After my Watershed U presentation, Mark Capelli send me an email that said, in part. "What we need is a comprehensive study of nutrient sources (particularly non-point)." I put off a quick reply since I thought the comment deserved more than a few lines in response. First, Channelkeeper has a proposal in the works designed to address that very question. (More on this later.) But second, we actually know – or can infer – a lot already, and I wanted to put together the evidence for this. A lot of the material presented here was originally included in the UCSB Report for the Ventura River Algal TMDL, but less simply and straightforwardly. So here is my answer to the question:

Where Do the Nitrate Come From?

Nitrogen, i.e., the total nitrogen (TN) contained within the water column, is usually the preferred parameter used with reference to algae and eutrophication, but I'm going to use nitrate. Initially for the practical reason that UCSB's TN analysis is now more than a year behind and I wanted to include the 2009 water-year in the data shown. And because nitrate, one of the components that make up total nitrogen, is the form of nitrogen most often associated with pollution. Most of the nitrogen in Ventura waters is in the form of nitrate. One way to think about the difference between total nitrogen and nitrate is the more polluted a stream – or if that's too pejorative a word, the more *enriched* the stream – the higher the percentage of nitrate; about 80 % of the total nitrogen found in the river below the Ojai wastewater treatment plant (WWTP) is in the form of nitrate; compared with only 20 % nitrate in the more pristine upper Matilija watersheds. Incidentally, the highest nitrate concentrations in the Ventura watershed are found on upper San Antonio Creek, where nitrate makes up about 90 % of the total nitrogen.

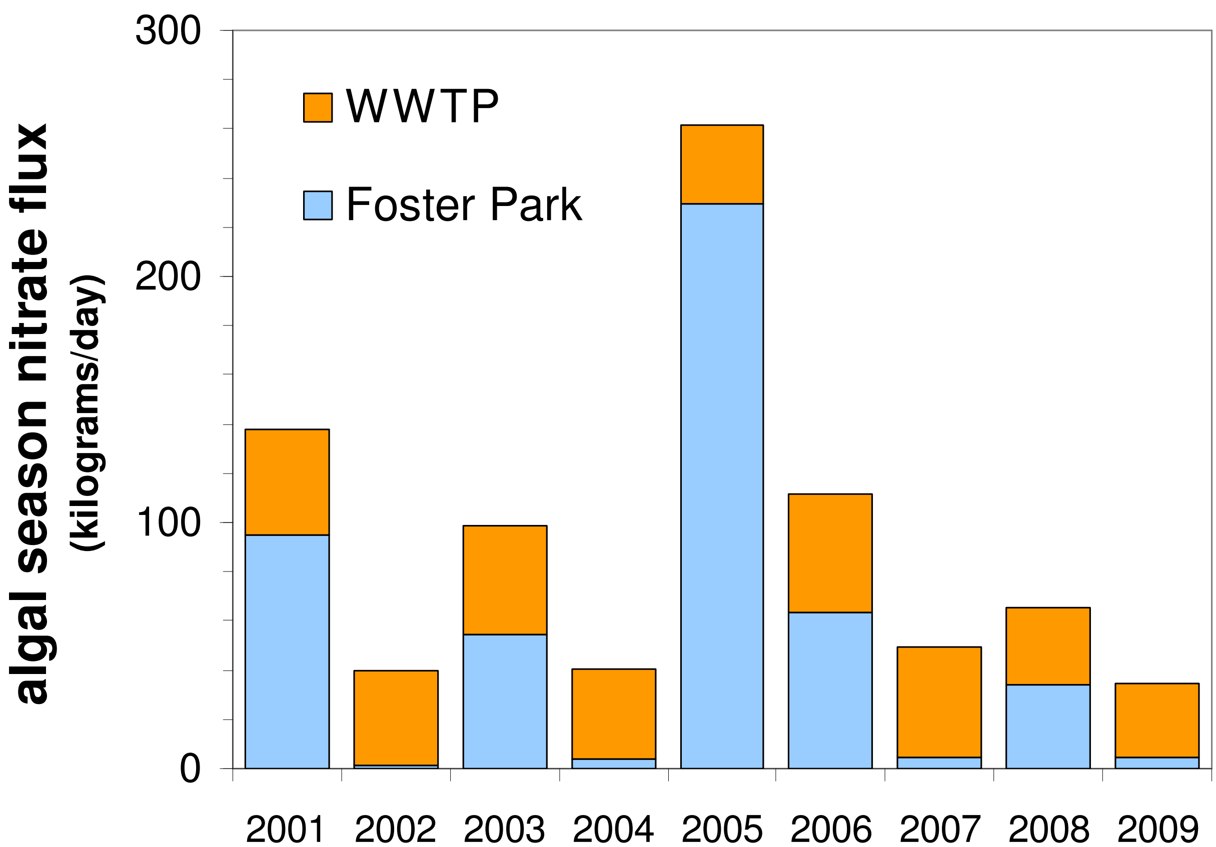


Figure 1. The average algal-season nitrate flux (in kg/day) discharged by the Ojai Wastewater Treatment Plant added to the flux measured at the Foster Park Bridge. The sum of the two represents an estimate of the available flux below the treatment plant.

Part I: What the Nitrate Flux Tells Us

All too often we tend to think of nitrate, and other elements carried along by stream flow, in terms of *concentration* – how much there in a unit volume of water, as in milligrams per liter (mg/L). Sometimes it's more important and useful to think in terms of *amount* – how much there is in total – in units like pounds or kilograms per day. *Flux* is the technical word for the amount of any constituent carried downstream by flow.

The preceding graph is the same one I used in my Watershed U presentation. It shows the flux of nitrate coming out of the Ojai Waste Water Treatment Plant (WWTP) *plus* the flux flowing past Foster Park in each of last nine growing seasons (the blue bars). I've added the two together, and we can consider the sum as an approximation of the total nitrate flux just below the WWTP.

It's not the exact value because it doesn't include nitrate removed by growing algae, plants and riparian vegetation in the river reach between Foster Park and the WWTP outfall. It also doesn't include any new sources (additions) of nitrate entering the river along that same stretch. An important point is that these fluxes are *algal season* fluxes – the amount of nitrate found in the river after winter rains are long gone and almost all seasonal tributaries have ceased flowing. In other words, considering only the algal season allows me to make the broad generalization that all the water we see in the river, and in its major tributaries, is groundwater, water seeping into the stream from various water tables in the watershed. *Except*, that is, for treated effluent coming from the WWTP.

While additional nitrate-carrying groundwater may add to algal-season flows between Foster Park and the WWTP it is, at best, a minor contributor, probably adding much less than the amount of nitrate removed. Thus I believe my assumption to be both reasonable and conservative, i.e., the sum of the Foster Park and WWTP nitrate fluxes probably overestimates the flux below the treatment plant

(My calculation of fluxes shown in the first, and subsequent graphs, also represent estimates, reasonable estimates, in my opinion, but far from exact. They are derived by multiplying monthly nitrate concentrations (measured from samples collected during Channelkeeper's monthly river monitoring program) by monthly flow (from USGS and Ventura County gauging station data), and then the estimated monthly fluxes are averaged for the months of each year's algal season. Obviously, an increased number of nitrate samples collected each month would yield more accurate results, but we have to work with what we have. That dry-season nitrate concentrations, at sites throughout the watershed, vary in a consistent month-to-month pattern, a pattern that repeats itself from year to year, helps substantiate the validity of this approach.)

I want to stress my point about groundwater. Away from the rainy season, and aside from the WWTP (and further exceptions for some rather rare and odd circumstances), all the water seen in the Ventura and its tributaries is surfacing groundwater. And it's the nitrate and nitrogen in that groundwater that fuels algal growth above the WWTP, as well as appreciable growth below the plant. Returning to Figure 1, if you look at the up-and-down pattern of the annual bars you'll see that they vary in pretty much the same fashion as annual rainfall and runoff. That's because a winter of heavy rainfall and runoff also appreciably recharges groundwater tables, and elevated groundwater levels, in turn, supply much greater flows to the river during the summer dry-season. And since the dry-season flux is flow multiplied by concentration, it will show the same annual variation as dry-season flow . . . or annual runoff . . . or annual rainfall.

Let's examine some details: in 2005, an average of 500 pounds of nitrate a day flowed past Foster Park during the dry-season (1 kg = 2.2 pounds); in 2002, the driest year of the past decade, the average daily flux was only slightly more than 2 pounds. That's a difference of 250-times. Think of it as 250-times the fertilizer flowing downstream. More nitrogen, more growth . . . more algae and more aquatic plants. And all this nitrogen is the reason why riparian trees grow so well along the Ventura River.

In contrast with the highly varying amount of nitrate flowing past Foster Park, the WWTP contributes a steady 80-90 pounds per day. In dry years pretty much the all the nitrogen below the treatment plant comes from the WWTP, but in wet years – the years with lots of algae – the treatment plant's contribution is much less important. Much more of the available nitrogen comes from upstream; in other words, from upstream groundwater nitrate.

Elsewhere in the watershed we see the same blue-bar pattern shown for Foster Park, even in the wilderness branches of the Matilija. The quantities are much less (1 pound per day in 2005 on the North Fork vs. less than an ounce in 2002), but the pattern remains the same. The reasons are straight-forward.

First consider relatively pristine sites, such as the upper Matilija. Our air contains appreciable amounts of nitrogen pollution (in the form of various oxides) which fall out as particulates or get deposited on branches and leaves and such. Winter rains eventually flush these deposits into streams. The key word is *eventually*. A dry winter leaves them sitting on top of or within the soil, and even a moderate winter may leave 'em transported only part way to water. But a big winter moves whatever nitrogen was deposited during the previous dry-season, along with whatever remains behind from earlier years, all the way to the ocean – and recharges the water-table with lots of nitrogen in the process. It turns out that there is a lot of nitrogen just sitting around, especially after a dry winter.

Further down the watershed, agriculture, humans and domestic animals make more impressive nitrogen contributions, but these contributions make their way into streams and groundwater tables in exactly the same fashion. So they exhibit exactly the same pattern. The only difference being that concentrations and fluxes increase appreciably – perhaps even drastically – the further down the watershed we go.

Keeping in mind that during low-rainfall years almost all the nitrate seen below the WWTP comes from the plant itself, and in big-rainfall years from groundwater seepage in the watershed above, let's examine the fate of that nitrate.

My next graph shows the annual average, algal-season, daily flux below the WWTP (in ochre, or whatever that color is) and the average algal-season daily flux at Main Street (bright green).

Again, these are dry-season fluxes and do not represent complete water-year values, and the individual bars are not, as in my first graph, additive (e.g., the average dry-season flux below the WWTP in 2001 was 138 kg/day but only 86 kg/day showed up at Main Street).

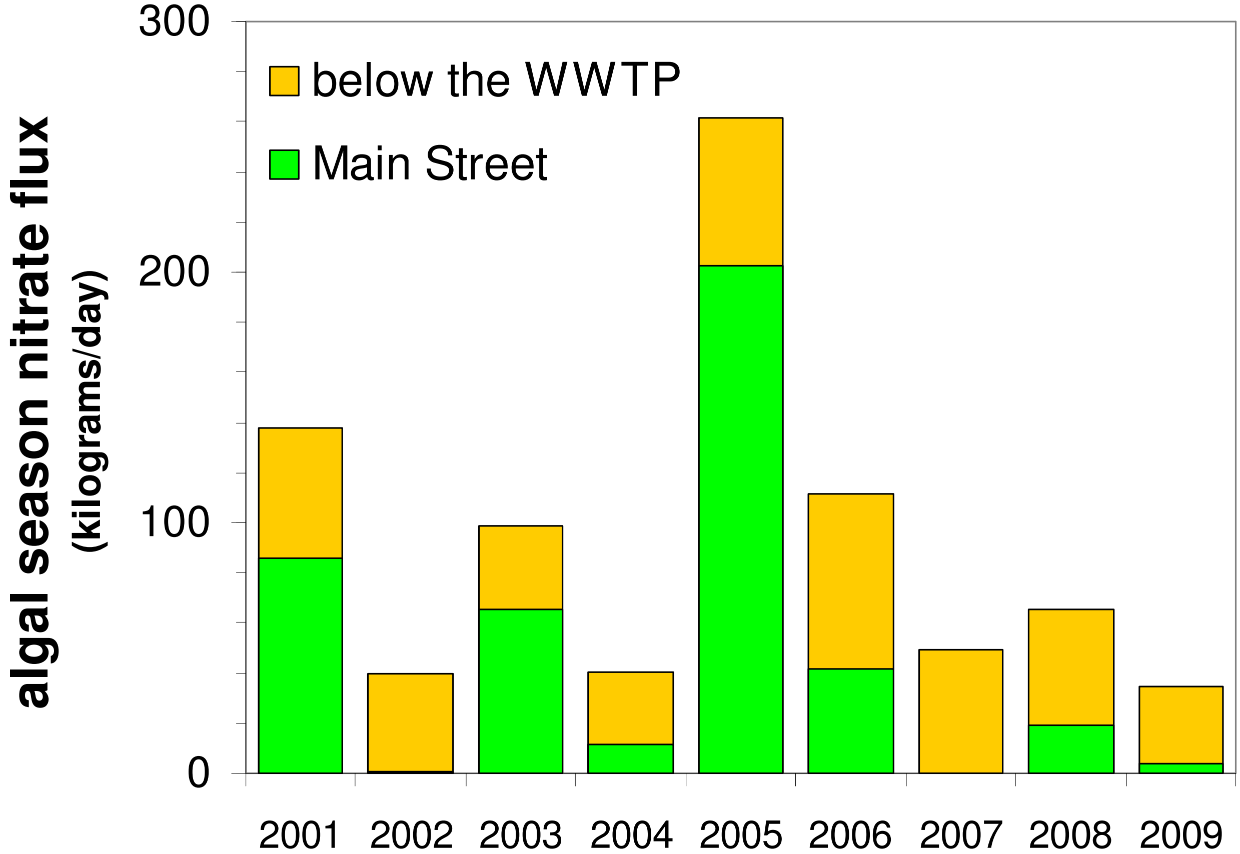


Figure 2. The average algal-season nitrate flux (in kg/day) just downstream of the WWTP (estimated from the Foster Park + WWTP fluxes) and at the Main Street Bridge. The ochre portion extending above the bright green represents the amount of nitrate removed from the river by biological processes (assimilated) between the WWTP and Main Street during each of the dry-seasons shown.

Thus the difference between these fluxes (represented by the amount of ochre showing above the green) is the average amount of nitrate removed or absorbed by the river – mainly taken-up, or assimilated, by its aquatic plants, algae and riparian vegetation. (Bacteria also play a role by converting nitrate to nitrous oxide or nitrogen, gasses subsequently released to the atmosphere. However, since denitrification occurs mostly in oxygen-depleted bottom muds, it's likely to be more important in aquatic plant dominated, drier years like 2002.)

Notice that in very dry years, like 2002 and 2007, nitrate disappears by the time flow past the WWTP reaches Main Street, and not very much is left in more ordinary drier years such as 2004 and 2009. Only in wet years, like 2001, 2003 and 2008, is appreciable nitrate flushed into the lagoon and coastal ocean. And, of course, in a real big year like 2005 a large majority of the available nitrate is swept out to sea. The river, especially the lower river, has a great capacity to assimilate nitrate (or nitrogen). This capacity is only exceeded during the dry-seasons of wet-years, years with above normal rainfall.

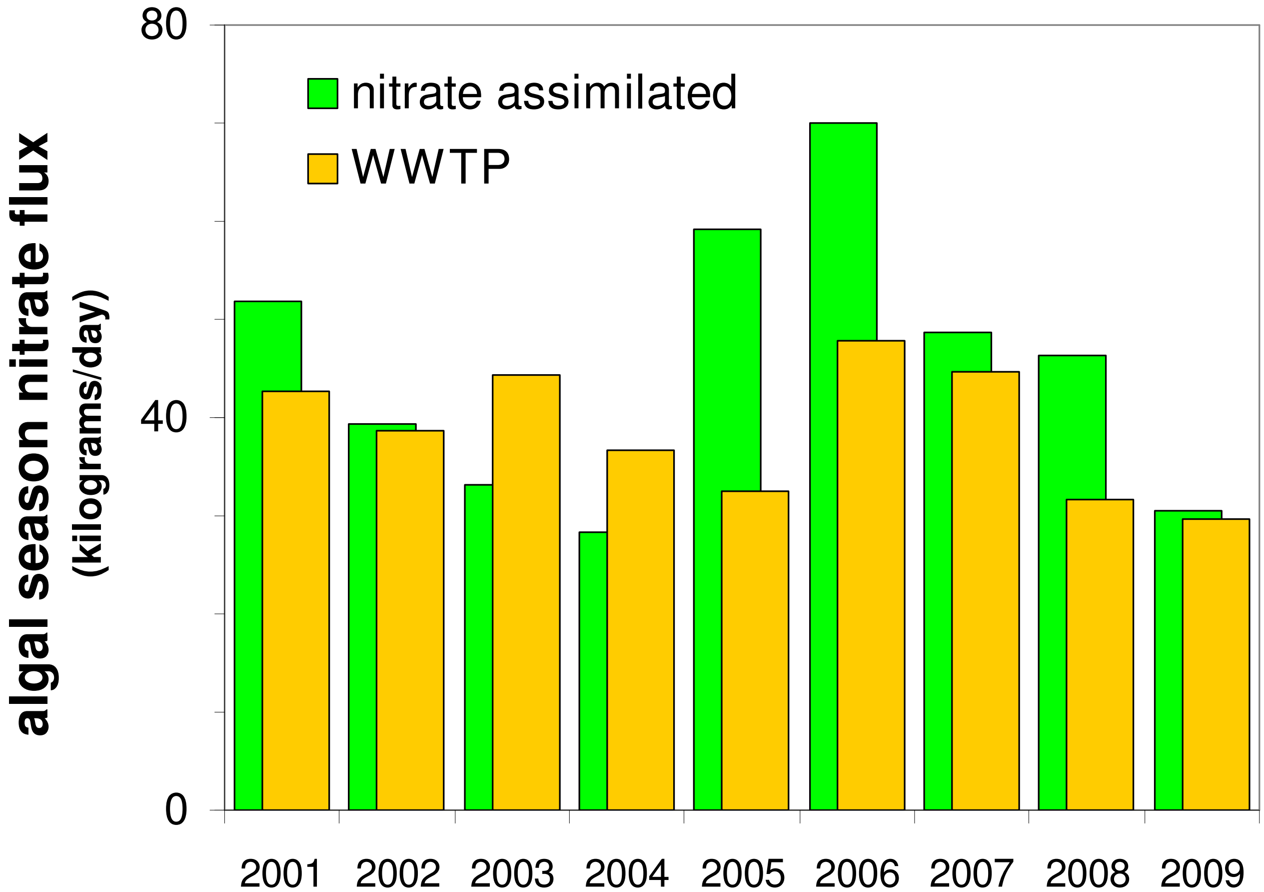


Figure 3. The average algal-season nitrate flux (in kg/day) assimilated in the reach between the WWTP and Main Street (bright green). For comparison, the average daily nitrate flux out of the WWTP is also shown.

The above figure shows just what the river's capacity to assimilate nitrate below the WWTP has been. It's interesting that, in spite vast differences in year-to-year biological character and flow, there are only small differences in assimilation: from a high of 70 mg/d in 2006, to a low of 29 mg/d in 2004, just slightly greater than a two-fold difference. While we can't know for sure, we can make some reasonable assumptions as to why this might be. The greater flows and increased nitrate fluxes of wetter years mean more aquatic habitat for assimilation, but it also means increased current speeds, i.e., increased water velocities providing less opportunity for plants and algae to grab nutrients. Conversely, much lower flows and water velocities give the greatly reduced habitat of drier years more of an opportunity. Bluntly stated, less available habitat but much more time for assimilation in dry years, more habitat but less time in wet. It also appears that assimilation is somewhat increased in algal years – that algae are a little more efficient at removing nitrate than aquatic plants.

If I were making a case for the Ojai Valley Sanitary District (OVSD), I might point to this graph as evidence that the river's capacity to assimilate nitrate below the treatment plant almost always exceeds WWTP output, and that any excessive nitrate problem on the lower river comes from.

above. But of course nitrate is completely fungible – plants and algae don't distinguish between nitrate from different sources. Whatever the source there is simply too much nitrate on the lower river, as can be easily seen each and every summer. A waterway choked with algae, or with aquatic plants, is an over-fertilized and over-productive waterway.

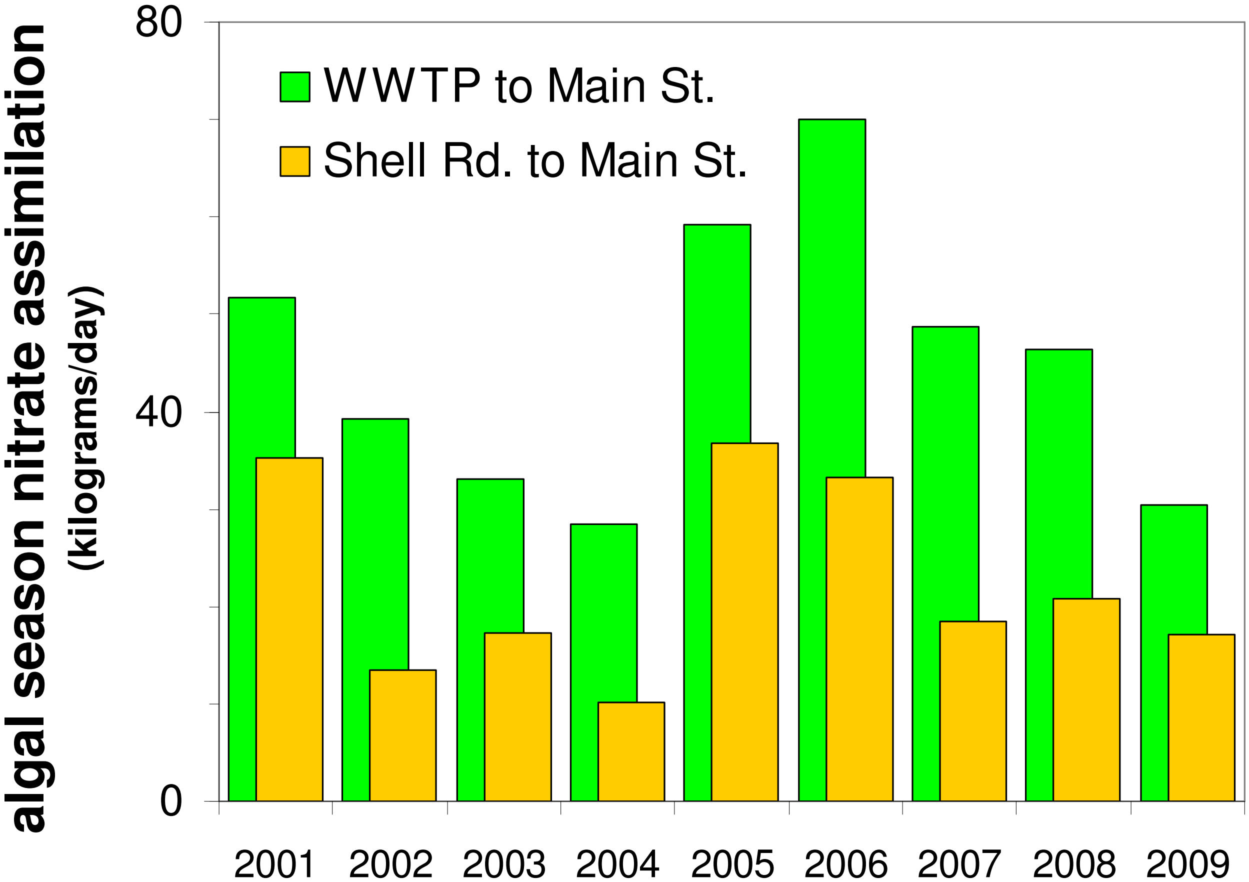


Figure 4. The average algal-season nitrate assimilation (in kg/day) measured in the reach between the WWTP and Main Street (bright green) compared with assimilation between Shell Road and Main Street. By assimilation I mean the amount of the average daily nitrate flux that "disappears" due to biological uptake between the given end-points.

I've made certain assumptions in getting to this point and Figure 4 offers an indirect way of checking their validity. The graph shows the amount of the daily nitrate flux assimilated between the WWTP and Main Street (as in Figure 3) along with the decrease in daily flux between Shell Road and Main Street. The flux at Shell Road has been independently measured (using monthly Channelkeeper nitrate concentrations and measured flows). It's 4.2 km from Main Street to Shell Road, and a further 3 km to the WWTP outfall. If we assume that assimilation along the lower river is more-or-less constant, assimilation below Shell Road should be roughly half the total assimilation below the WWTP (4.2/7.2 or 58 % would be a more exact figure). And that is just about what the graph shows. Inconsistencies can be blamed on different rates of assimilation in different reaches and in different years, along with whatever assimilation (also variable from year-to-year) takes place with the Foster Park flux between the further 1.6 km that separates that location and the WWTP. However two differences between estimates of the assimilated nitrate flux shown in are Figure 4 are noteworthy: first, the below Shell Road estimates indicate that the greatest amount of assimilation took place in 2005, not 2006; second, the Shell Road values unequivocally show that nitrate assimilation was greater in algal years than in years dominated by aquatic plants.

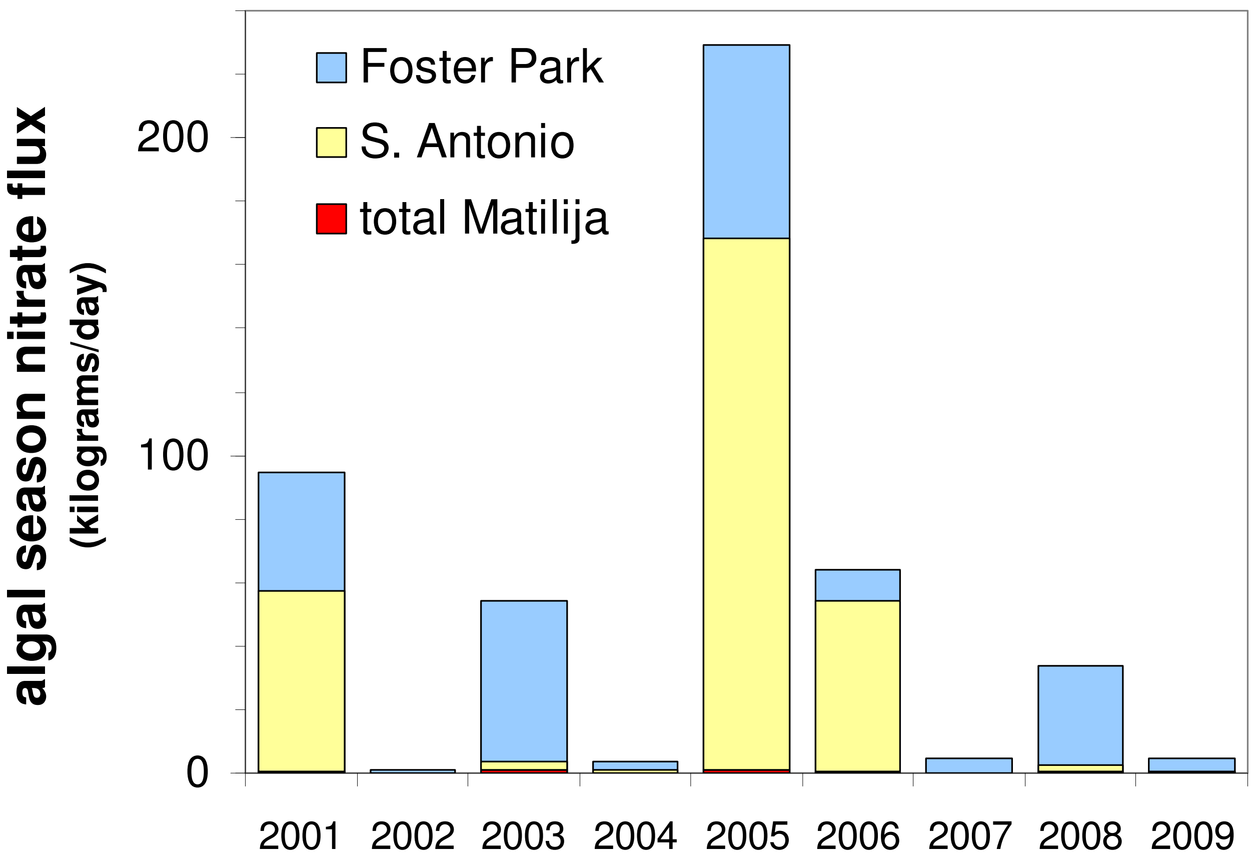


Figure 5. The average daily algal-season nitrate flux at Foster Park (in kg/day) compared with the **sum** of the average daily fluxes from upper Matilija (Matilija and N.F. Matilija) and San Antonio creeks. The "blue" portion of each bar showing above the "yellow" represents the nitrate flux from groundwater seepage into the river in the reach between the mouth of Matilija Canyon and Foster Park

Now we come to the crux of the matter: what is producing the very high nitrate flux we see at Foster Park? Figure 5 shows the sum of the daily algal-season, upper Matilija and San Antonio nitrate fluxes superimposed on the daily Foster Park flux. The graph can be interpreted this way: red represents the nitrate contribution from the upper watershed (Matilija and N.F. Matilija creeks, and the upper Ventura River); yellow represents the nitrate entering the Ventura River from San Antonio Creek; and blue represents the nitrate from groundwater inputs in the reach that extends from below the mouth of Matilija Canyon to Foster Park. Since much of this stretch of the middle Ventura is a *losing* reach (i.e., far more water is lost via downward seepage through the porous river bottom than is gained by groundwater infiltration into the river) and is, more often than not, bone-dry from the canyon mouth to below the Santa Ana Bridge, most of this groundwater enters the Ventura lower down. The flux from this region is, in reality, greater than the graph indicates since subtracting the San Antonio flux from the Foster Park flux (which is what the graph visually does) ignores nitrate assimilation occurring above Foster Park. In other words, were we able to account for assimilation, the "red" and "yellow" portions of the graph would be reduced and the amount of "blue" Foster Park flux exposed above them would be noticeably greater. We can make an educated guess that the actual groundwater nitrate contribution from the middle Ventura is about twice that shown: the amount of nitrate assimilated being arguably similar to that occurring below the WWTP (the distances involved are roughly equivalent: 3.4 km from Foster Park to the San Antonio confluence, 2.5 km from the confluence to the Santa Ana Bridge, and a further 3.2 km from Santa Ana to the Hwy. 150 Bridge).

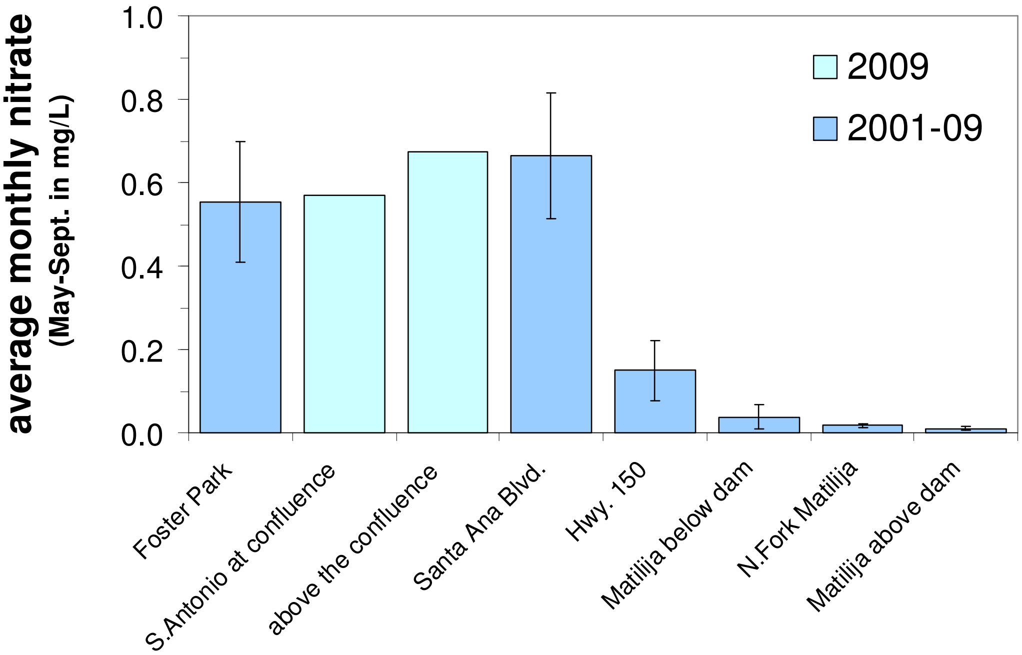


Figure 6. Average dry-season nitrate concentrations from the upper Matilija tributaries downstream to Foster Park (from right to left). Where available, monthly Channelkeeper data from 2001-2009 were used to calculate the mean dry-season annual average (error bars indicate the standard error of the mean); for locations recently added to the Channelkeeper sampling program only 2009 data were available.

Other data substantiate this assertion of very high nitrate contributions from this region. Figure 6 presents a compelling picture of how nitrate concentrations (from dry-season groundwater sources) abruptly begin to increase after the Ventura exits from its upper canyon. Groundwater nitrate concentrations from well water samples collected between 1932 and 2008, as shown in Figure 7 (my thanks to Nadine Martins for the figure) offer more direct evidence. Red circles indicate

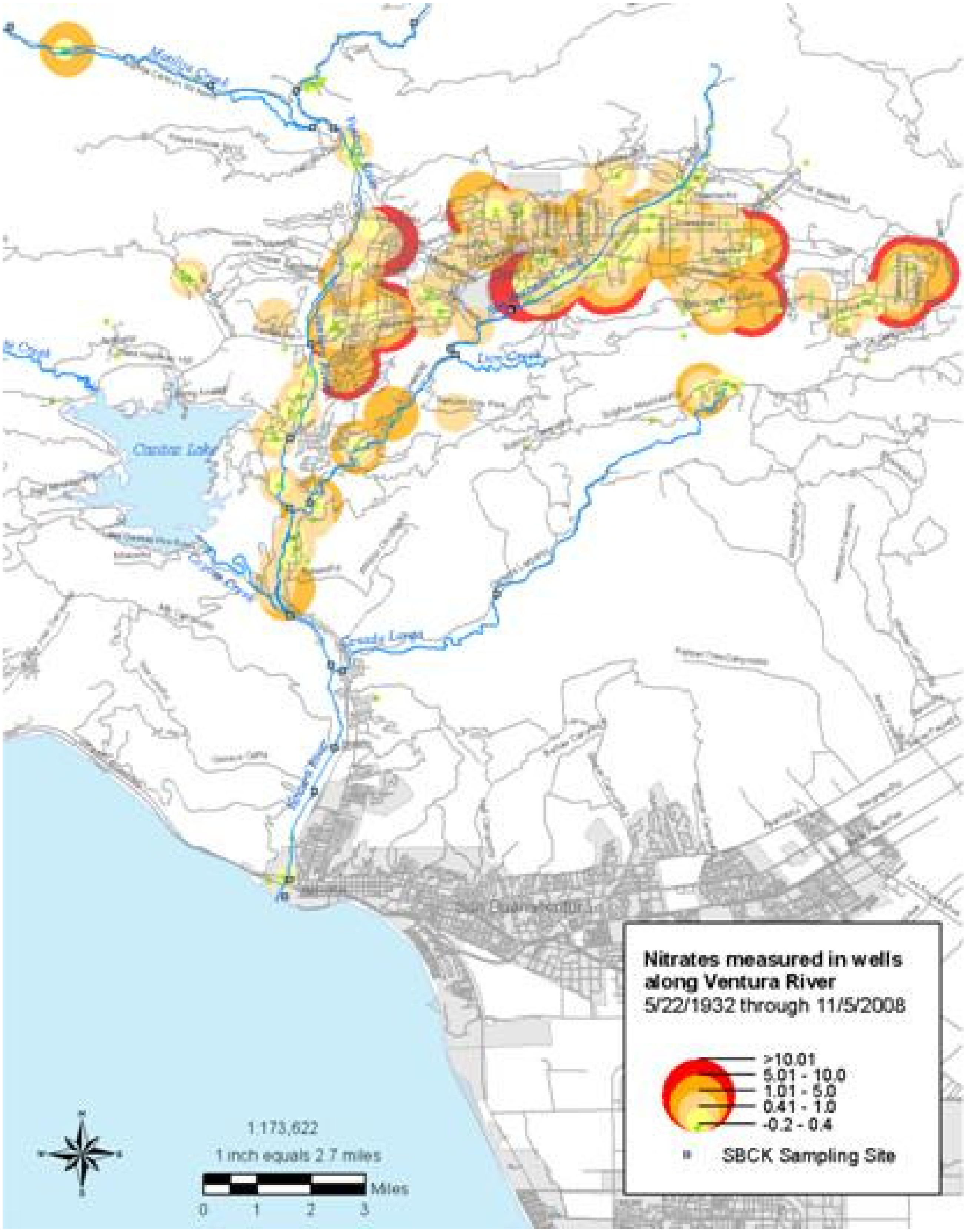


Figure 7. Nitrate concentrations (mg/L) in Ventura watershed wells: 1932-2008 (Ventura County Water Protection District data). Note that the highest concentrations are concentrated in areas tributary to the middle reaches of the Ventura River and upper San Antonio Creek. (Map created by Nadine Martins, 6/3/2009.)

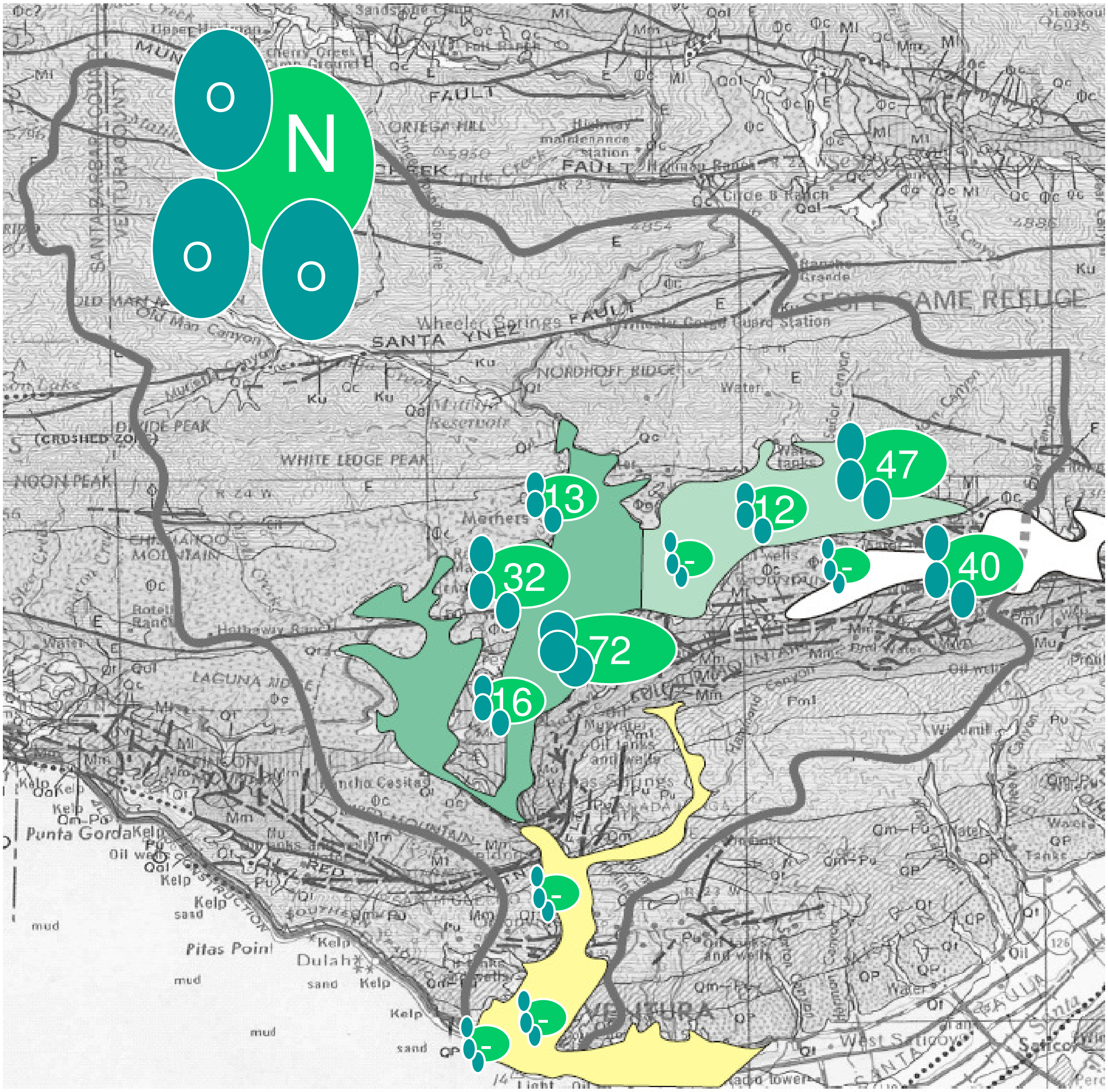


Figure 8. This is a copy of a slide used by Jordan Kear of Daniel B. Stephens & Assoc. during his May 6th presentation at the Ventura Watershed U lectures (used here with permission). It shows nitrate concentrations (in mg/L) from a variety of catchment wells during 2009. It presents essentially the same picture as Nadine's graphic (Figure 7): extremely high nitrate concentrations in the groundwater basin through which the middle reaches of the Ventura River (above Foster Park) run, and in the groundwaters of eastern Ojai tributary to upper San Antonio Creek.

concentrations greater than 10 mg/L (the Public Health drinking water limit) and circles of dark-orange mark concentrations of 5-10 mg/L; wells with episodic results this high are concentrated in locations tributary to precisely these reaches exhibiting nitrate problems. Figure 8, taken from a slide presented by Jordan Kear at one of the recent Watershed U lectures, shows well water nitrate concentrations for 2009; some of these results, with concentrations far above the 10 mg/L limit, can only be termed astounding.

The photos above, taken this year (we're looking upstream from the Highway 150 Bridge), demonstrate what results from this excessive nitrate infiltration. The left-hand photo (from April 14th) shows the river near the height of the 2010 algal bloom; the right-hand photo, taken a month later (May 19th), shows dying algae being left high and dry as seepage from this losing reach decreases flows to a trickle.

Very little, if any, of the nitrate fueling this bloom comes from the upper watershed. As figures 5 and 6 indicate, the nitrate flux and nitrate concentration coming from the Matilija forks and the upper Ventura are both negligible. And the drying up of the reach below the canyon, as shown in the photo (in drier years there is never any algal-season flow between Highway 150 and Santa Ana Blvd.), means that very little, if any, water from above ever exerts an influence on algal growth below. Although the availability of nitrate in the upper watershed varies appreciably from year to year (something we'll touch on later), and has interesting consequences on local algal growth, it is of no practical concern for growth on the river below.

We can similarly parse out what's happening on San Antonio Creek. Although there are no consistently reliable flow data for the various tributaries that make up San Antonio Creek,

Figure 9. These photos, taken just above the San Antonio confluence on the same dates (April 14 above, May 19, 2009 below) show algal conditions further down. The red arrow marks the same feature in both photos. Although flow in May is noticeably less than that shown in the April photo, it is still substantial, i.e., the surfacing groundwater supplying this flow is occurring below the, by now, dry conditions at the Highway 150 Bridge.

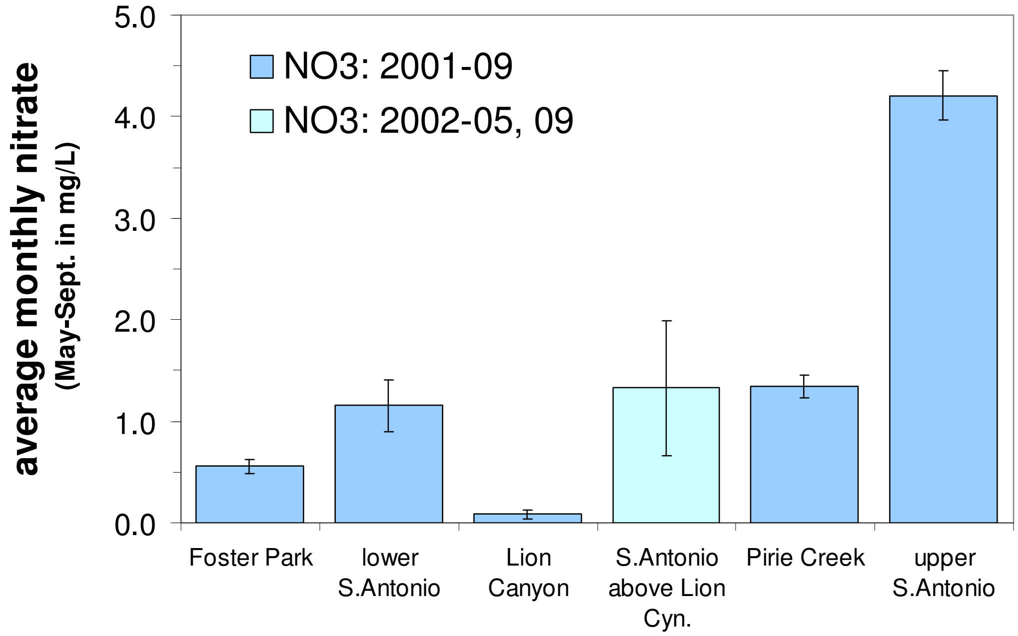
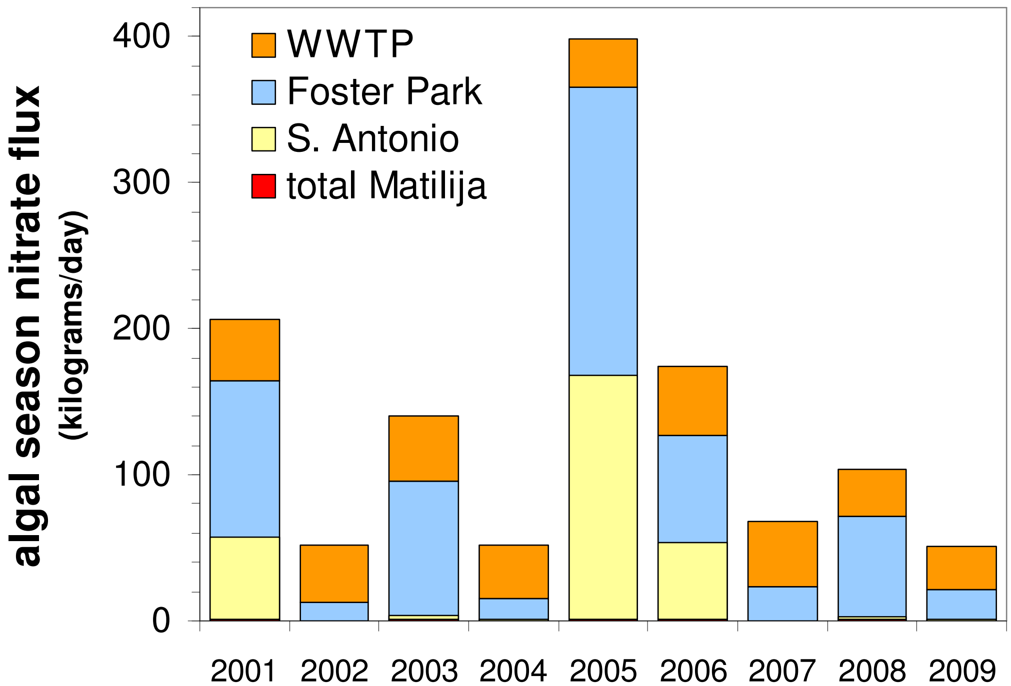


Figure 10. Average dry-season nitrate concentrations for San Antonio Creek and its major tributaries: sites are arranged moving downstream from right to left. Monthly Channelkeeper data from 2001-2009 were used to calculate the mean dry-season annual average for all locations except for San Antonio Creek just above the Lion Canyon confluence (error bars indicate the standard error of the mean).

Channelkeeper does monitor nutrient concentration at a number of locations (shown in Figure 10). As the graphic indicates, the dominant nitrogen source lies in the watershed of upper San Antonio Creek. Pirie Creek (so named in my *Thomas Guide*, but I've heard others refer to it as "Ojai Creek"), measured just before its confluence with San Antonio, has much lower nitrate concentrations (but still excessive from an ecological standpoint: California and the USGS would probably define a "good quality" stream as having less than 0.5 mg/L of total nitrogen, and anything over 1.0 mg/L as too high). Although Channelkeeper flow measurements for these two sampling points have not been consistent enough to reliably calculate seasonal fluxes, dry-season flow in upper San Antonio Creek is usually 3-times that of Pirie. Since nitrate concentrations in upper San Antonio are also approximately 3-times those of Pirie, we can estimate that 90 % of the flux in the upper sections of the combined creek originate in the upper San Antonio watershed (3 x 3 = 9-times the amount of nitrate)

By the time flow reaches Lion Canyon (3 km downstream) the combined nitrate concentrations are appreciably reduced by biological assimilation. During the dry months Lion Creek contributes very little nitrate and can be disregarded as a source (during the Summer, Lion Creek slows to a trickle, and an extremely effective algal population reduces nitrate concentrations to near zero). Interestingly, Figure 10 shows that nitrate concentrations on lower San Antonio Creek are roughly the same as those at the Lion Canyon confluence. Since appreciable biological assimilation takes place in the 6.3 km separating these two sampling locations, there has to be considerable amounts of new nitrate entering along this stretch. Luckily for the Ventura River, lower San Antonio Creek almost always goes nearly or totally dry prior to the confluence. This often happens early in the dry-season. As Figure 5 indicates, nitrate fluxes from San Antonio play an important role only in wetter years, years like 2001, 2005 and 2006. However, a seasonal accounting disguises the important contribution that high nitrate fluxes from San Antonio can play in the early months (March, April and into May) of the annual algal bloom.



Finally, I want to sum up Part I with this graph. It shows the magnitude of the various nitrate fluxes originating in different parts of the watershed, and how they vary from dry-season to dry-season: from the minuscule contributions of the upper watershed (barely visible in red); to those from San Antonio, important mainly in wet years (but probably playing an important role in the first month or two at the beginning of every algal season); to surfacing, high-nitrate groundwater from the middle Ventura above Foster Park (blue); to a relatively steady WWTP contribution, the major source of lower river nitrate in drier years.

(This is a modification of Figure 5: I've added the WWTP flux and modified the Foster Park flux, increasing it with an estimate of the amount of nitrate lost by assimilation in the reaches above – as mentioned previously. I estimated assimilation by applying the % decrease in nitrate flux per km below the WWTP to the distance between Foster Park and the San Antonio confluence for each year, and added the total loss, thus calculated, to the Foster Park fluxes shown earlier. Where there was a difference between the % flux loss below the WWTP, as calculated by the two methods shown in Figure 4, I used the lower value. The figure does not show the flux at any particular point on the river, but, rather, the various contributions from different regions of the watershed. The label "Foster Park" might be better stated as "groundwater inputs to the Ventura River above Foster Park.")