % of the collected data is "saved"; the downside being a possibly serious underestimation of total phosphorus in some cases. Perhaps the way to think about it is that total phosphorus can never be less than the data shown, but may well be higher in 30-40 % of the cases. (As with nitrogen, any regulatory requirement imposed as a result of the TMDL is likely to specify total phosphorus and not phosphate, which is why I'm emphasizing TDP.)

The Ventura and its tributaries are usually high in phosphorus because of geological contributions from the surrounding watershed (blame it on easily eroded and relatively recent, seabed deposits rich in this element). A desirable concentration for total phosphorus would be below 0.01 mg/L. All Ventura monitoring locations often exceed this limit, and some sites *always* exceed it. (The standards I'm referencing are from the California Water Quality Control Board's 2006 report on the condition of coastal waters and wadeable streams: it defines good quality waters as having total nitrogen concentrations < 0.5 mg/L and total phosphorus < 0.01 mg/L, poor quality waters are defined as having concentrations of > 1.0 and > 0.1 mg/L, respectively.) The EPA has proposed a less stringent 0.03 mg/L for the Ventura area, but even our lowest total phosphorus sites (locations in the upper basin and above the S. Antonio confluence) occasionally exceed even this.

Sites below the WWTP often exceed the 0.1 mg/L upper limit (e.g., Main Street and above the C. Larga confluence in Figure 6), because human excrement – indeed all mammalian excrement, e.g., horses, cows, dogs, etc. – is rich in phosphorus. For similar reasons, in this case animal excrement, Pirie Creek, flowing out of Ojai, also has noticeably high phosphorus. The Pirie Creek contribution leads to relatively high phosphorus concentrations at all locations further downstream on San Antonio Creek (lower panel, Figure 6).

Notice in the upper panel of Figure 6 that phosphorus is at a maximum below the treatment plant when river flow is low; this holds true for all pollutants released from the plant (e.g., nitrogen in Figure 1). Low flow at Foster Park means that a majority of the water seen in the lower river consists of WWTP effluent – often more than 80 % of total flow during the latter part of drought years (note the high TDP concentrations during the Autumn of 2007; I've truncated the top of the graph to better display lower values; concentrations at Shell Road reached as high as 1.35 mg/L). Low flowing river sections below waste water treatment plants are prime candidates for other kinds of pollutant problems. Any chemical ingested by humans, or flushed by them down their toilets (e.g., caffeine, cocaine, hormonal disrupters . . . a range of chemicals that now has its own acronym – PPCPs, for *pharmaceuticals and personal care products*), will end up highly concentrated whenever the majority of flow consists of treated effluent.

The spikes in phosphorus concentration at Foster Park and above the S. Antonio confluence are usually caused by small storms flushing sediment into the river. Phosphorus is strongly attached to soil particles and stormflows usually cause peaks in concentration, but only as long as stream flow remains turbid. Because of the strong attraction between soil and phosphate, dissolved phosphorus concentrations are particularly low in groundwater. In this it is quite different than nitrogen which is quite easily dissolved. Dry-season Ventura flows above the WWTP, which consist principally of groundwater inflows, are typically much lower in phosphorus, as are those in upper San Antonio Creek.

Nitrogen and Phosphorus Together

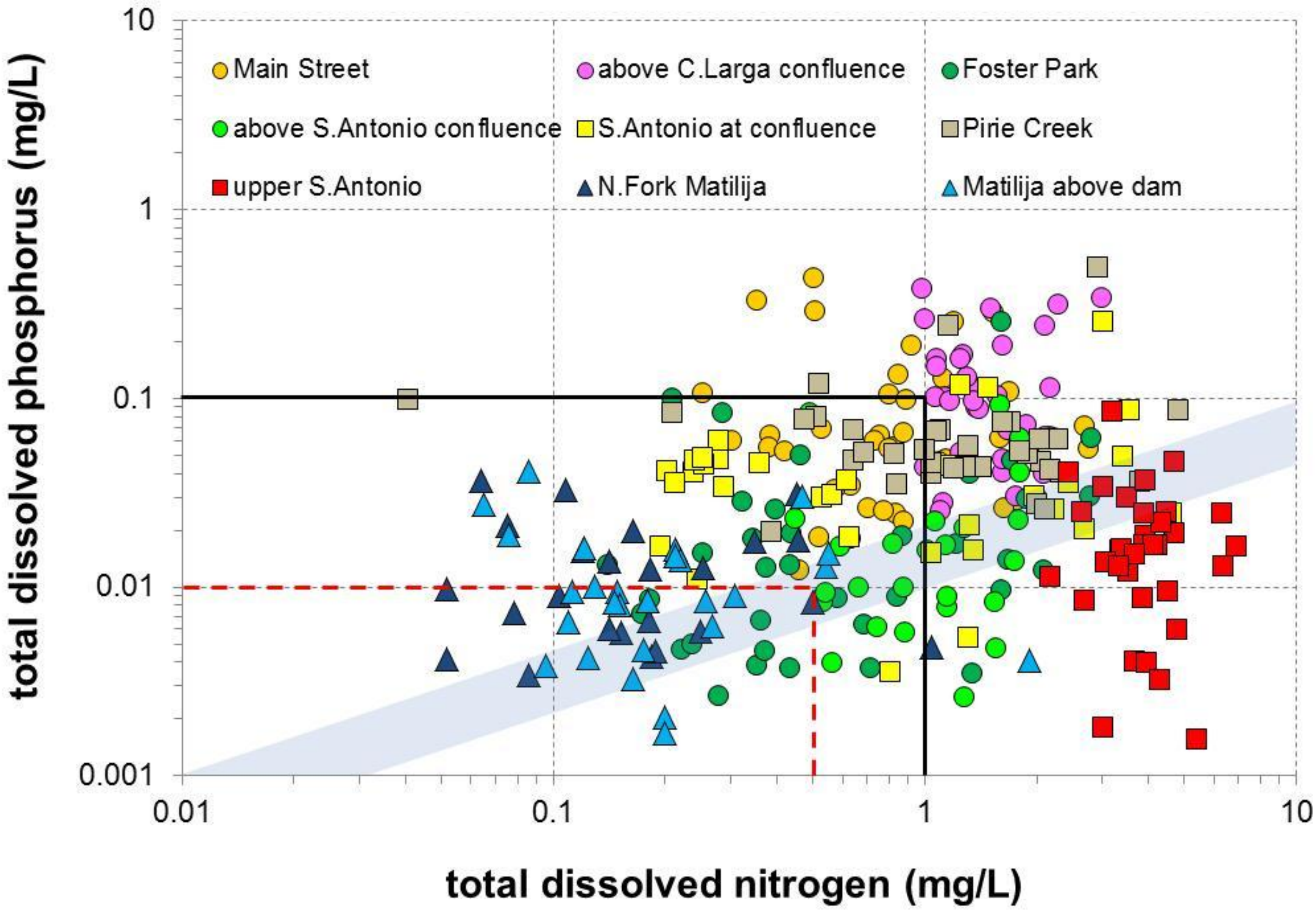


Figure 8. Monthly TDP* is plotted against monthly TDN concentrations from selected SBCK monitoring sites for water-years 2008 through 2011. The black solid and red dashed lines represent proposed California nutrient standards (good quality waters below and to the left of the dashed lime, poor quality above and to the right of the solid line).

Finally, I want to consider what conclusions might be drawn if SBCK nutrient sampling results are viewed jointly instead of separately. Figure 7 represents nutrient data plotted in N-P space: each sample's total phosphate concentration plotted against its total nitrogen result. The chart represents four years of data; I've left out a few sites: those with limited data, or those that remained dry throughout most of the period, or those with data similar to adjacent locations (a total of 5 sites out of the 14 being currently monitored were omitted).

The chart is read thusly: Any sample below the red dashed line can be considered good quality water with low phosphorus (<0.01 mg/L); any sample above the black line is poor quality water with too much phosphorus (>0.1 mg/L). Any sample to the left of the red dashed line is a good water with low nitrogen (<0.5 mg/L); any sample to the right of the black line has too much nitrogen (>1.0 mg/L). Put simply, inside the red dashed line, no nutrient problems; outside the black solid line, problems with either nitrogen or phosphorus or both. And if it lies between the two lines, consider it neither good nor bad, merely "acceptable" (but the location probably needs watching for future changes in direction).

It doesn't tell much about nutrients on the Ventura we didn't already know: (1) the relatively pristine upper basin streams are in good condition; (2) San Antonio Creek is characterized by excessive nitrogen; (3) locations below the WWTP exhibit excessive concentrations of *both* nitrogen and phosphorus, although nitrogen values are not as high here as those on San Antonio; (4) nitrogen on the middle Ventura straddles the line between acceptable and poor, while phosphorus remains low; and (5) in general, excessive nitrogen is a much larger problem than excessive phosphorus. Perhaps, above all, each sampling location exhibits a wide range of nutrient concentrations. This is not, in itself, surprising considering the wide range of conditions over the course of a year: from feast to famine. Feast being the introduction of renewed nutrients from storm runoff or groundwater recharge, famine being the long dry-season when nutrients are removed by biological uptake. Some years, the wetter ones, favor feast over famine, and some, dry years, are mostly famine.

The light blue bar across the graph represents the typical range for the ratio of nutrient utilization by stream biota: from 10 to 1 to 30 to 1. In other words, freshwater life requires both nitrogen and phosphorus, but it usually requires 10 to 30 times more nitrogen than phosphorus (this range of ratios is much broader than the more familiar 16:1 Redfield ratio that defines the nutrient requirements for oceanic phytoplankton mainly because of the increased complexity of freshwater ecosystems). Samples within or near the blue band provide the proper nutrient diet; those lying below it are deficient in phosphorus (>30:1); those above deficient in nitrogen (<10:1). Looking at it another way, phosphorus would be the limiting nutrient (P-limitation) for the continued growth of aquatic life at sampling locations lying below the band; limiting in the sense that phosphorus would run out long before the supply of nitrogen. Similarly, above the band nitrogen is limiting (N-limitation); the supply of nitrogen going to zero before phosphorus was exhausted.

With all this talk about the "limiting nutrient" comes an important caveat: other factors – such as temperature and other stream parameters, or the amount of available habitat, or sunlight, or a host of other requirements – may be far more limiting than the supply of nutrients, in which case no mismatched ratio of nutrient availability can limit growth. The stream will have more than enough nutrients to fuel whatever growth does take place, irrespective of any nutrient ratio. Perhaps then, I should term it the *potentially* limiting nutrient, *limiting if, and only if*, no other possibly limiting factor comes into play prior to running out of either nitrogen or phosphorus.

The chart shows a tendency of upper basin streams to be N-limited, and possible P-limitation on reaches of the Ventura above the WWTP. Below the WWTP concentrations of nitrogen and phosphorus are both probably too high provide any limitation at all; an exception being N-limitation at Main Street where nitrate concentrations (the most biologically labile form of nitrogen) are often driven to near zero in the late dry-season. Although upper San Antonio might appear to be highly P-limited because of very high nitrogen concentrations, it probably suffers no such restriction; the true factor limiting algal growth on much of San Antonio Creek is lack of sunlight reaching its shade-covered reaches. On the other hand, those areas open to sunlight on the middle and lower stretches may well be P-limited on occasion. These conclusions are, roughly, in line with nutrient limitation experiments conducted by UCSB in the summer of 2008: 10 of the 12 locations studied were found to be either N-limited or limited by both N and P; only Foster Park was P-limited and Shell Road, below the WWTP, was limited by neither. It should be kept in mind that N and P concentrations at most of the SBCK sampling sites vary from year to year as do the ratios between N and P. Thus a nutrient found limiting in one year may not be limiting in another.