More than you ever wanted to know about Algae in the Ventura River

or

How I learned to stop worrying about Afghanistan, imbecilic politicians and my love life by visiting the same crummy locations month after month and year after year for more than a decade.

This is tale about algae, and why and when it grows in the streams, creeks and river that convey water to the ocean in what is called the Ventura watershed.

Algae are aquatic unicellular or *multicellular* plant-like organisms containing chlorophyll; *plant-like* since they lack the specialized roots, stems, leaves and complicated sex organs that characterize plants.

Algae need:

Water – and the warmer the water the faster they grow

Sunlight – for photosynthesis so they can utilize carbon dioxide as food

Nutrients – mostly nitrogen in the Ventura watershed, but phosphorus too

What are algae? Well, algae are hard to define, hard to classify and even harder to identify. Above is as good a definition as I could come up with. Recall that old cliché: "I don't know anything about art, but I know what I like"; we might as easily say most people know almost nothing about algae, but they usually know it when they see it. It's green, and it doesn't quite look like a plant. And lots of people don't like any non-plant green stuff growing in their water. For some reason they seem to prefer the color blue. Algae is a lot like art in that sense too.

To grow and prosper algae need water – they're aquatic organisms. No water, no algae. They need sunlight – algal cells contain chlorophyll which enables 'em to photosynthesize, a big word meaning using sunlight to convert carbon dioxide into cellular material. In simple terms, they utilize carbon dioxide the same way we utilize food. No sunlight, no algae. And, like us, like all living things, they also need a host of minor ingredients to go along with the carbon, the most important of which are nitrogen (for building proteins) and phosphorus (for energy transformations within cells). No nitrogen and phosphorus, no algae.

Here I'm going to talk about ***multicellular*** or ***macro*** algae – algae you have no trouble seeing with the naked eye. There are also lots of ***unicellular*** or ***micro*** algae out there, but we'll leave that discussion for another occasion. Micro-algae cause no problems in any Ventura freshwater stream.

Algae grow everywhere there is water and sunlight: from the most polluted stream in this area (Franklin Creek in Carpenteria on the left) to the most pristine (e.g., the wilderness headwaters of Matilija Creek on the right). Perhaps in the past – before the Twentieth Century – algae were not found in remote untouched locations like the upper Matilija, because one of the essential nutrients, nitrogen, would have been in short supply. But no longer.

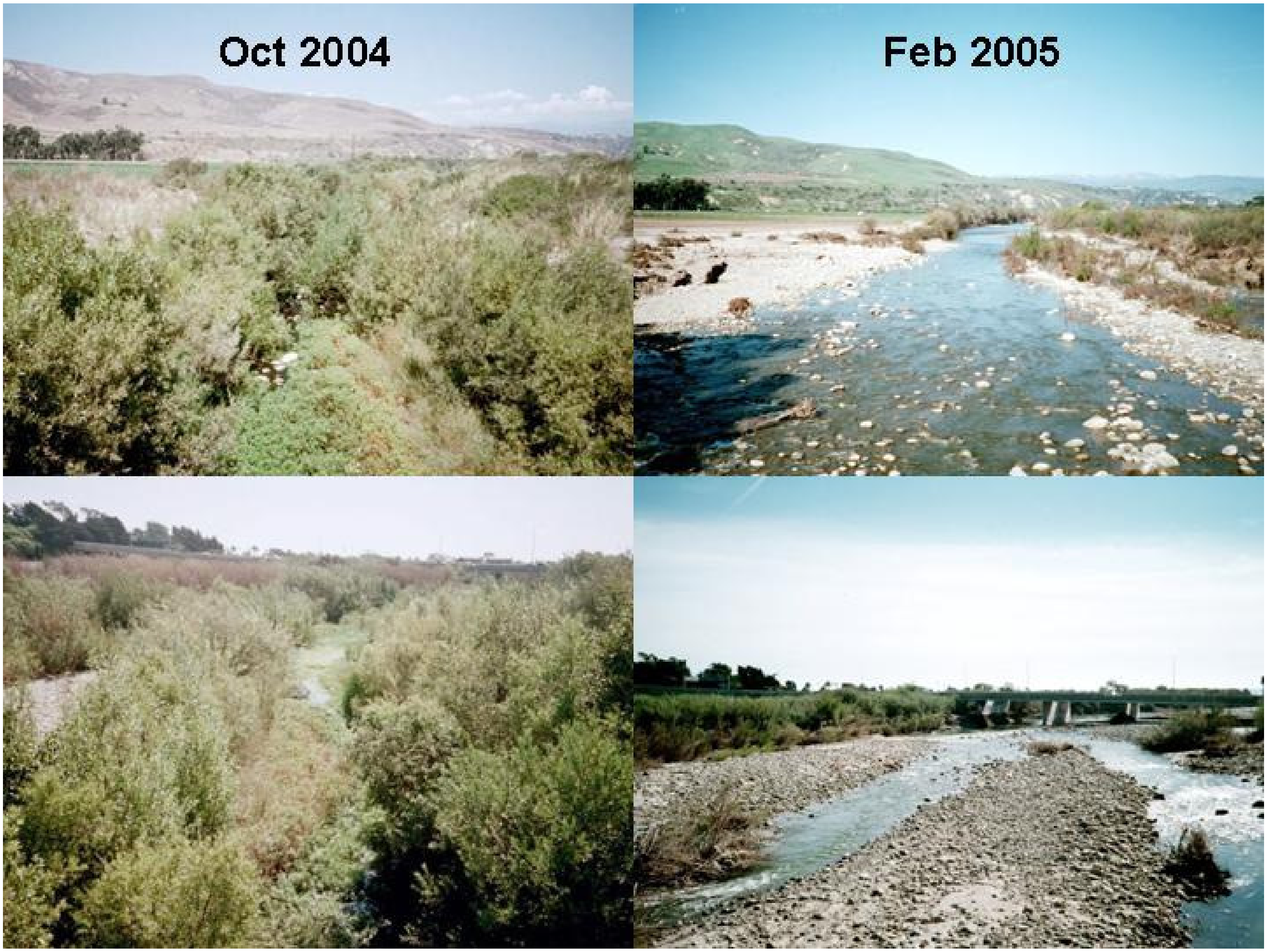
One of the secrets of humanity's success is that we've tripled the supply of fixed nitrogen available on the planet. Without which, we would never be able to feed the nearly seven billions of us now alive. One consequence has been a drastic increase – at least six-fold – in the amount of nitrogen deposited by air pollution everywhere in California. So nothing that still looks "pristine" is actually pristine. As for the other necessary major nutrient, phosphorus, we have a plentiful natural supply since the relatively recent, piled-up, seabed deposits we call our local mountains are rich in this element.

Algae can be found everywhere in the Ventura watershed (in 2008 at Foster Park, on the left, and in Matilija Creek – just below the Wilderness Area – on the right). The photos show the same kind of algae – called *Cladophora* – growing in both locations, but there can be great differences in the ***amount*** of algae found growing. Different amounts of algae grow in different locations; and different amounts of algae grow in different years.

And there are differences in what ***kinds*** of algae grow in different locations and at different times. Not all algae are equal. The type, or species, of algae present often makes as much of a difference as does the density, or the pounds of algae per square foot, growing in a stream. We might even grow to think that some species add beauty . . . or maybe not.

The photo on the right shows a dense mat of *Cladophora* growing in Franklin Creek (Carpenteria), a stream polluted by very high nitrate discharges from industrial agriculture (nitrate concentrations circa 40 mg/L); on the left is *Mougeotia* growing in the near-pristine Ventura River headwaters.

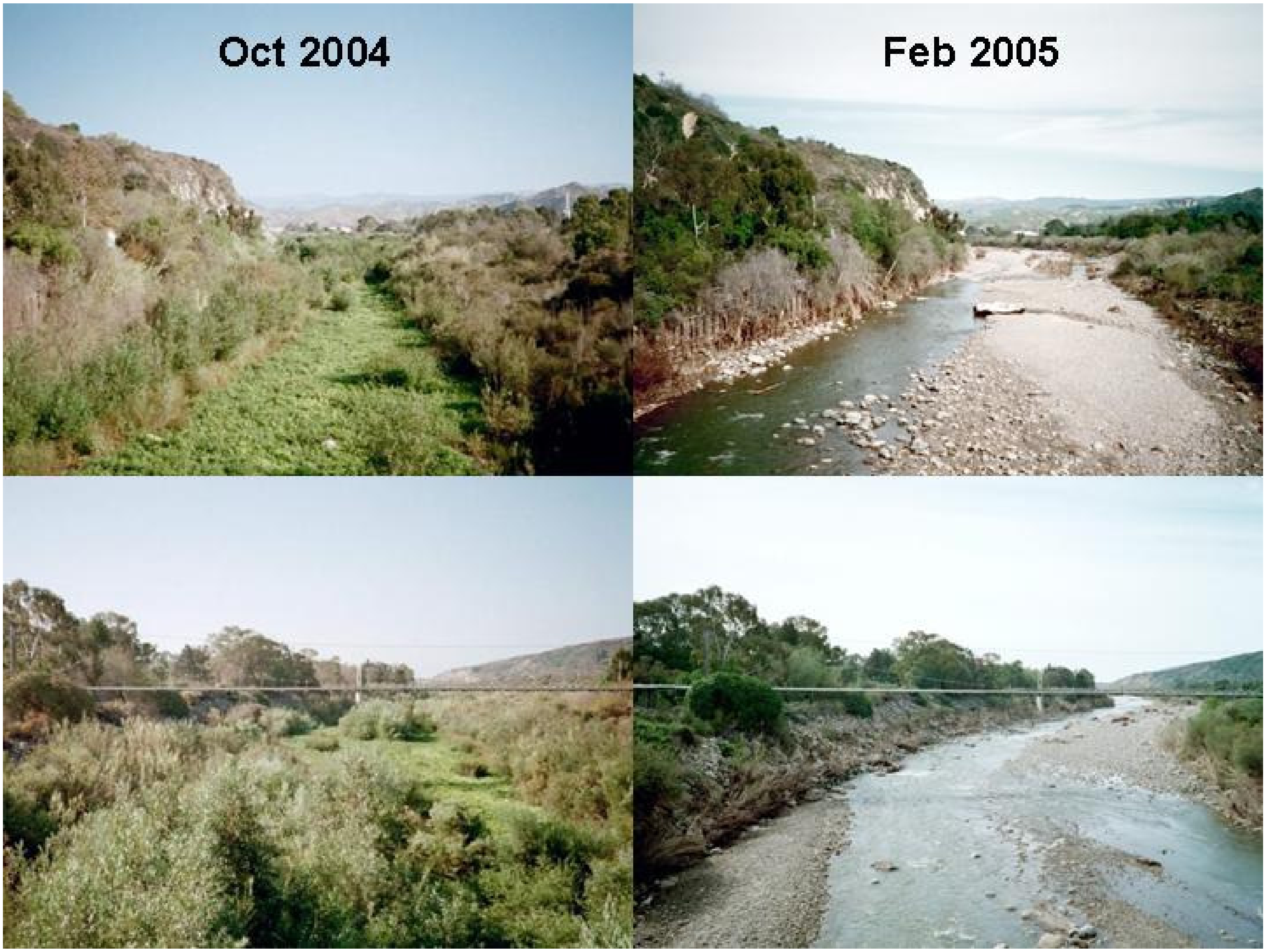
Different algae prefer different conditions. Some like a rocky bottom to hold on to, and a fast current; some like it quiet and still; some need lots of nutrients while others can thrive on a meager nutrient diet; some like it warm and others pretty much don't care. (I use the term *species* loosely, algae are usually so hard to classify that identification usually stops at *genus*.)



We see different kinds and amounts of algae because, from year to year, the Ventura River and its tributaries never look the same. The change can sometimes be quite dramatic as these photos show. It all comes down to the amount of winter rainfall; rainfall determines not only how things look, but how much algae will be growing. Because along with changes in appearance go changes in the conditions for algal growth.

The photos on the left show how things looked late in 2004, both upstream (top) and down (bottom) from the Main Street Bridge. The photos on the right show the same locations after a very wet December and January . . . and some very big storms. A "big" winter, one with lots of rainfall and big storms, produces open water and a stream bed scoured of sediment, plants and riparian trees – perfect conditions for subsequent algal growth, especially for algae that like to attach themselves to a rocky bottom as our most common type does (*Cladophora*).

And algae ***did*** dominate these open waters during the following dry-season. However, as years pass without a significant big storm, aquatic plants and riparian trees like those shown in the 2004 photos again become the major ecological players in and along the waterway – and algae become relatively hard to find.

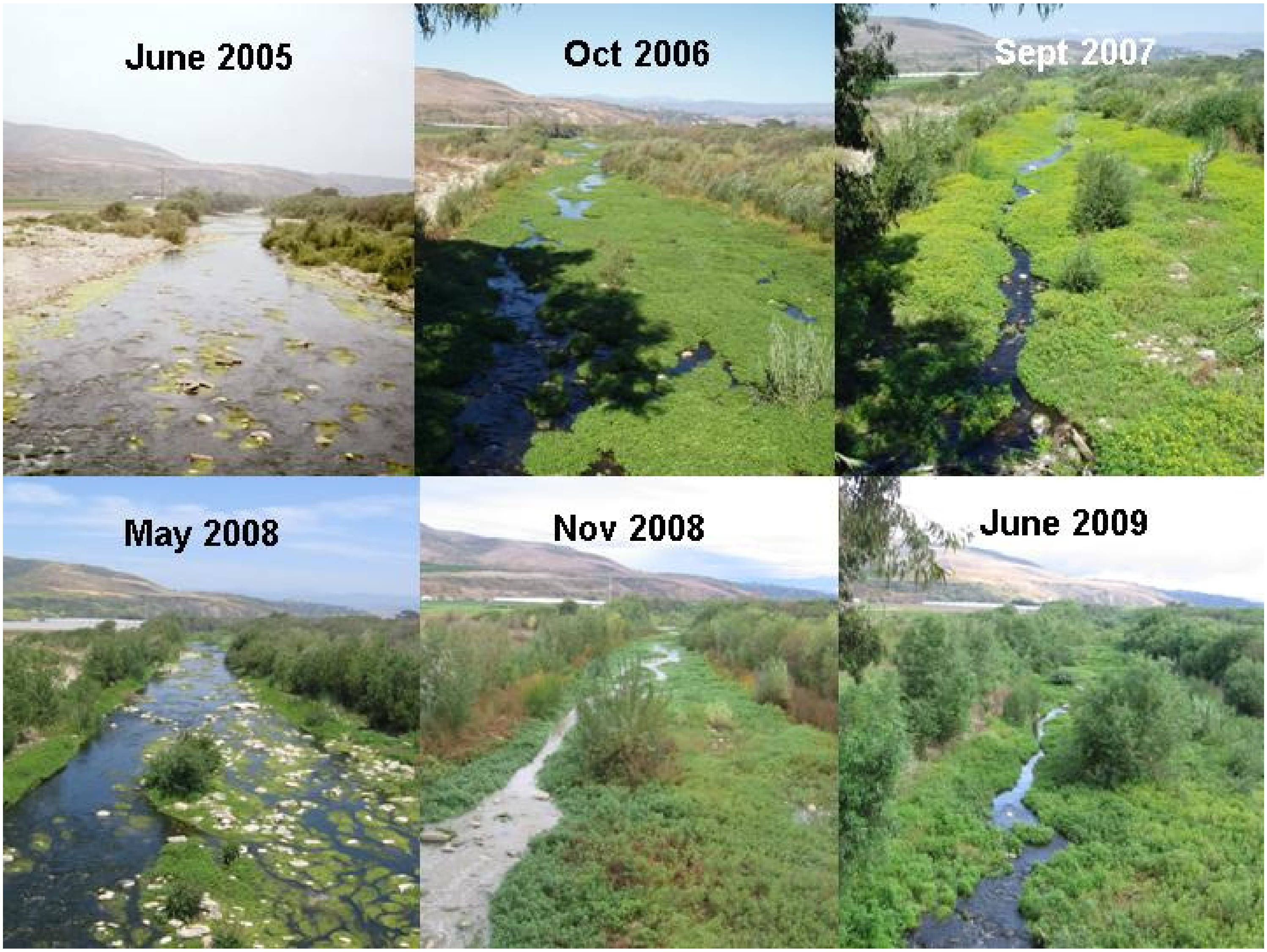


This is the same 2004/2005 change a little higher up on the river: as seen upstream (top) and down (bottom) from Shell Bridge. The photos on the left show conditions in 2004 . . . and a few months later in early 2005. Notice the size of the trees that were removed during the 2005 storms. And that all aquatic plants were removed, along with the sediment those plants and trees were growing in, creating near-perfect conditions for algae such as *Cladophora* which like to cling to rocks.

Lots of water, lots of sunlight, lots of rock and gravel, warming weather, no riparian trees shading the waterway . . . and no competition from aquatic plants . . . if there is an algal heaven this is what it probably looks like.

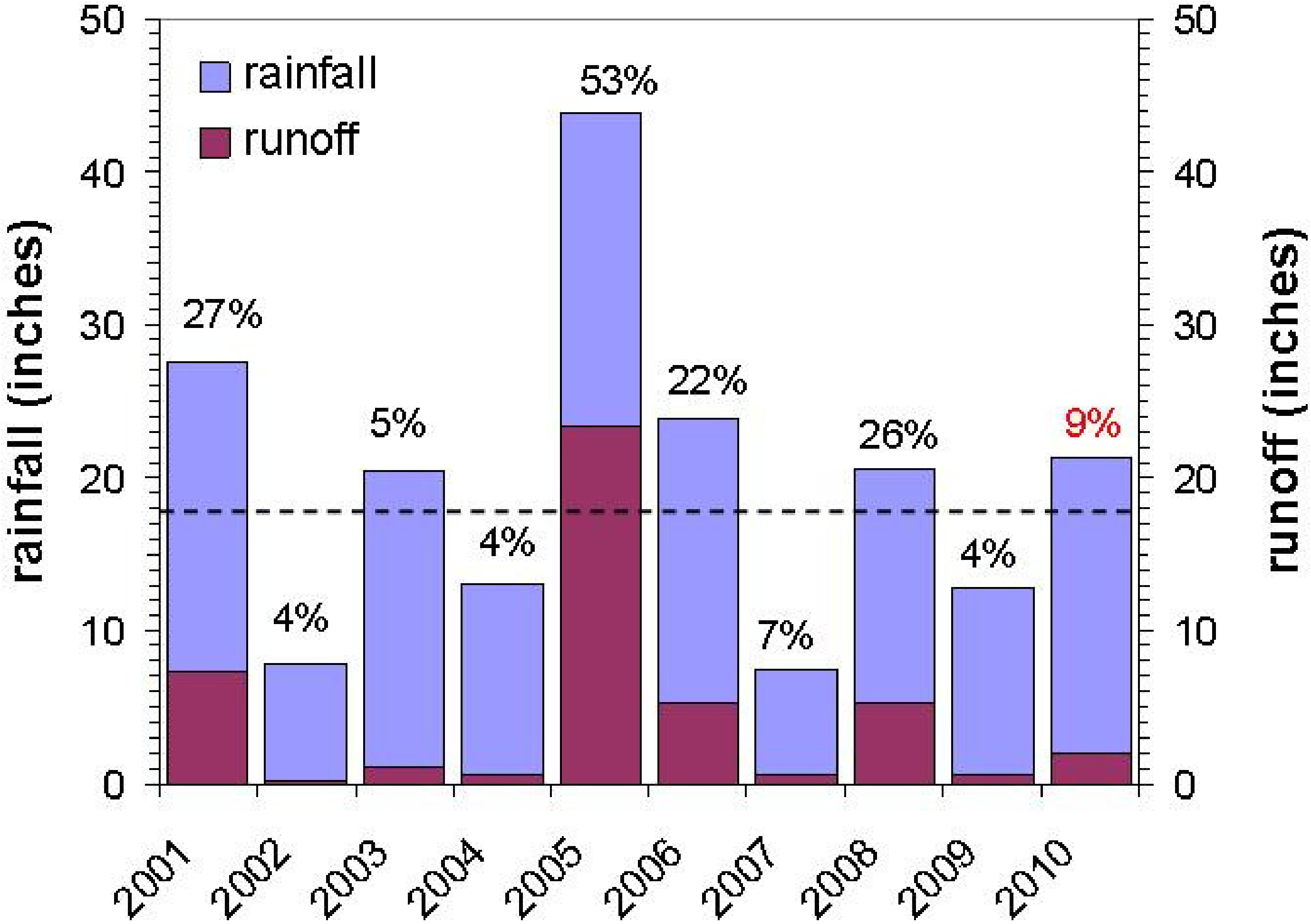
Change doesn't only occur because of one big rainfall winter; the more gradual modifications that take place from year to year, or even within a singe year can be almost as dramatic . . . and consequential. In the photos we are again looking upstream from the Shell Road Bridge (I've included the annual runoff/annual rainfall amounts, in inches, for each year in **bold face** type): from left to right, on top: July 2001 (algal growth following a wet winter; **7.4/27.6**); Aug. 2002 (aquatic plants dominate during a dry year; **0.3/7.8**); March 2003 (an open algal environment following a large storm; **1.1/20.4**); on the bottom: Oct. 2003 (aquatic plants succeeding algae by year's end); Sept. 2004 (aquatic plant dominance at the end of another dry year; **0.6/13.1**); May 2005 (a ***real*** big year clears the riverbed and algae return; **23.3/43.8**).

The photos document changes caused by wet-winter/dry-winter rainfall differences on the lower Ventura River: large storms = algal dominance; the absence of large storms = dominance by aquatic plants. Think of it as either, ***a lot of rain, a lot of algae***; or ***not much rain, not much algae but lots of aquatic plants***. And a winter with a moderate rainfall and a moderately large storm results in algae at the beginning of the dry-season being replaced by aquatic plants during the latter months. And these kinds of changes, although perhaps not as dramatically as shown here, occur throughout the watershed.



Let's bring things forward up to the present by going back to the Main Street Bridge; we are again looking upstream. The photos show the changes that took place from June 2005 through June 2009 (**bold face** numbers again give the amount of annual runoff/annual rainfall, in inches, for that year – to lend a sense of how much difference runoff amount makes in the river's appearance . . . and ecology): on top, left to right: June 2005 (algal takeoff after the big winter; **23.3/43.8**); Oct. 2006 (aquatic plant dominance by the fall of a moderately wet year – thanks to the wettest April on record; **5.2/23.9**); Sept. 2007 (aquatic plant dominate throughout a dry year; **0.6/7.4**); on the bottom: May 2008 (algae again dominate following a wet winter; **5.3/20.6**); Nov. 2008 (but aquatic plants are dominant by fall); June 2009 (aquatic plant dominance throughout another dry year; **0.6/12.6**).

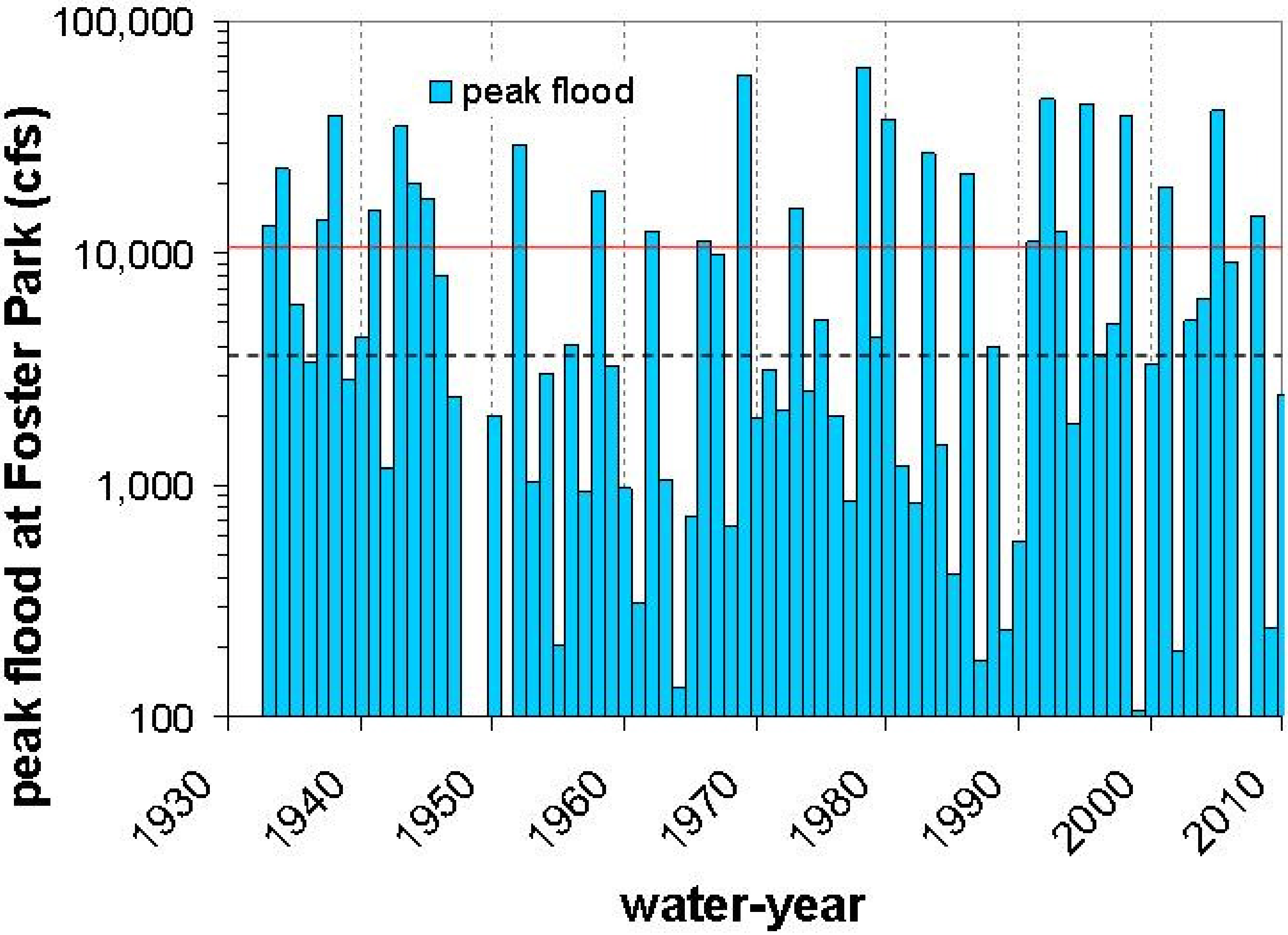
Again, as a reminder, ***a clock-cleaning winter = algal dominance throughout the dry-season*****;** ***a moderately wet winter with moderately large storms = algal dominance in the beginning, but aquatic plants by the end of the season*****;** ***the absence of large storms = dominance by aquatic plants***.



Since runoff is the key to how the river looks and functions let's consider the relationship between runoff and rainfall. The connection between rainfall and flow (runoff) – i.e., the more rain, the more runoff – may be obvious, but it's not linear. Watersheds both store (mainly as groundwater and soil moisture) and utilize (via plant uptake and evaporation) rainfall. Most rainfall does not end up in the stream or the river; only the biggest years have lots of runoff, low rainfall years have almost none.

The graph shows the difference between annual rainfall and total annual flow (runoff) as measured at the USGS gauging station on the Ventura River (Foster Park, between Ventura and Ojai). The percentages shown above each bar indicate the percent of rainfall that ended up as streamflow that year. The dashed line marks the median annual rainfall for the watershed (18 inches, as measured at Ojai): years with less than the median rainfall have very little flow and only the biggest years (e.g., 2005) have lots. And not all years with similar rainfall have similar runoff – details matter. Lots of small storms produce much less flow than a single big gully-washer. I've added 2010 to the graph by estimating what I think the remainder of this year will look like – it will probably look a lot like 2003.

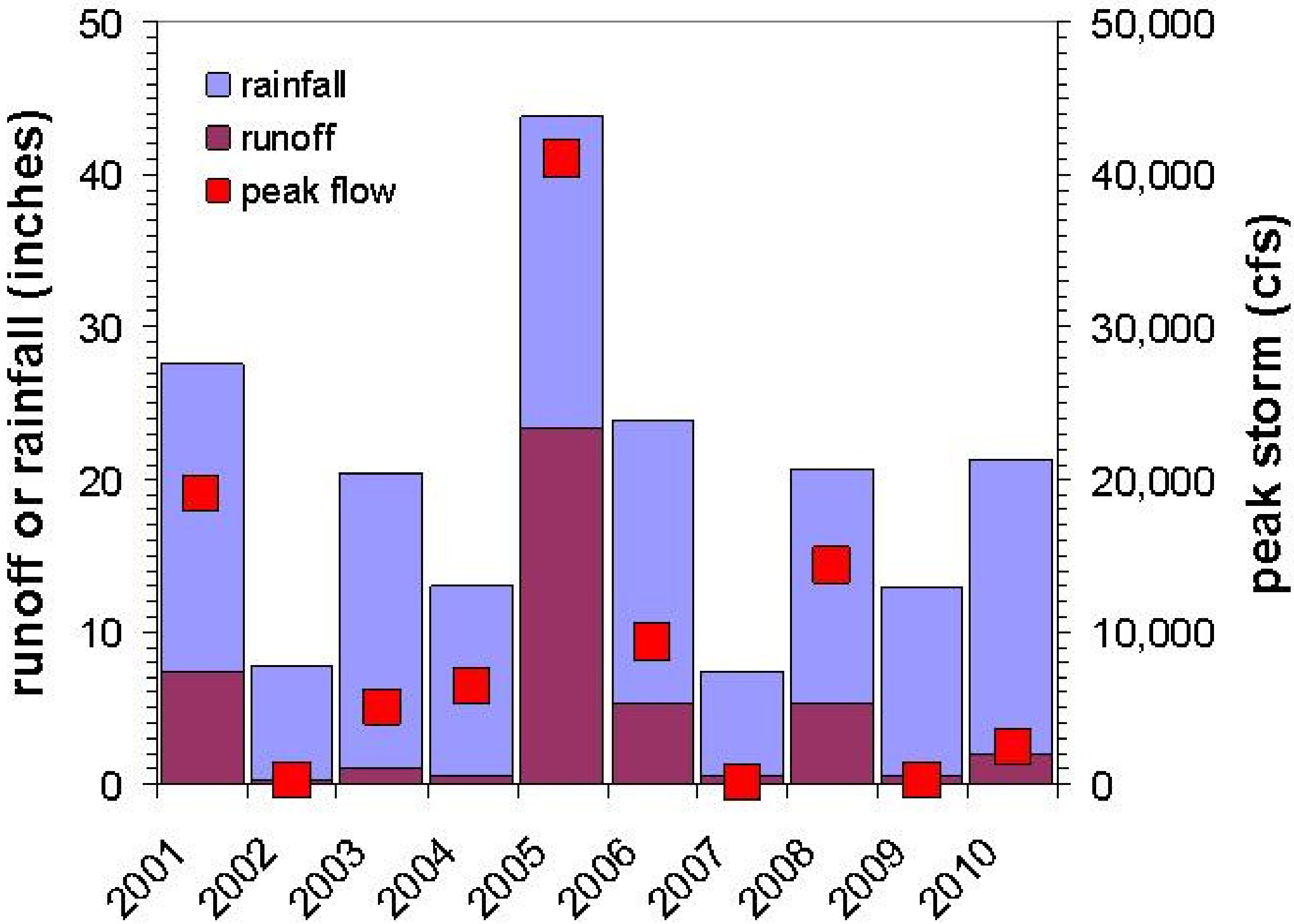
Oh yes, one more thing, the years shown in the this graph and all of the following graphs, are water-years. The water-year begins on October 1 and ends on September 30, e.g., water-year 2010 began on Oct. 1, 2009 and will end this September. Hydrologists think celebrating New Year's Day on January 1 was a really bad idea.



The amount of annual rainfall is important, but so too is the size of the biggest storm of the year and ***size*** of the flood it produces. The graph shows annual peak flows, i.e., the biggest flood of each year, as measured at Foster Park by the USGS. The peak annual flood determines how much modification and transformation takes place in the river channel. Or whether or not any modification takes place at all.

There are two lines drawn on the graph, the dashed black line marks the median annual flood; it's roughly 3,000 cfs – half the years since 1941 have had floods less than this, half the years had floods greater; the red line marks the average annual flood, around 10,000 cfs. So during most years (roughly 2 out of every 3) the big flood is not very big, it's a lot less than average. Big storms, like those of January 2005, are important because they completely transform the stream channel and its ecology. Thus affecting, well . . . everything.

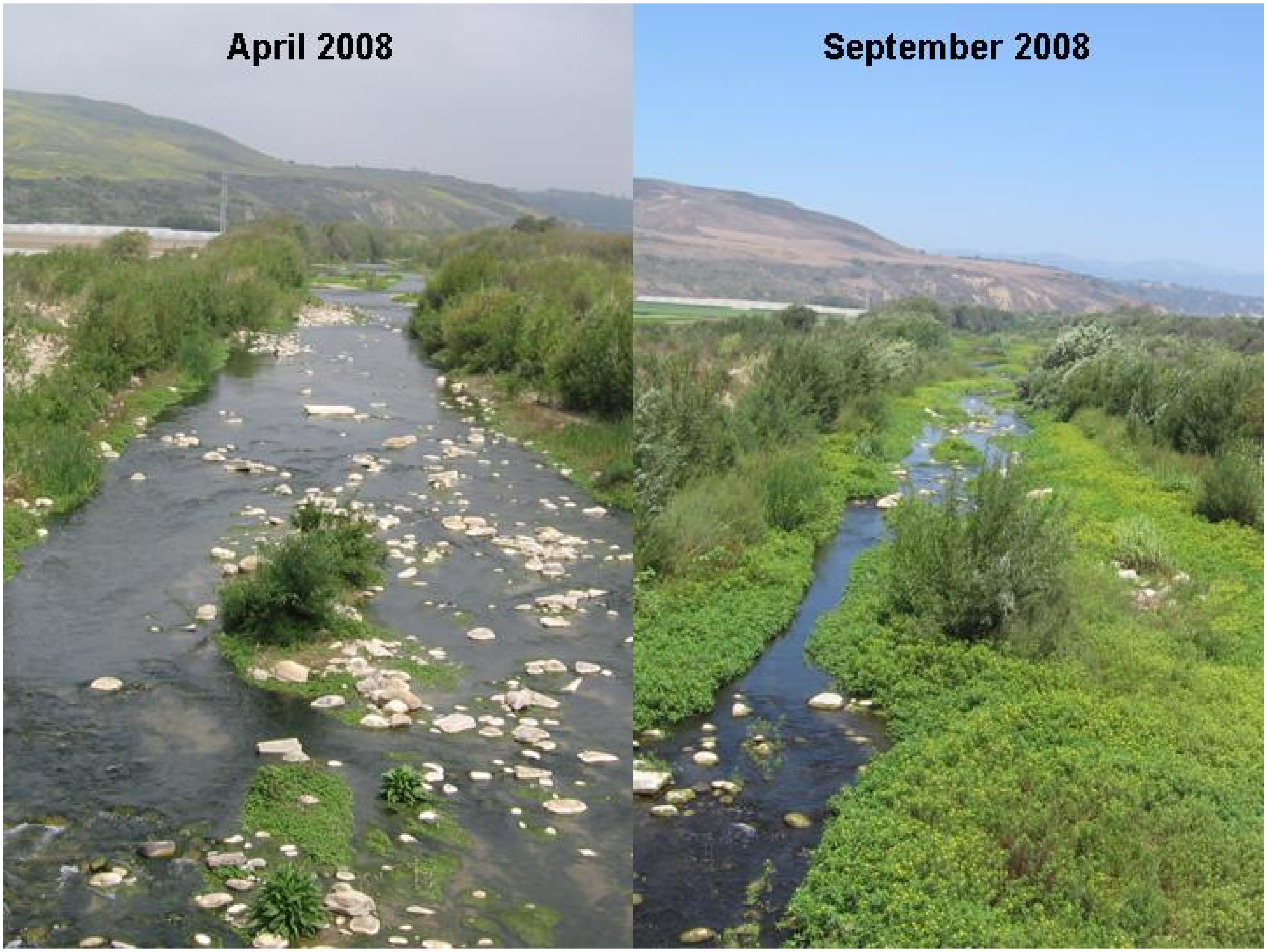
Really big flows occur rarely, usually, but not invariably, during those big waters years (I would define a big year as one with more than 27 inches of rainfall at Ojai); they occur roughly once every 6 to 10 years. And major sediment moving events are even rarer, occurring only once every thirty or so years. Literally, once a generation.



This is a repeat of the graph shown before, only I've now added the size of each year's peak flood (the red boxes). Years with lots of rainfall and a pretty big flood, years like 2001, 2005 and 2008, were peak algal years. In these years water tables were recharged and elevated, flows were higher and the amount of habitat available to algae greater, competing aquatic plants had been removed, sunlight-shading riparian vegetation knocked back, and any sediment preventing bottom-clinging algae from getting a grip washed into the ocean.

Conversely, drought years, years like 2002, 2007 and 2009, were years of low rainfall and very little algae. Aquatic plants from the previous Autumn survived the winter and got a head start early in the growing season, the absence of groundwater recharge kept flows very low and desirable habitat in short supply, riparian vegetation had grown taller and encroached further in on the water's edge, and fine sediment continued to choke the river bottom – great for plants, not so good for algae.

And during those "in-between" years, years with rainfall above the median, but not by all that much, years with a so-so flood, years like 2003, 2004 and, most likely, 2010? In those years we saw, and will see, a combination: abundant algae in the beginning of the dry-season, a river covered with aquatic plants near the end.



This is what an "*in-between year*" looks like. Both photos were taken from the Main Street Bridge looking upstream. The one on the left at the beginning of April 2008, the one on the right during the first week in September of the same year.

This is what happens in a year with moderate rainfall – above the median but nothing for the record books. Winter storms cleaned out a lot of the aquatic plants and the water table was somewhat recharged, all of which set the stage for a big early-season algal bloom. But by mid-summer flow was down, aquatic plants were back, and most of the remaining algae consisted of diatoms nestled among the plant roots and shoots.

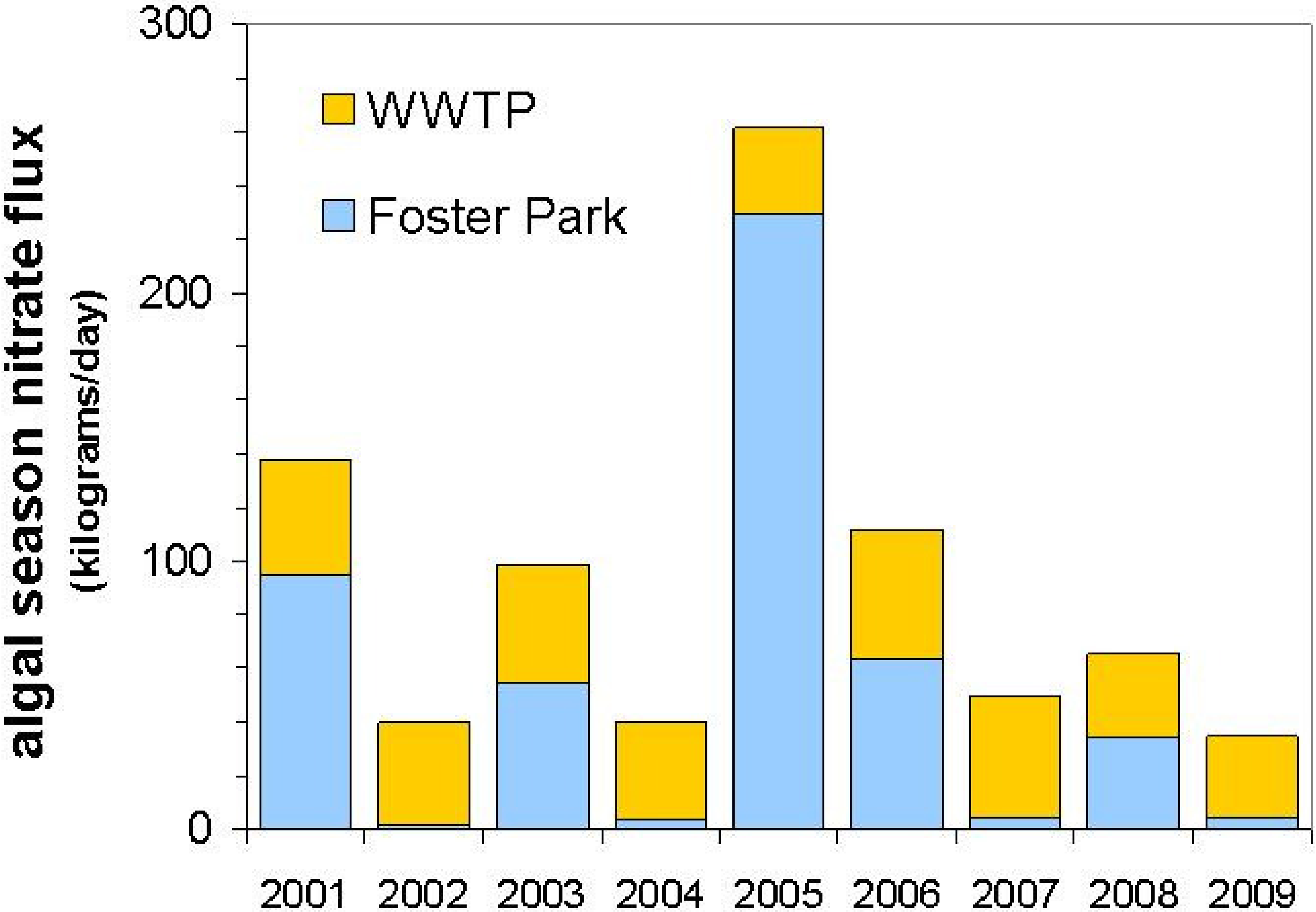
Notice how rapidly the tree in the center of the photo grew in the 5 months between photos. I wish things in my garden did as well.

This is another example of the changes that follow a moderate rainfall winter. These photos were taken looking upstream from the Foster Park Bridge in 2003. The one on the left in early January, the one on the right in May. Even above the wastewater treatment plant aquatic plants (in this case watercress) dominated throughout 2002. An appreciable March storm, and another smaller storm in early May, set the stage for the algae you can see growing in the photo on the right. In 2008, the last major rainfall occurred in February, giving the algal season a very early start. In 2003, late storms postponed the algal season by a couple of months.

Even so, by the end of 2003 the watercress was back. I suspect that the late start, postponing the initial algal bloom until warmer weather had arrived, combined with the extreme dryness of the year before, may have given an extra intensity to that year's bloom. The algae, impeding flow at Foster Park, literally raised the water level by almost a foot.

These additional photos from 2003, looking upstream on the river near Stanley Drain, show how aquatic plants can rapidly replace algae during a moderate runoff year (one with above median rainfall, but not too far above). The photo on the left was taken on February 1, the one on the right on March 22.

The big flood of that year, on March 15, removed sediment from the stream bottom (you can see the cobbles and gravel left behind in the March photo) and stripped the leaves and shoots from the aquatic plants (the plant is called *Ludwigia hexapetala*, sometimes known as water primrose, and it's probably a visitor from Bolivia) but did not remove the roots. Algae got a good start, with a nice cleaned-bottom in the open channel, but by July the aquatic plant was again dominant. The storm didn't destroy the plants, merely retarded their growth. They took a punch, but it was not a knock-down. *Ludwigia* is one tough mother.



Rainfall and storm size directly affect algal and plant growth in another way – by determining how much nitrogen, usually the nutrient in scarcest supply, enters the watershed's streams and river. Lots of nitrogen gets washed into creeks and rivers during winter rainfall, but this nitrogen is long gone by the time our dry-season – the growing season – comes around. What isn't gone is all the nitrogen that was flushed downwards during those storms, down through the soil and into the groundwater-table. During the summer increased groundwater seepage from these recharged, nitrogen-enriched, water-tables sustain higher stream and river flows.

All too often we tend to think of nitrogen, and other elements carried along by stream flow, in terms of ***concentration*** – how much there is per unit volume as in mg per liter. Sometimes it's more important to think in terms of ***amount*** – how much there is in total – in units like pounds or kilograms per day. ***Flux*** is the fancy word for the amount carried by flow and the graph shows the flux of nitrate flowing past Foster Park in each of last nine growing seasons (the blue bars).

(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; compare this with only 20 % nitrate in the more pristine upper Matilija watersheds. 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.)

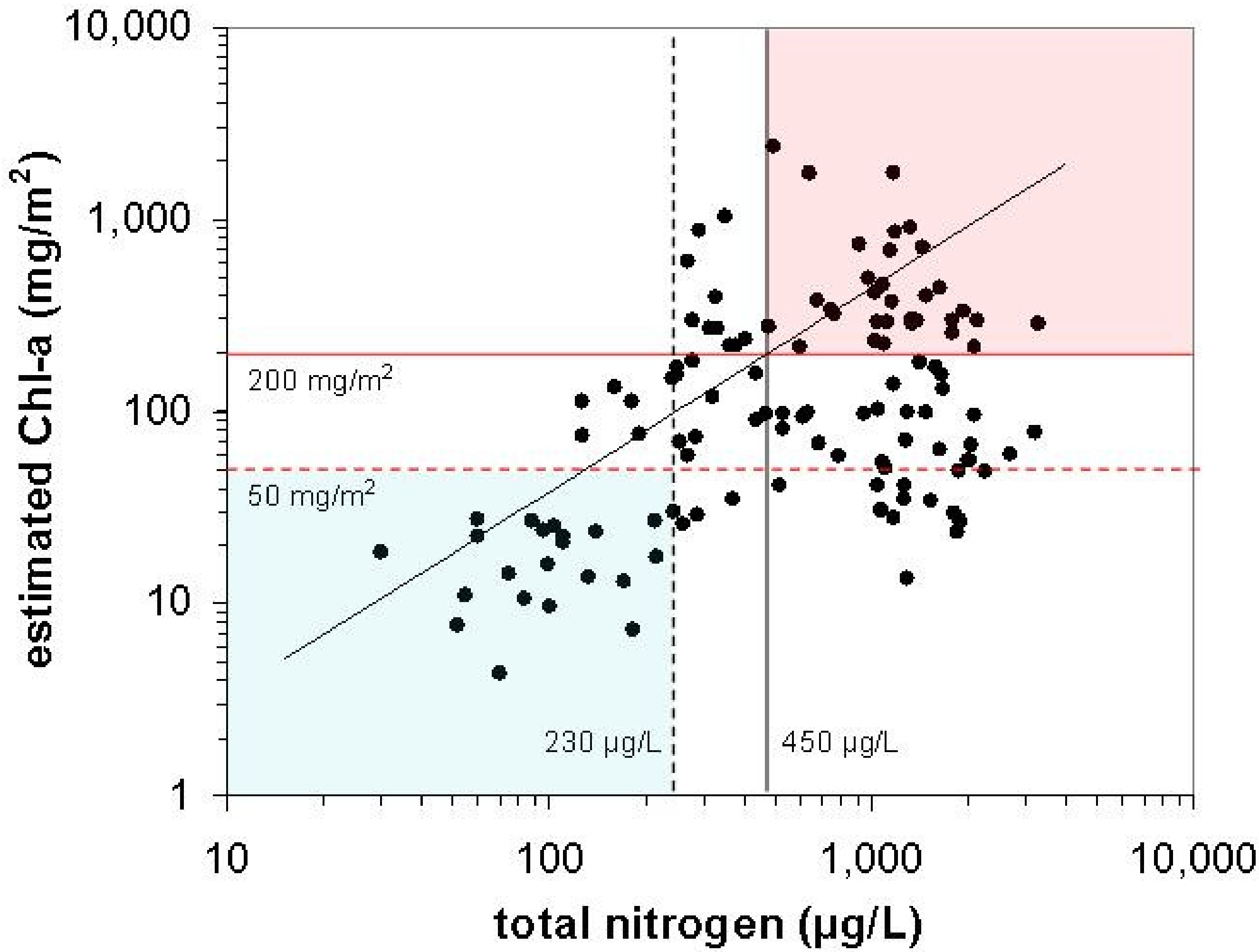
If you look at the up-and-down pattern of the blue bars you'll see it's pretty much the same as that shown for runoff in earlier graphs. In 2005, an average of 500 pounds of nitrate a day flowed past Foster Park during the dry-season (1 kg = 2.2 pounds); in 2002, the driest year of the past decade, the average daily flux was only slightly more than 2 pounds. That's a difference of 250-times. Think of it as 250-times the amount of fertilizer flowing downstream. More nitrogen, more growth . . . more algae, and more aquatic plants. All this nitrogen is the reason why riparian trees grow so well along the Ventura River.

On the graph I've also shown the amount of nitrate contributed by the WWTP; it's a pretty steady contribution, around 80-90 pounds per day. The nitrogen available to the lower river is roughly the amount coming out of the WWTP ***plus*** what's heading downstream past Foster Park. In dry years pretty much the all the nitrogen comes from the WWTP, but in wet years – the years with lots of algae – the treatment plant's contribution is relatively unimportant. Much more nitrogen comes from upstream. And in drier years most of the treatment plant's nitrogen goes towards growing aquatic plants, not algae. It's ironic, but without the WWTP we might well see more algae growing, not less, since there would be far fewer of those stubborn *Ludwigia* providing competition.

(Actually, we would see less, but only because the lower river would go dry during many of the summer months in drought and most moderate rainfall years – remember, no water, no algae. The WWTP often supplies more than 80 % of the river's flow in dry months.)

Everywhere 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 reason is pretty simple. 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 these deposits 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 remain 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 their more impressive nitrogen contributions. And these contributions appreciably increase the further down we go.



The connection between total nitrogen – or nitrate – and algae is often simplistically put: ***the more nitrogen the more algae; and algae bad, more algae very bad***. However, it's not that simple. Algae are more often than not just a symptom of a more basic problem, not the real problem in themselves.

Nitrogen is never at the top of the list of the things algae need. At the top is water; no water, no algae. Next is sunlight; no sunlight, no algae. Then, and only then, come nutrients; and between nitrogen and phosphorus, phosphorus is probably the more important because some algae need no external source of nitrogen; they are able to fix nitrogen from the atmosphere – i.e., convert nitrogen gas into a biologically useable form like ammonium (with the help of some friendly bacteria).

The ***real*** problem is too high a level of nutrients; call it over-fertilization, or over-enrichment, or eutrophication; it's simply too much life trying to make a living in too small a space. If you're a farmer that's great news, but it's bad news for any natural environment, and really bad news for any body of water. I'll get to why in the next slide, but the point I want to make here is that over-enrichment is the real problem on the Ventura and the presence of large amounts of algae, or a river covered with aquatic plants, is how the problem manifests itself.

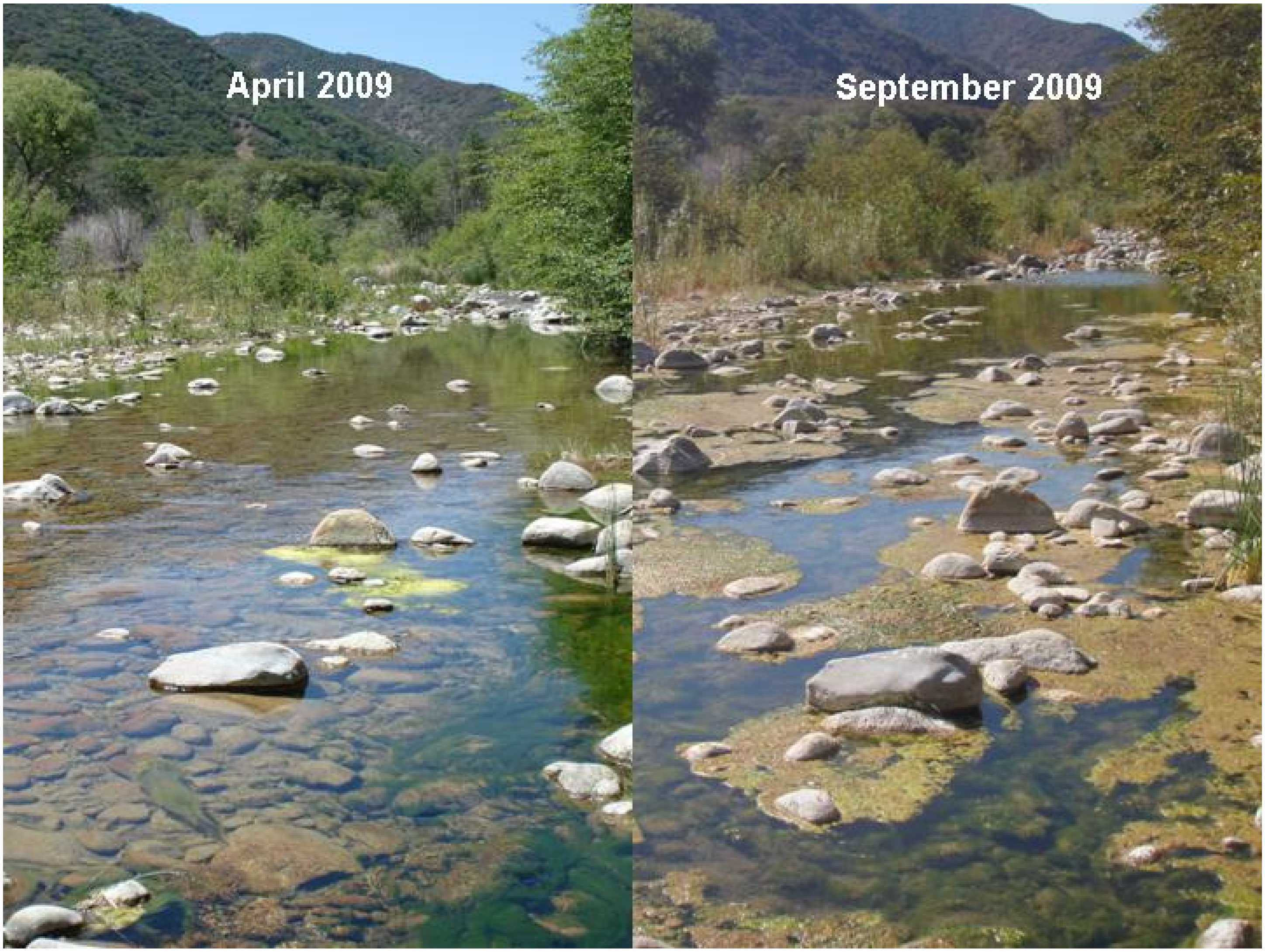
Going back to the connection between nitrogen and algae on the Ventura, I've plotted chlorophyll density (Chl-a in mg/sq-meter) against concentrations of total nitrogen (micro-grams per liter, µg/L) in the graph.

(The amount of chlorophyll in a given surface area of a stream is the most popular way of measuring how much algae were present; since all algae contain chlorophyll, the premise is a simple one, the more chlorophyll, the more algae.)

Each point on the graph represents a measurement of both the amount of chlorophyll and the total nitrogen concentration along some reach in the Ventura watershed, on some day. These data were collected at various times during 2003, 2008 and 2009, and some of the measurements are undoubtedly more valid than others. The details, available elsewhere, are not all that important. But the point I want to make, that ***there is no simple relationship between nitrogen and how much algae are growing in the water***, is. Too many other factors are involved in algal growth for the relationship to be simple.

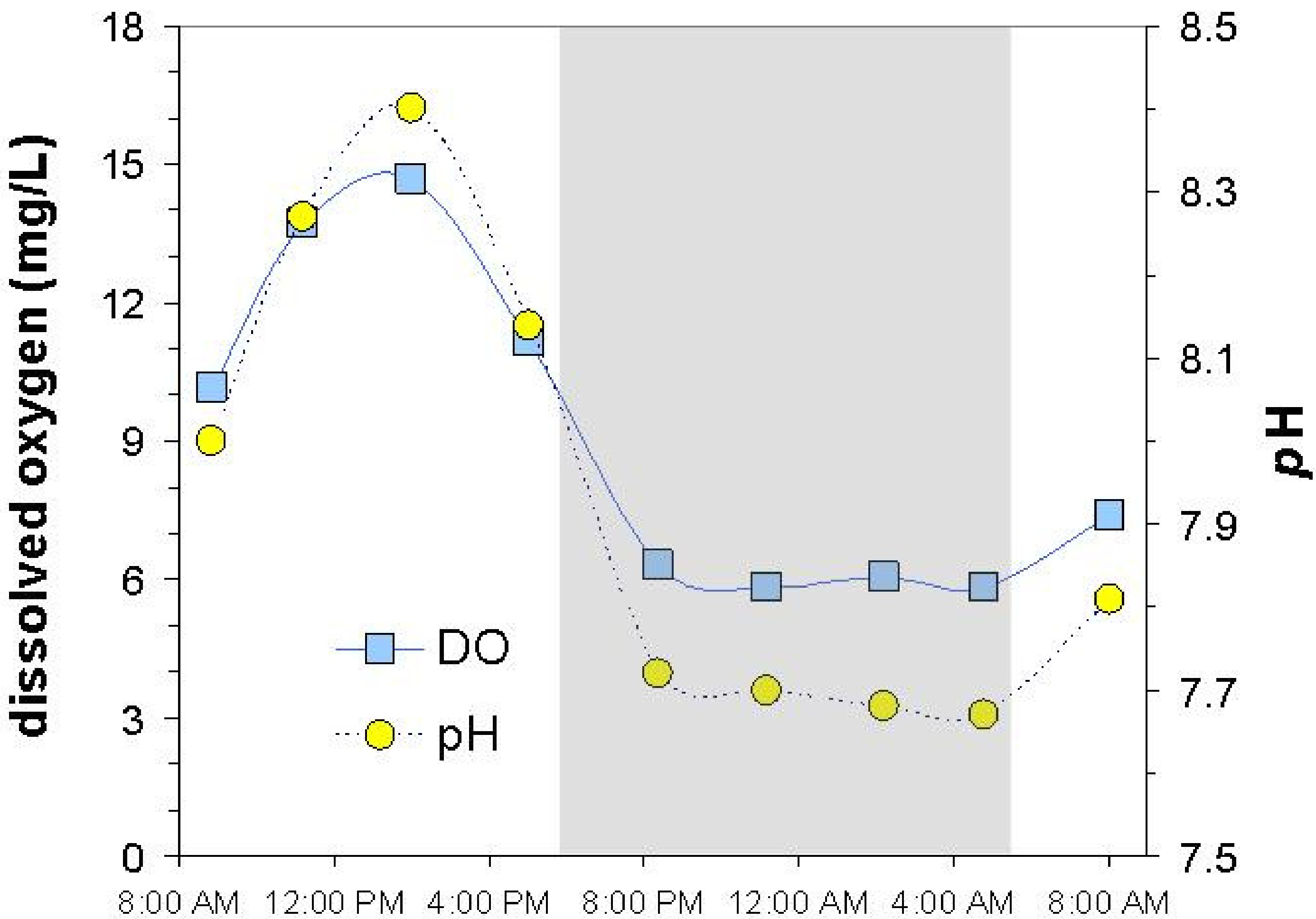
The straight line on the graph represents the correlation set forth in the UCSB Report, and the graph also shows the report's recommended impairment thresholds for Chl-a (50 and 200 mg/square-m) and total nitrogen (230 and 450 µg/L) as red and black lines – dashed for the lower threshold below which no impairment exists, solid for the upper threshold above which a reach is definitely impaired. I've colored the two areas that delineate (1) the region of ***both*** algal and nitrogen impairment in red and (2) the region of ***no*** impairment in blue. Notice that the majority of points fall outside of these two areas.

I would emphasize, however, that although there is no simple relationship between nitrogen and algae there ***is*** a relationship: ***the greater the amount of nitrogen in a reach the greater the probability of finding high densities of algae***. Notice that no points fall within the square representing both low nitrogen concentrations and high algal density. Low nitrogen may mean some algae, but probably not a lot.



But there can be exceptions. In a drought year most of the river is either dry or dominated by aquatic plants, and algae are not typically a problem. Little winter rain means few aquatic plants uprooted (algae deprived of sunlight), reduced flows because of falling water tables (reduced algal habitat), a muddy, sediment laden river bottom (bad news for algae that like to hold-fast to rocks and gravels) and very low amounts of available nitrogen.

These photos were taken in 2009 looking upstream on Matilija Creek, above the dam. The photo on the left in mid-April, the one on the right near the end of September. You can see the meager algal crop during that year's early season bloom (on the left); however, there was also a late season bloom and it, ironically, produced the worse low dissolved-oxygen conditions on the river because flow was so low. At very low flows it doesn't take very much algae to create a problem situation – and in drought years the pristine upper watershed is probably more threatened than any of the lower reaches.



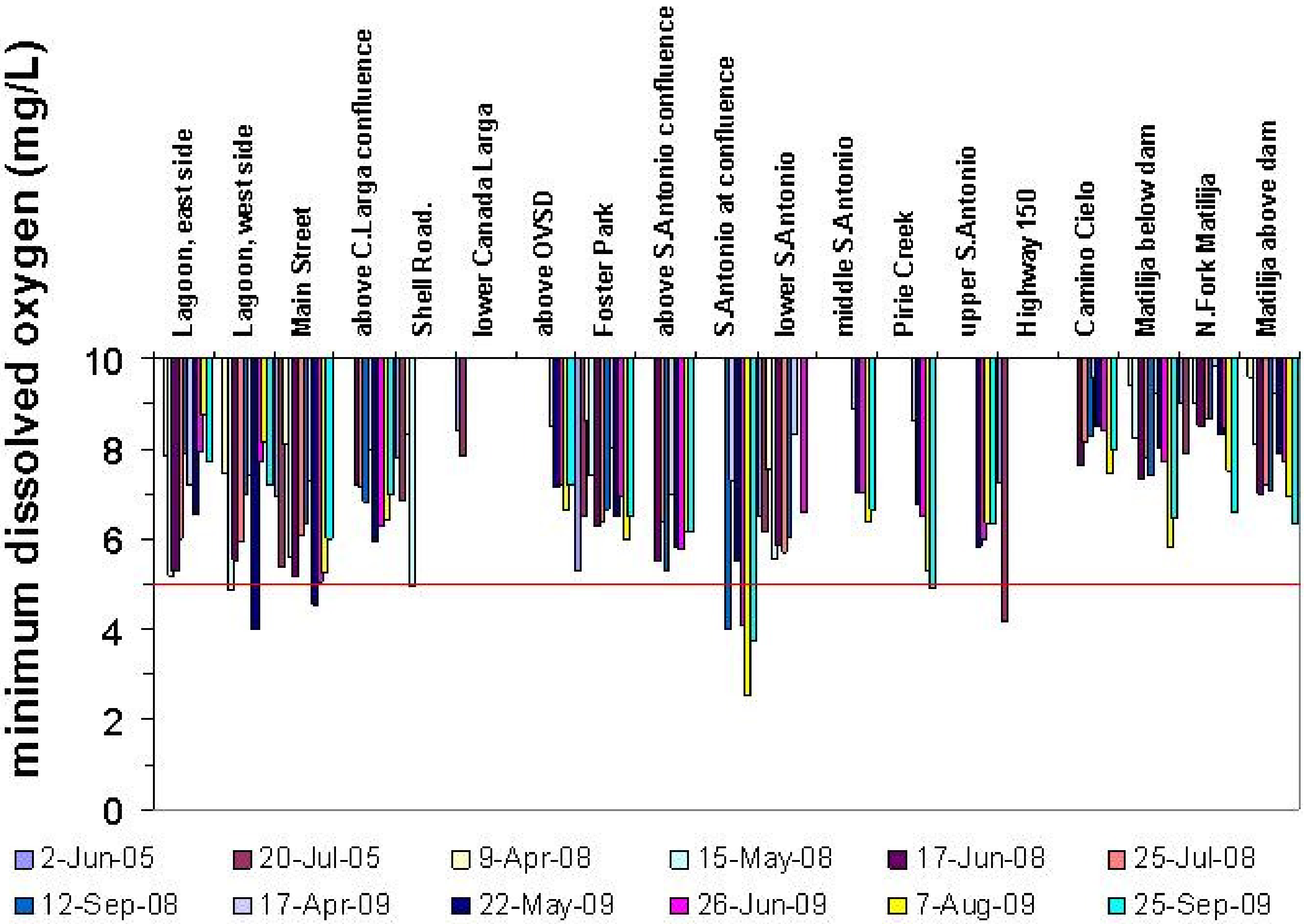
Finally, let's discuss why algae might be a problem on the Ventura; a problem beyond the esthetic concerns mentioned earlier; a problem in and of themselves, and not just a symptom of the underlying problem of nutrient over-enrichment.

If you're a trout or steelhead the appearance of algae might seem to be nothing but good news – since algae can be an important food source. It's true that some algal species (e.g., dinoflagellates and diatoms) excrete poisonous toxins, but these usually present problems only in marine environments (a good example being dying sea lions and dolphins washing up on our beaches as a result of domoic acid poisoning). Toxic algae and a close relative, cyanobacteria – a cross between algae & bacteria, are rarely found at concentrations high enough to cause trouble in freshwater, and are not considered a problem in the Ventura watershed.

Absent direct deleterious effects, however, algal photosynthesis – the removal of carbon dioxide from water using sunlight for the creation of biomass – can, by itself, adversely impact the river. During photosynthesis algae generate oxygen: increasing dissolved oxygen concentrations as they decrease CO2. But at night, algae respire, reversing the process by removing oxygen and increasing CO2. During daylight oxygen and *p*H levels can be driven far above normal, and driven far below at night. Aquatic plants do not have the same effect since most of their green (photosynthesizing) parts are ***above*** water – algae photosynthesize ***under*** water.

The chart shows results from a 24 hour sampling of dissolved oxygen (DO) and *p*H on the Ventura River at Foster Park on September 10-11, 2003. These measurements provide a look at changes that took place over the course of a day in the presence of abundant algal growth. The grey area on the chart indicates nighttime.

Dissolved oxygen varied from a high of 15 mg/L in the early afternoon to a low near 5 mg/L at night. The change in acidity (*p*H) followed the change in DO: from a high *p*H of 8.4 to a low of 7.6. Five mg/L is the limit set by the Regional Water Quality Control Board on how low Ventura DO should go and the change in *p*H represents a 6-fold increase in acidity, so the potential for harm to aquatic life from algae certainly exists. The real question though, is how often does it happen. How often, for example, is the established minimum DO level violated? Dead steelhead eat very little algae.



For 3 years (2005, 2008 and 2009, the first two big algal years, the last a dry, plant-dominated, year) Santa Barbara Channelkeeper monitored a wide range of locations in the Ventura watershed for excessive fluctuations in dissolved oxygen (DO). DO was measured in the early morning hours (circa 4-6 AM), presumably when oxygen levels were at a minimum (this is not quite correct, but close enough to make little difference).

The graph shows the results. The red line indicates the current minimum acceptable oxygen level (5 mg/L) established by the Regional Water Quality Control Board. As you can see, at very few locations was oxygen driven below this level (ignore details, just note how many measurements fell below the red line). Most of the time this occurred only at extremely low flows (e.g., on San Antonio Creek near the end of Summer), and was often due to a combination of circumstances (processes other than algal respiration also lower oxygen concentrations, the most important being the decay of organic material).

The mathematics of algal impact on dissolved oxygen concentrations are rather straightforward. An **X** amount of algae acting on a **Y** volume of flow will lower nighttime DO by **Z** mg/L. Twice as much algae will lower oxygen concentrations about twice as much. Conversely, so will the original amount of algae if the flow decreases by half. **X/Y = Z**, decrease flow or increase algae and oxygen will be further depressed, increase flow or decrease the amount of algae and oxygen recovers.

Luckily for the Ventura the densest growth of algae occurs early in the dry-season, when nitrogen levels and available habitat are at a maximum – and so is flow. As the graph indicates, dissolved oxygen levels are rarely driven below the allowable limit at this time because of these high rates of flow.

Later in the season, when flows are considerably lower, the amounts of algal habitat and available nitrogen have also greatly decreased; not only are less algae usually present, but they are in the process of losing out in the competition with aquatic plants. However, it’s usually during this time that most of the incidents of sub-par DO levels occur. Small amounts of algae can exert a very big impact when flows are extremely low. This seems to hold particularly true for San Antonio and the upper Ventura watershed in dry years, when organic decay in accumulated sediments adds to the nighttime algal oxygen demand.