More than you ever wanted to know about local creeks and rivers

or

How I learned to stop worrying about Afghanistan, Iraq, Syria, global warming, environmental pollution, ecologic catastrophe, imbecilic politicians, Supreme Court Justices, President Donald and my love life by visiting the same crummy locations month after month and year after year.

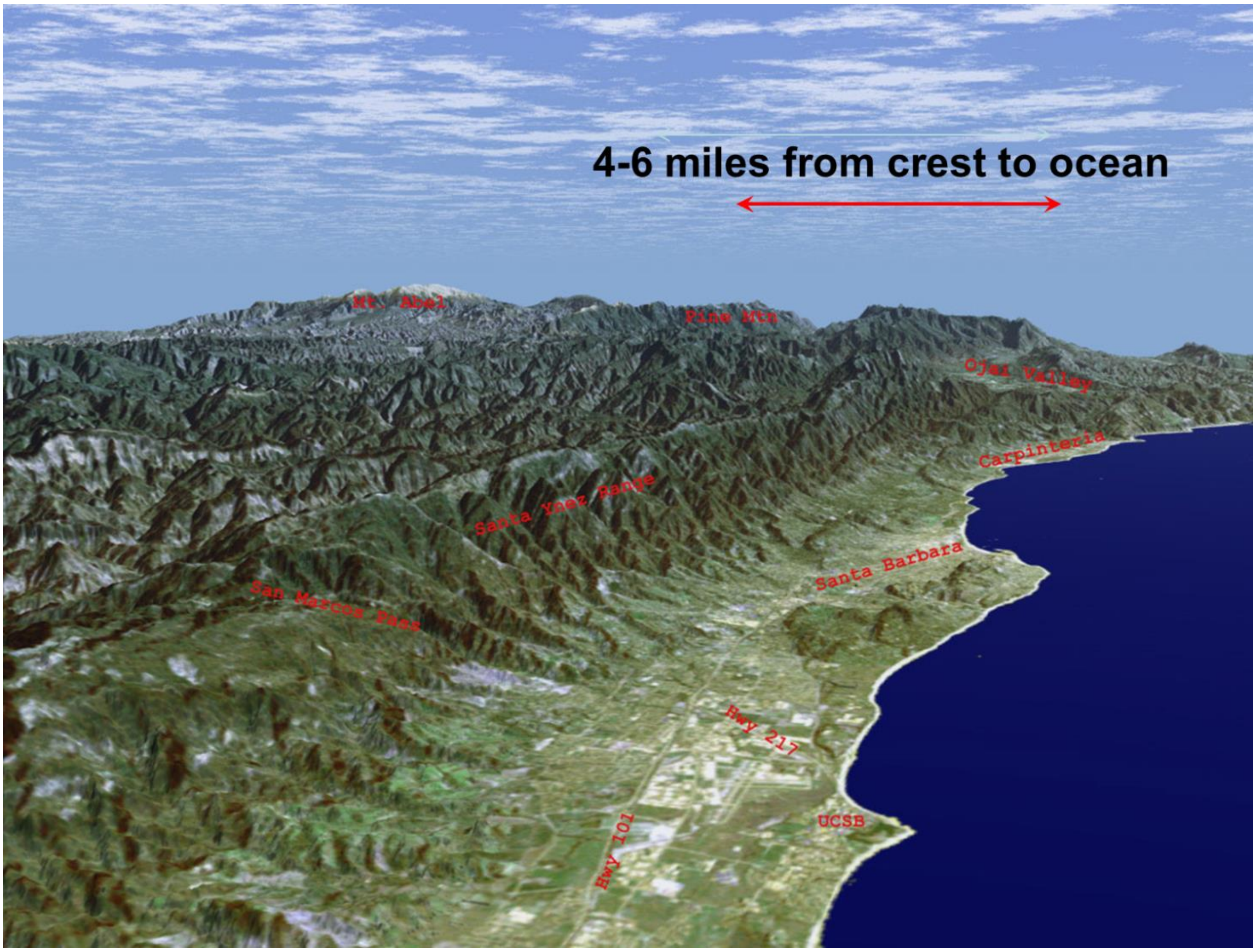
A look at some of Goleta's and Santa Barbara's creeks, and the Ventura River, along with some results of Santa Barbara Channelkeeper's monthly monitoring programs (2001 to the present); and some personal thoughts on how to look at, and think about, data. By this I mean the search for patterns, or the absence of patterns, and the stories that might give them meaning. As James Bond, of double-o-seven fame, said, "once is happenstance; twice is coincidence; three times is enemy action." When we do stream monitoring we're looking for enemy action. Today, in science, simple data collection is a route towards professional suicide. Everyone wants a story.

Al Leydecker, Feb. 2017

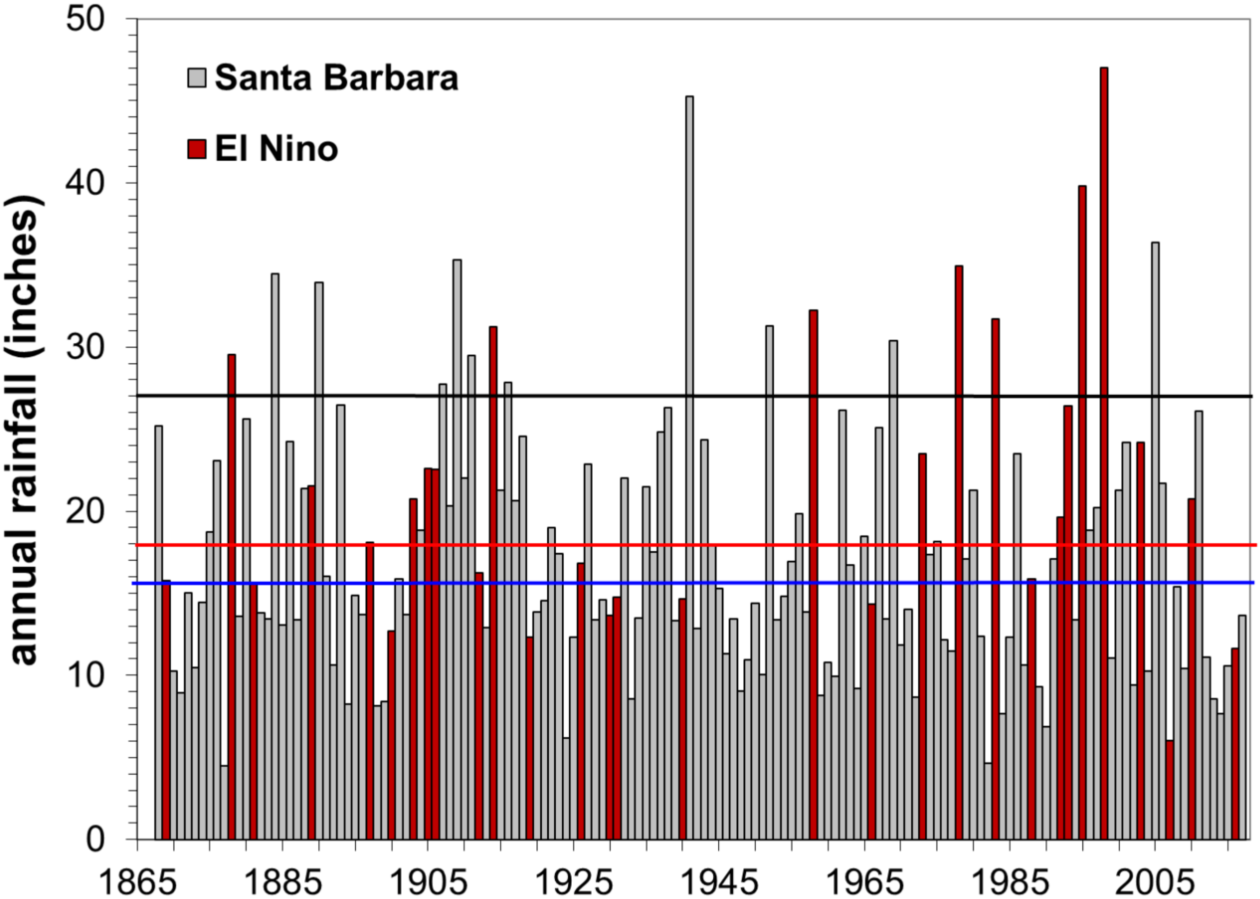
'NEST EGG'

"For in creating the modern west we have gone a long way towards ruining this magnificent and fragile habitat. And as Marcus Aurelius said a long time ago, *what is bad for the beehive cannot be good for the bee*." Wallace Stegner

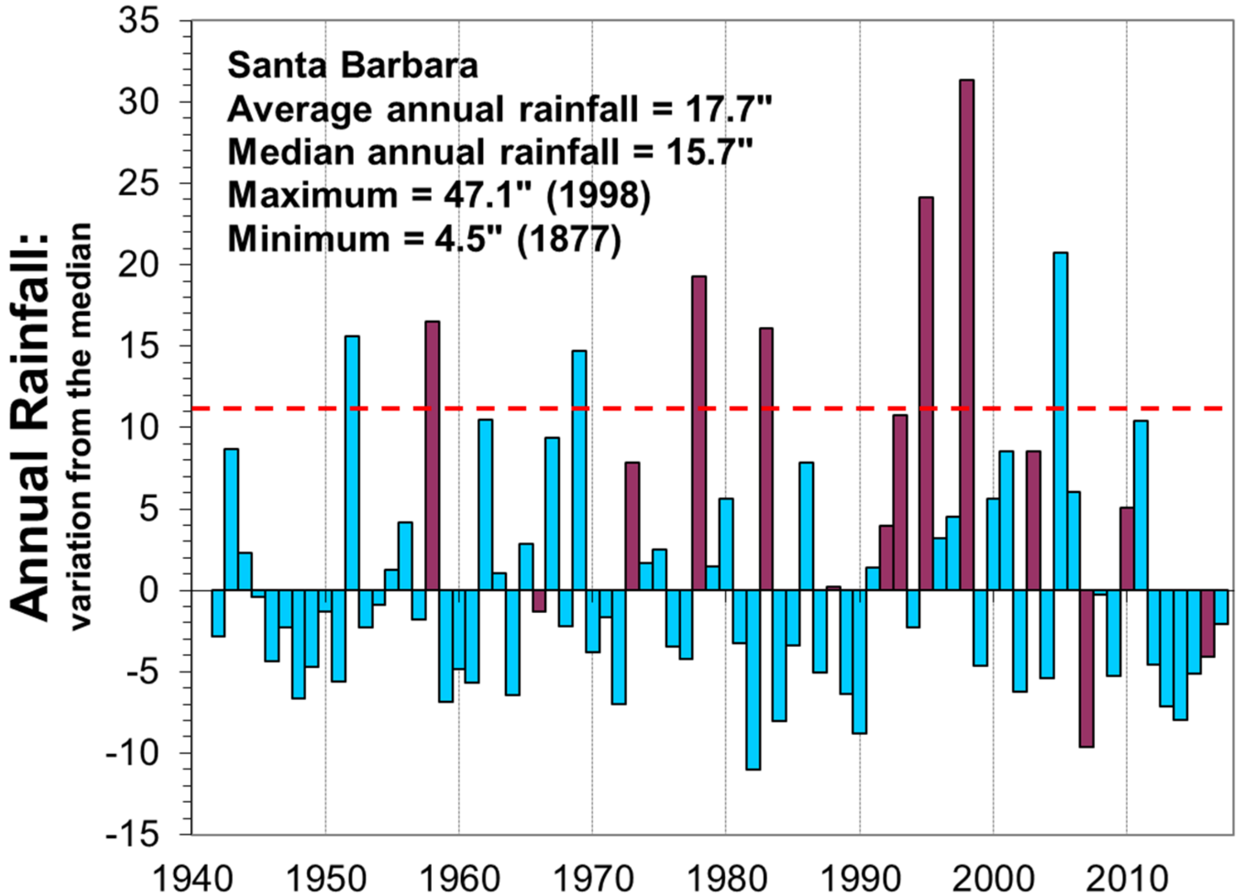
Forget recycling or donating your annual twenty bucks to Greenpeace or the Sierra Club. If you really want to help your generation to a better future think about pushing your grandparents down the stairs.



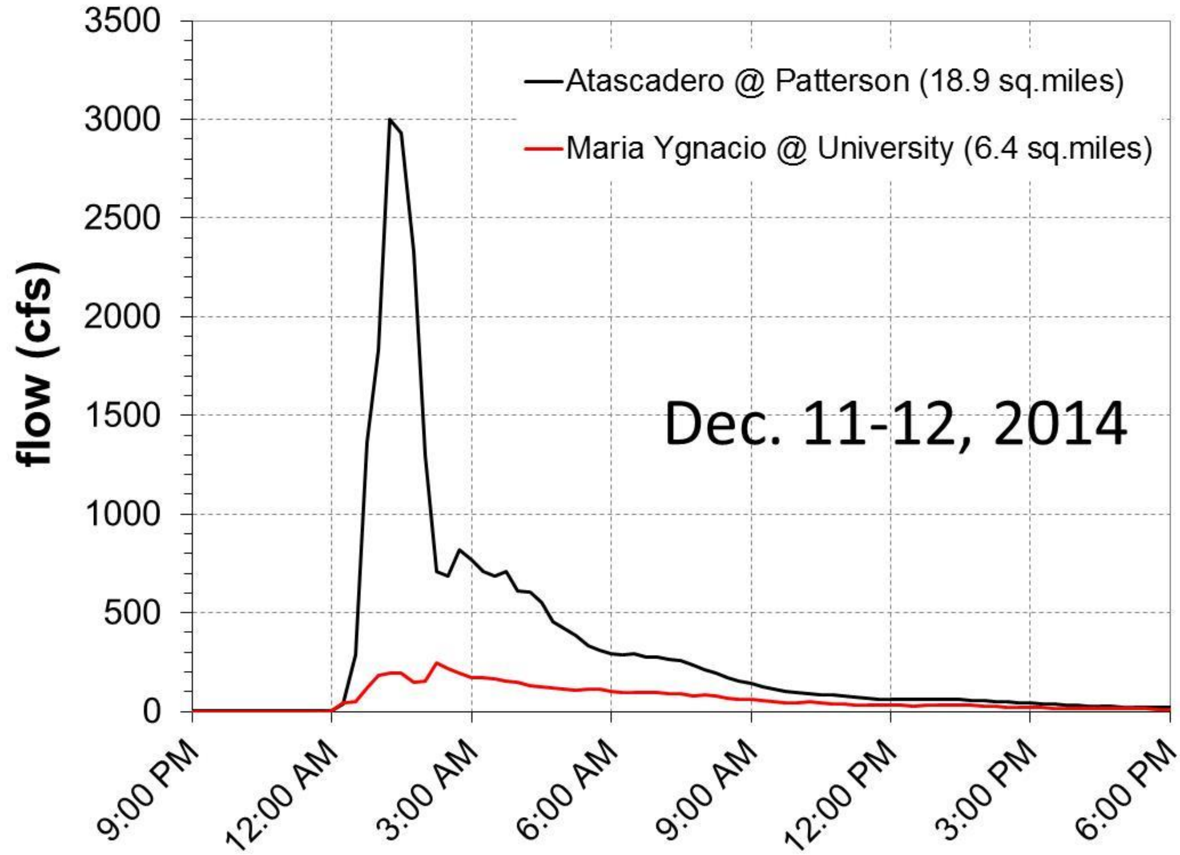
Topography is fate. Streams in this area are short and extremely steep. The mountains are made up of relatively recent, easily eroded. marine sediments. Storms produce ***flashy*** runoff: flows rise and fall rapidly – and are heavily sediment laden. The climate is ***Mediterranean***, meaning rainfall normally occurs only in a single season. In our case, winter. During the dry-season (spring, summer and fall) the normal stream condition is very low flows from groundwater seepage in the mountains, dry streambeds in the foothills and upper coastal plain, and flowing groundwater seepage near the coast. Where year-round flows occur they are usually produced by some combination of excessive agricultural runoff (or enhanced groundwater flows from excessive irrigation) and urban nuisance waters. These days, if there is water in a creek during the summer someone put it there.



Streamflow is produced – and the character of the stream determined – when rainfall is added to topography. The graph shows annual (water-year) rainfall in downtown Santa Barbara from 1868 to Feb. 2016 (CSB-PWD): The red line represents the 18 inch average rainfall (the blue line is the median annual rainfall – 15.7 inches), the upper line marks 27 inches or 150 % of the average (anything above this line was a *big* rainfall year). El Nino years are shown in maroon. We do tend to get more rainfall in El Nino years – at least sometimes (2016 was a noteworthy exception). Note also that the median is less than the mean, meaning the distribution is skewed towards the low side. Our typical annual (by annual I mean water year: October through September) rainfall is below average. More precisely, it has been below average 62 % of the time. I would imagine the opposite situation prevails at Lake Woebegone.

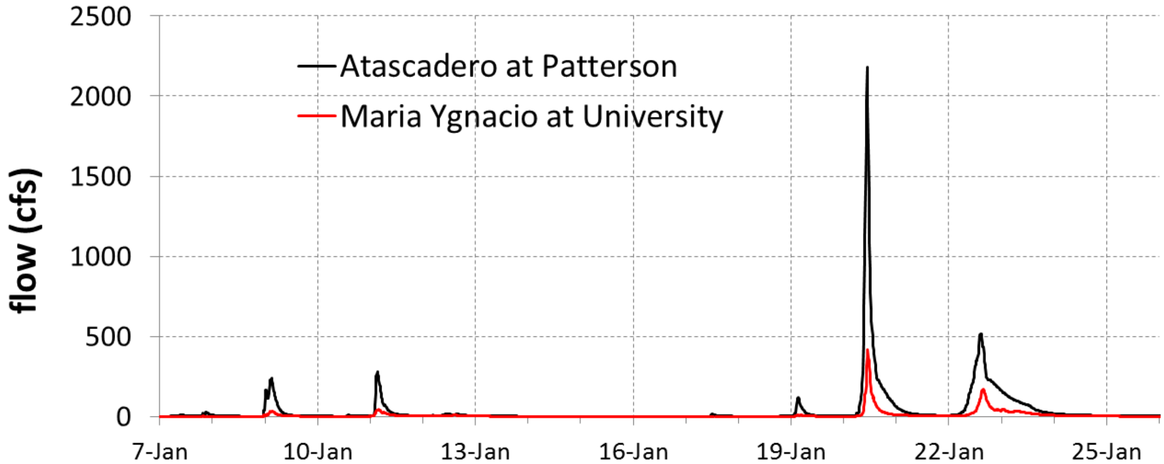


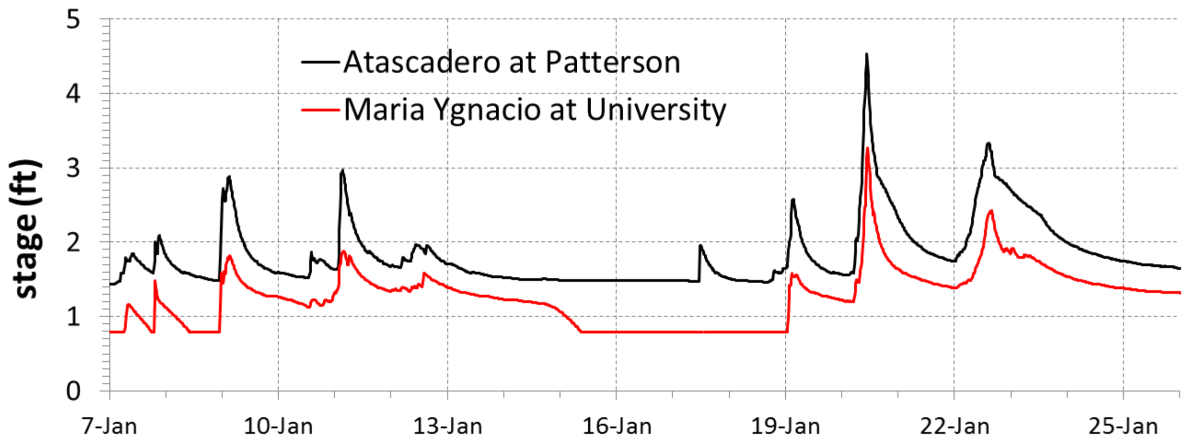
Another, and perhaps more meaningful, way of looking at annual rainfall (1942-2016): by indicating how far below or above the long-term median each year's total was. (The median, with half the years measuring greater rain and half less, is a better estimate of the most likely or expected rainfall than the average.) Each bar represents the measured rainfall minus the long-term median (15.7 inches), in other words, if we got less than the median the bar is negative, if we got more the bar is positive. The statistics on the graph represent the entire rainfall record as shown in the previous slide, and the red line represents 150% of the annual average rainfall, i.e., *big* years; any year sticking above the red line was a big year. There have been 8 big years since 1942, or about one every nine years (or maybe one in seven if we count three other years that came pretty close). As we'll see, big years are very important in determining how streams look and function.



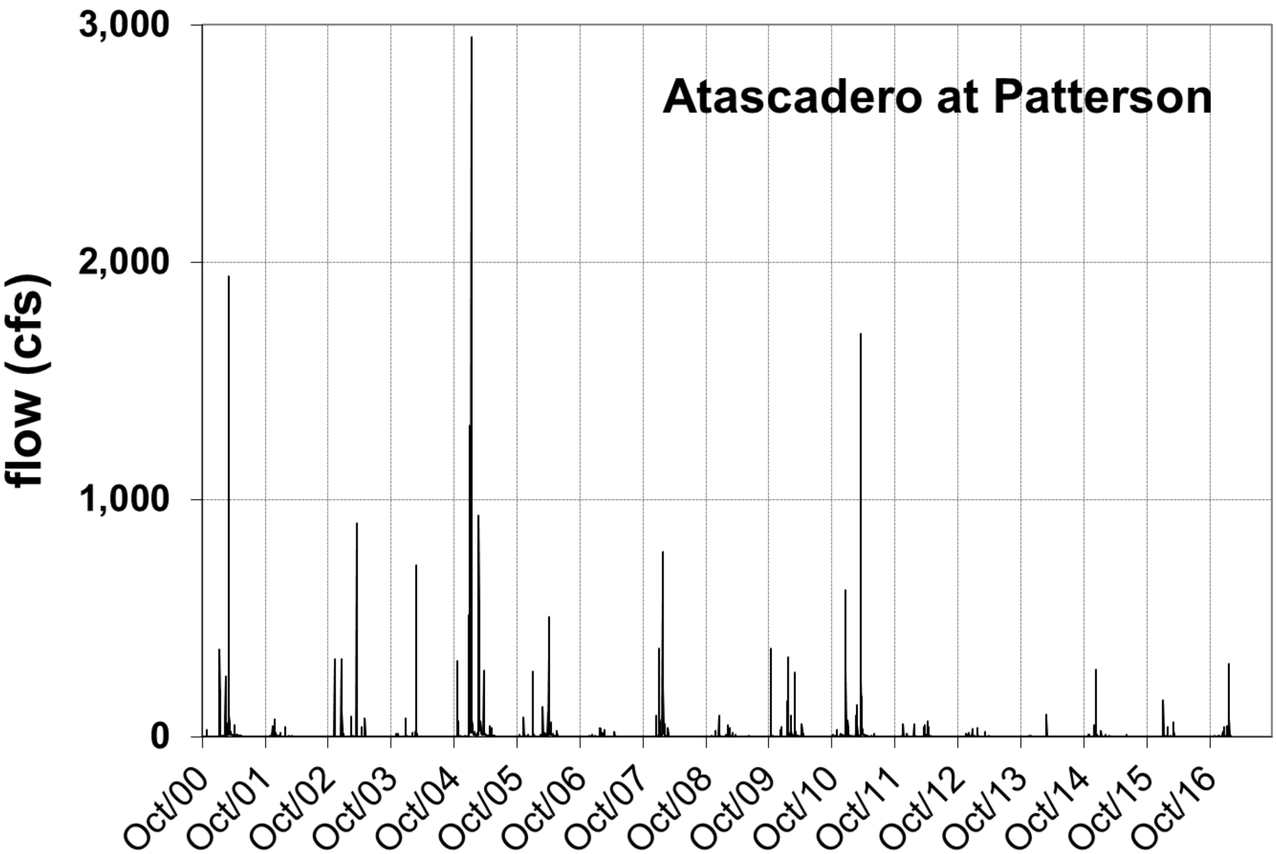
The hydrologist's principal tool is called a ***hydrograph***, a plot of streamflow (it can also be water depth) vs. time. This particular hydrograph is for Atascadero Creek at Patterson Ave. Flow is measured in cubic feet per second (cfs), that's one cubic foot of water (about two buckets full – 7.5 gallons) every second. This hydrograph records a storm in early December 2014. To add some perspective, since few of us think in cfs, the storm caused water levels to rise three and a half feet under the Patterson Bridge. I've also shown the hydrograph for Maria Ygnacio Creek at University Drive. Maria Ygnacio is the biggest Atascadero tributary, and its watershed above University includes more than 1/3 of the total Atascadero drainage area. However, flow here was only about 7% of the Patterson flow during the storm; it's usually much less than that during smaller events.

This is the difference between urban and undeveloped land runoff – Maria Ygnacio flows out of the mountains (keep in mind the mountains get about twice the rain we see in downtown Goleta), the remainder of Atascadero flows mostly out of urban Santa Barbara. Development means "flashier" streams: fast rising and rapid fall, with more stormflow and less rainfall going towards groundwater recharge, thus lower subsequent dry-season stream flows.

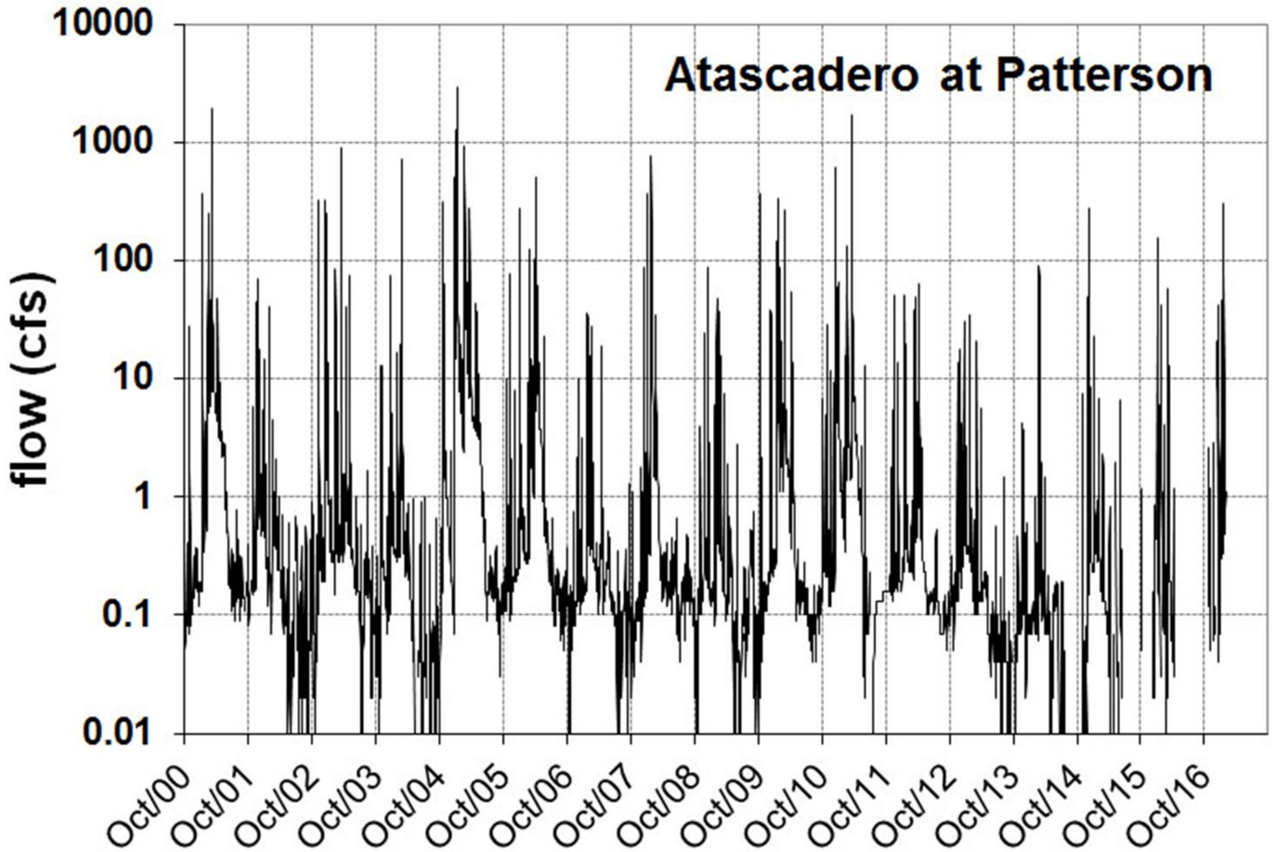




A more recent comparison: January 7 through 25. The flow hydrograph is shown above, the stage (or water height) hydrograph below. (Minimum stage height—when the creek is dry—is usually set to some number above zero.) Note that the earlier January storms (and also the November and December storms) generated almost no flow in Maria Ygnacio. Not until Jan. 20 did Ygnacio begin to flow, and even then flow was relatively low compared with Atascadero. Not until Jan. 22 did Maria Ygnacio appear to be a sizable contributor to Atascadero flow. By that time something like 11-13 inches of rain had fallen in Santa Barbara since November. That it took so much rainfall before undeveloped areas of the watershed began contributing runoff is an indication of how dry soil conditions had become during the drought. During the biggest storm we've had so far this year (as of Feb. 2), flow at Atascadero was about 3.5 feet deep (at a flow of 2,200 cfs).



I’ve expanded the Patterson hydrograph to include more than 16 years of flow data (shown as average daily flow): winter storms cause abrupt spikes of flow in what is basically a desert of dryness. On average, we get about 15 or so storms a year, usually only one or two of considerable size, and in some years (2002 or 2007 or 2013), no appreciable storms at all. Atascadero is the biggest creek in the Santa Barbara area. A year, whenever I refer to it in this presentation, refers to the “water” year: a water-year begins on October 1 and ends on September 30 (be aware that some agencies may use a different time-frame). Hydrologists consider beginning the year on January 1 a big mistake, especially in California.

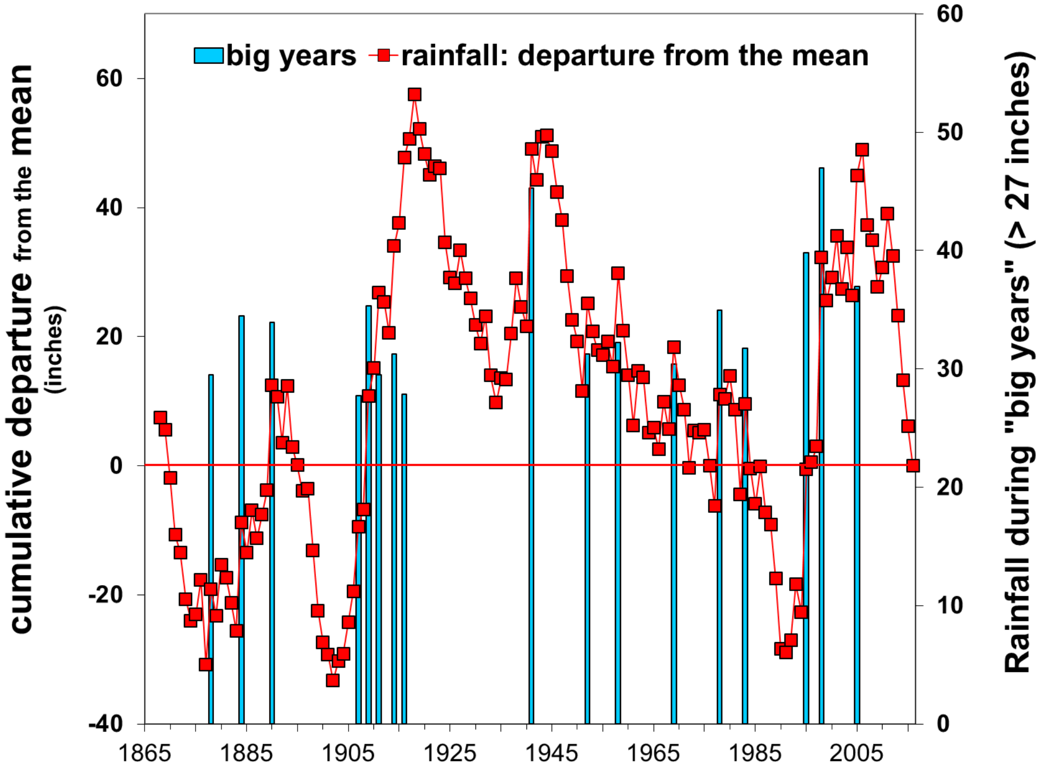


This is the same hydrograph data but displayed using a log scale so that low flows can be seen in some detail. A flow of 0.01 cfs is roughly a bucket of water a minute – pretty low. Something like the amount coming out when you crank your kitchen faucet fully open. Storms can cause an almost 7 order-of-magnitude increase in flow. That's a one followed by seven zeros – a flow increase of about ten million times (the six orders-of-magnitude you can count here plus another representing a typical 10-fold difference between mean daily flow, the measure shown in the graph, and peak instantaneous storm flow). The biggest storms on the graph represents 10-13 feet of water flowing under the Patterson Bridge. If the length of your stride was 10,000,000-times longer, five steps would carry you around the earth's equator.

at Puente Ave. at Patterson Ave.

Atascadero Creek: Jan. 9, 2005 (above), May 5, 2005 (below)

Here’s what the contrast between dry-season flow (and a relatively high dry-season flow at that – 2005 was a very wet year) and storm runoff looks like on the ground.

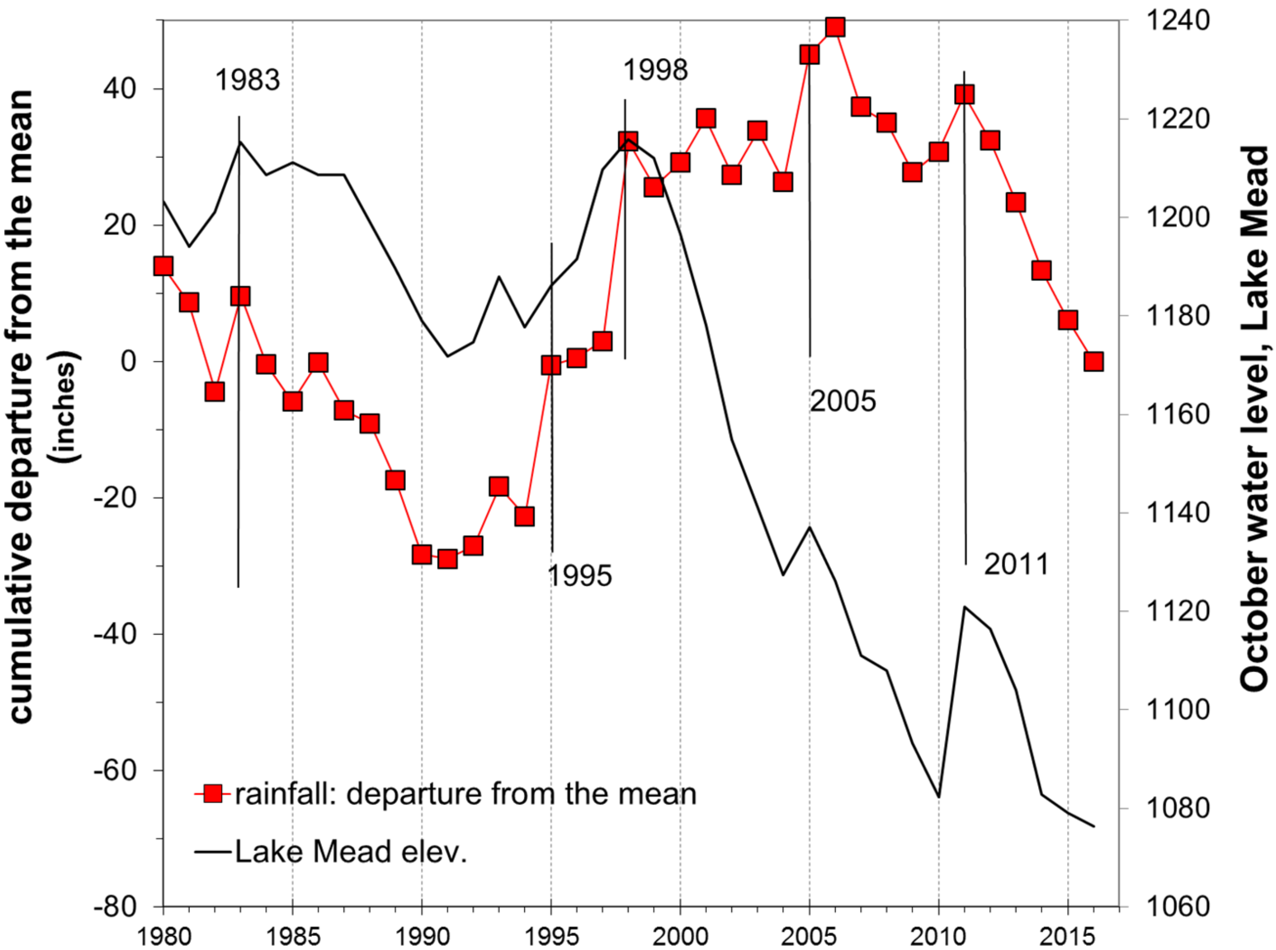


We know that annual rainfall varies, but the big question is whether or not that variation is random? Are the five years of low rainfall we've just gone through no different than tossing 5 heads in a row, or is something else at work? One way of deciding is to look at the **cumulative departure of rainfall from its mean**. The cumulative departure for any year is simply the sum of all the departures (variations from the mean) that have gone before; perhaps a better term might be *a running total of differences from the mean*. The graph shows long-term trends away from—or back towards—the average rainfall—e.g., how much the annual rainfall varied from its 18 inch average and whether the long-term trends were up or down (thus identifying periods where annual rainfall seemed to be on the increase, and those where it appeared to decrease).

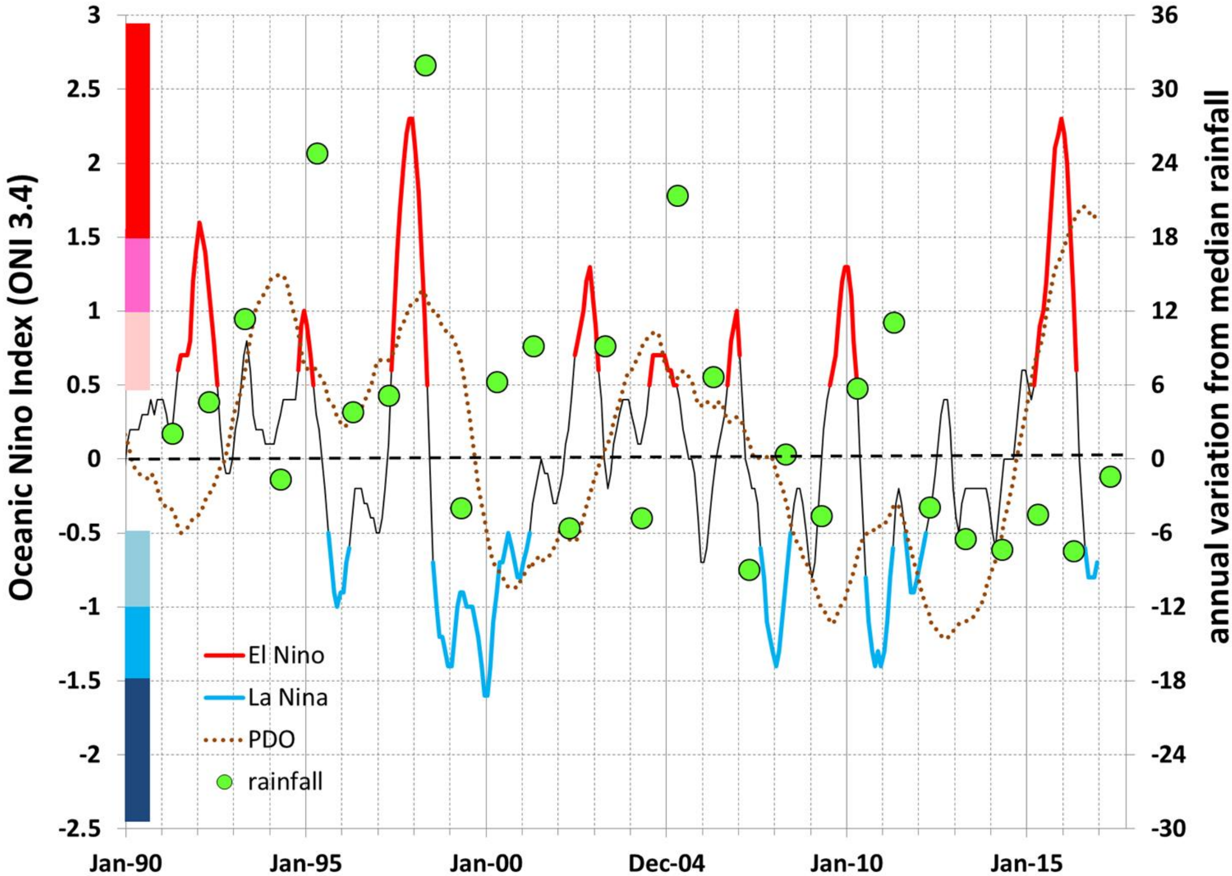
There are two patterns in the Santa Barbara data: The first, the big pattern, is produced by something called the **Pacific Decadal Oscillation** (PDO): a roughly 50-year cycle of alternately cold and warm waters that abruptly shift location in the eastern Pacific Ocean. The "cold" PDO phase moves the jet stream (and a lot of winter rain) northwards, while the "warm" phase shoves it, and the rainfall, southwards – giving us wetter winters.

And then we have the changes produced by a relatively few really big years (often associated with strong **El Nino** events). If we define a "big" year as having rainfall at least 150% above the average (>27 inches), the blue bars represent the big years; there have been seventeen "big" years since 1868: approximately one every nine years. The 1990s were unusual in that we had 3 big years in the same decade (1993-almost, 1995 and 1998). While most big years were associated with the strong El Niños that often dominate South Coast rainfall there have been lots of exceptions: 1969 and 2005 being good examples.

Unfortunately for our local streams, we appear to have entered a new cold PDO phase after 2000. With less rainfall, we can expect a return to conditions of the 1950s. We might also expect more wildfires, increased summer fog and extended drought conditions.

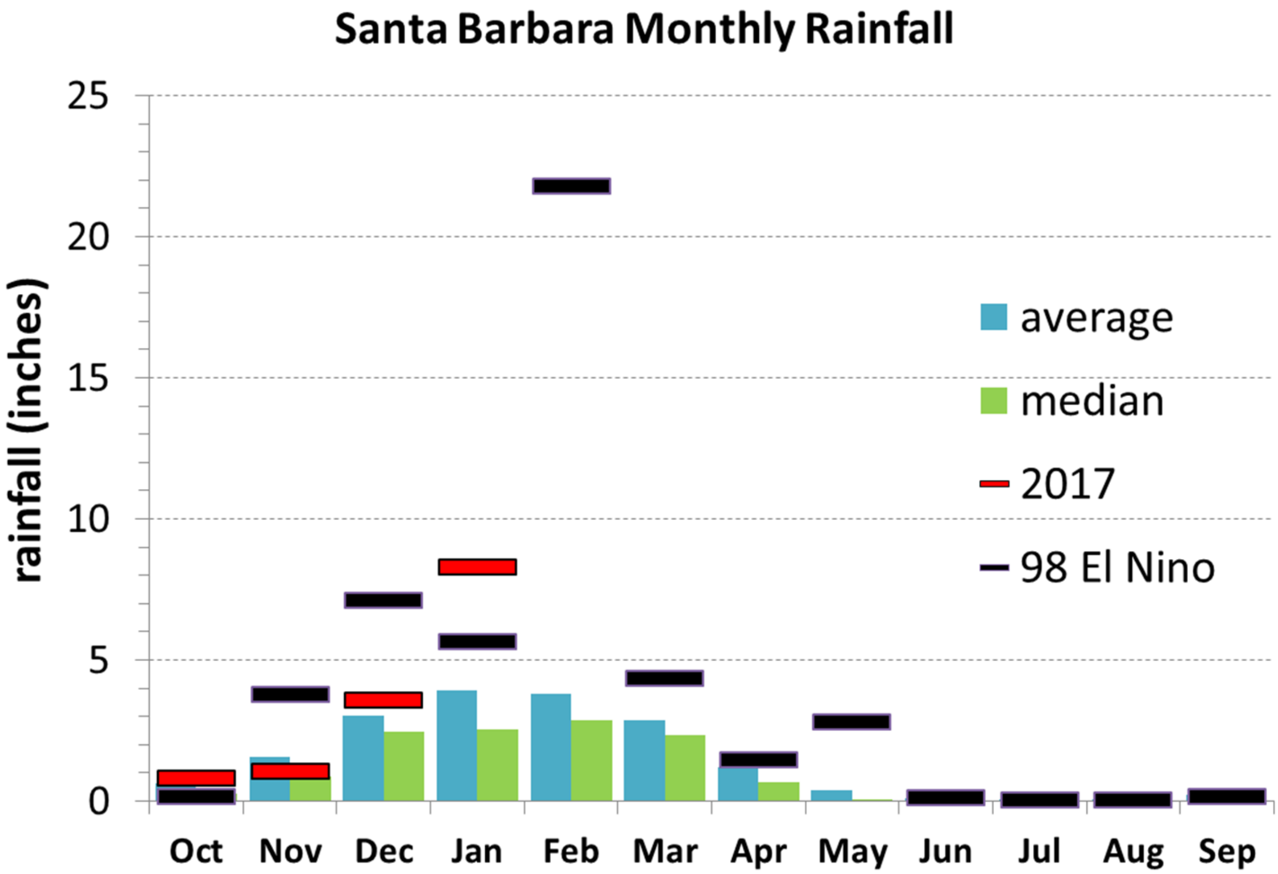


This is again the cumulative departure of Santa Barbara rainfall from the mean (red squares). Plotted with it are October water levels at Lake Mead (measured at Boulder Dam on the Colorado River). The point here being that rainfall in the west is most often caused by big frontal storms coming out of the Pacific. And rainfall in Santa Barbara is usually well correlated with rainfall throughout the west US. Although not a perfect match (we shouldn't expect it to be since Lake Mead levels also respond to upstream electrical power production and irrigation water withdrawals) you can see a reasonable correlation between the two. Both respond to *big* years; I've labeled a number of them (2011 was our most recent El Niño—prior to the 2016 flop). The drastic Lake Mead decrease since 1998 points out the extend by which we have overwhelmed the capacity of the Colorado River.

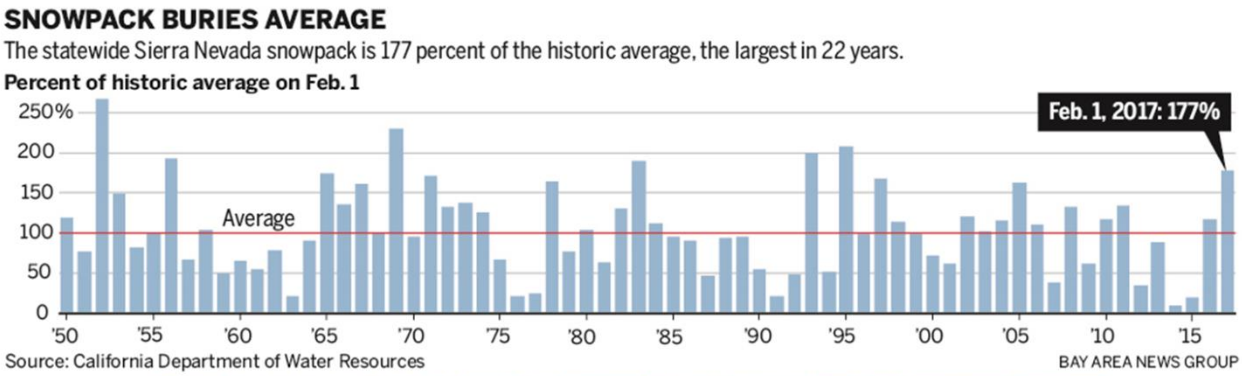


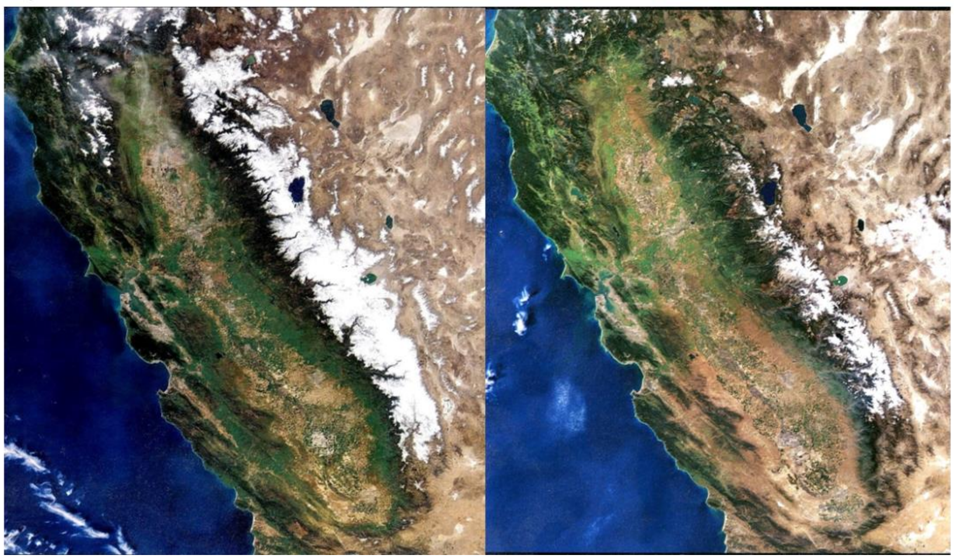
El Niño or La Niña events are defined as 5 consecutive overlapping 3-month periods when oceanic sea surface temperatures (SST) in the Nino 3.4 region are at or above the +0.5 anomaly for warm (El Niño) events and at or below the -0.5 anomaly for cold (La Niña) events. We can further break 'em down into Weak (with a 0.5 to 0.9 SST anomaly), Moderate (1.0 to 1.4) and Strong (≥ 1.5) events. The red or blue line colors on the charted line mark official events since 1990, and the color scale to the left indicates their intensity. Also shown is each year's rainfall (2017, as yet, incomplete) and the 24-month running average of PDO indices. In 2016 we were in a strong El Niño (compare with 1998) and the PDO was also strongly positive (when both are positive they tend to reinforce each other, and visa versa). This combination should have brought us lots of rainfall. But it didn't. This year we are in a weak La Niña while the PDO remains strongly positive, i.e. a mixed signal. Theory says a strong PDO should weaken the impact of any La Nina. So far, so good; it surely seems to be doing that. But as you can see, it's far from rocket science.

One of the problems with climate change is that you can't really tell that the climate has changed until years after it has already begun to take place. Weather is what happens in a given year, climate is a long-term average. So is what we're experiencing just a few dry years? (We've had years this dry before.) Or does it represent a change in climate? We wouldn't really know for quite a while. But as far as our local streams, rivers and reservoirs are concerned, the predictions of climate change, that it will get hotter (increasing evaporation losses) and drier (decreasing storm runoff), are not comforting. But the big thing to keep in mind, if it's climate change, is that we will no longer be able to use the past to predict the future. Because the future can no longer be expected to resemble the past.

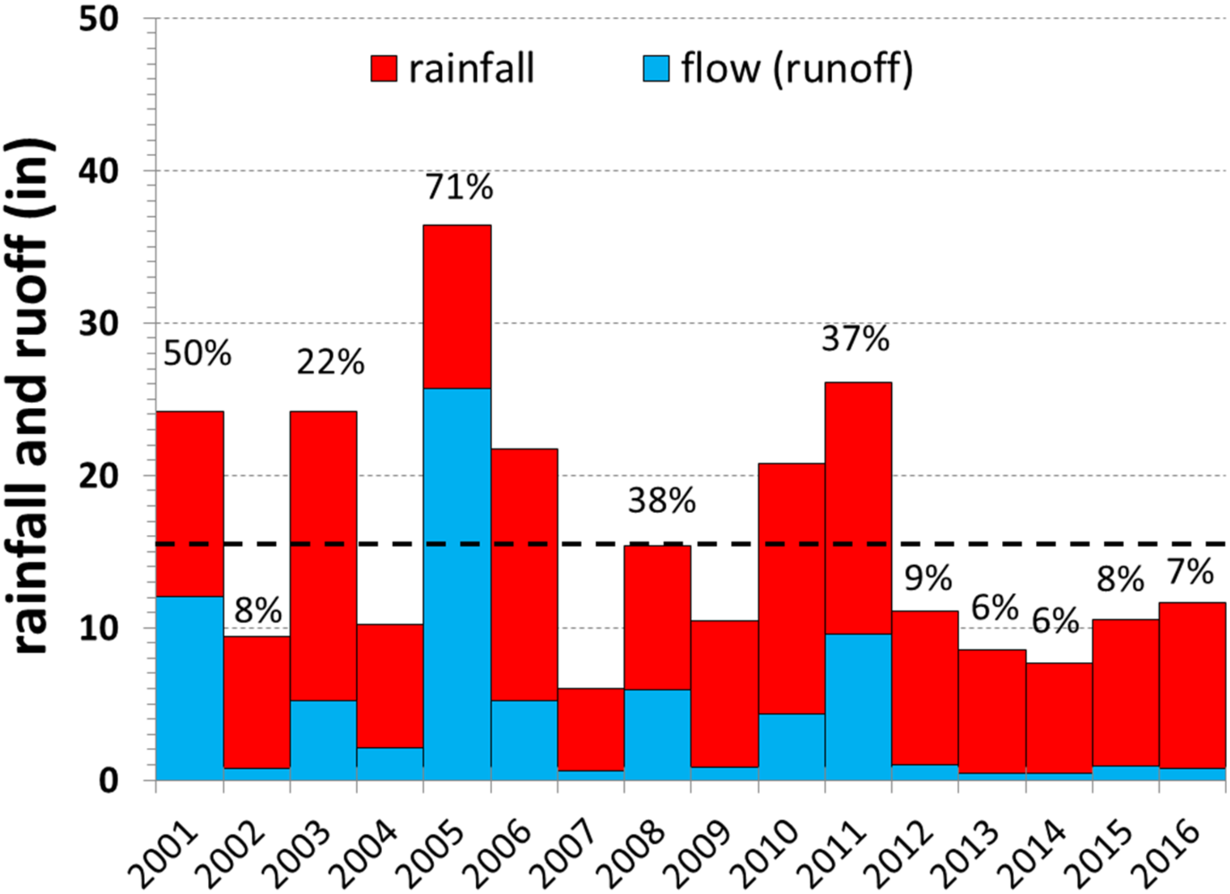


Where are we today? This is downtown Santa Barbara rainfall for this year as of the end of January. As you can see, January was wonderful, even better than December (both were above long-term monthly means and medians)—as long as you wanted rain. Not so good if you were getting to like the drought. The graph, as a comparison, also shows what happened back in 1998—a truly impressive El Nino year. We got 22 inches in February of that year, 47 inches in total, almost 3-times our annual average. This year, at the end of January, we're already pretty close to our annual median rainfall, 13.6 inches vs. 15.7. February will be the key to whether or not this turns out to be a *big* year in Southern California.

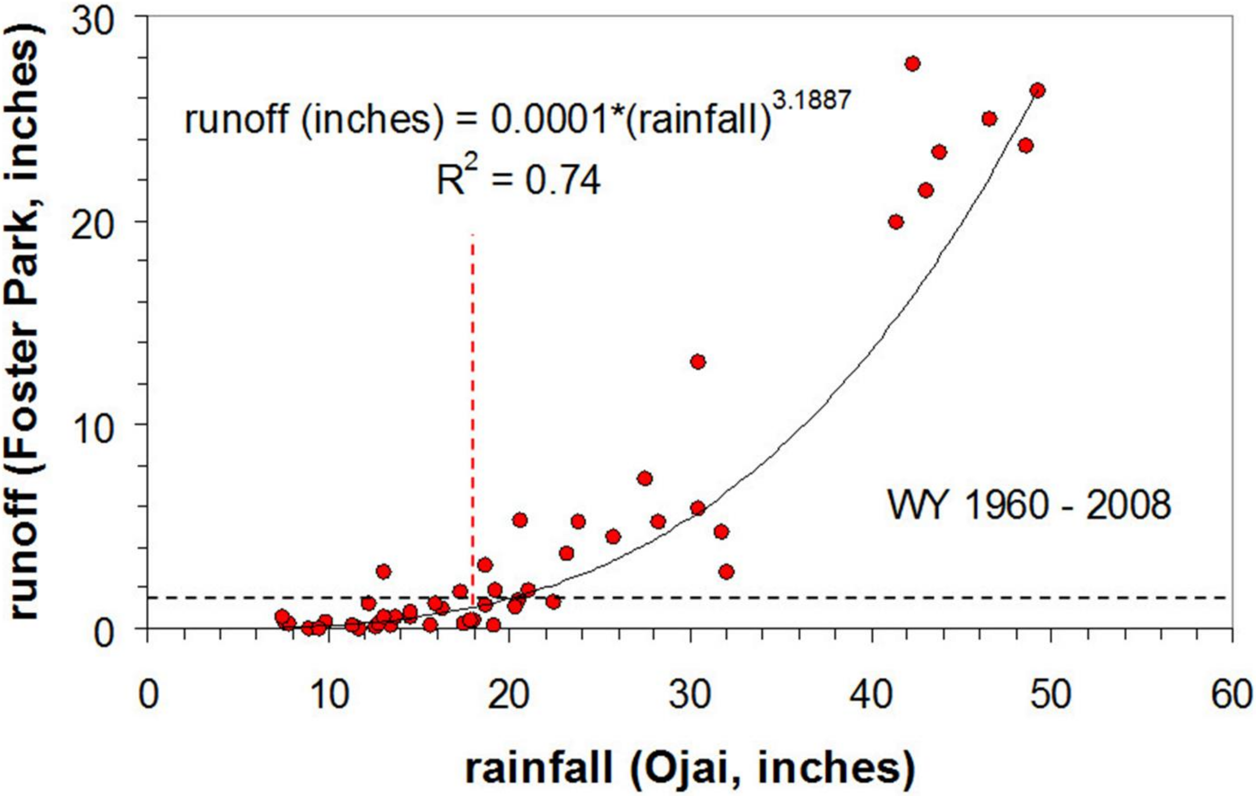




However, the key to California's water supply is not rain but snow, more precisely the snowpack in the Sierra Nevada. Rain produces quick runoff which rapidly fills reservoirs, and there's the rub. California reservoirs are designed to not only capture water for dry-season use, but to prevent floods and cannot be allowed to completely fill until very late in the rainy season. Capacity must be retained so as to capture runoff from late season storms. Indeed, rain-on-snow events in the mid-elevations have produced most of California's big floods in the past. Snow on the other hand just sits there in the mountains, waiting for late-spring and summer to melt it slowly; trickling it down exactly when it's most needed for agriculture. With global warming the worry has been less snow and more rain, with much of the early rain unavailable for capture because of the need to maintain flood storage for later storms. And with a thinner snowpack the possibility of late devastating rain-on-snow floods would be greatly increased.

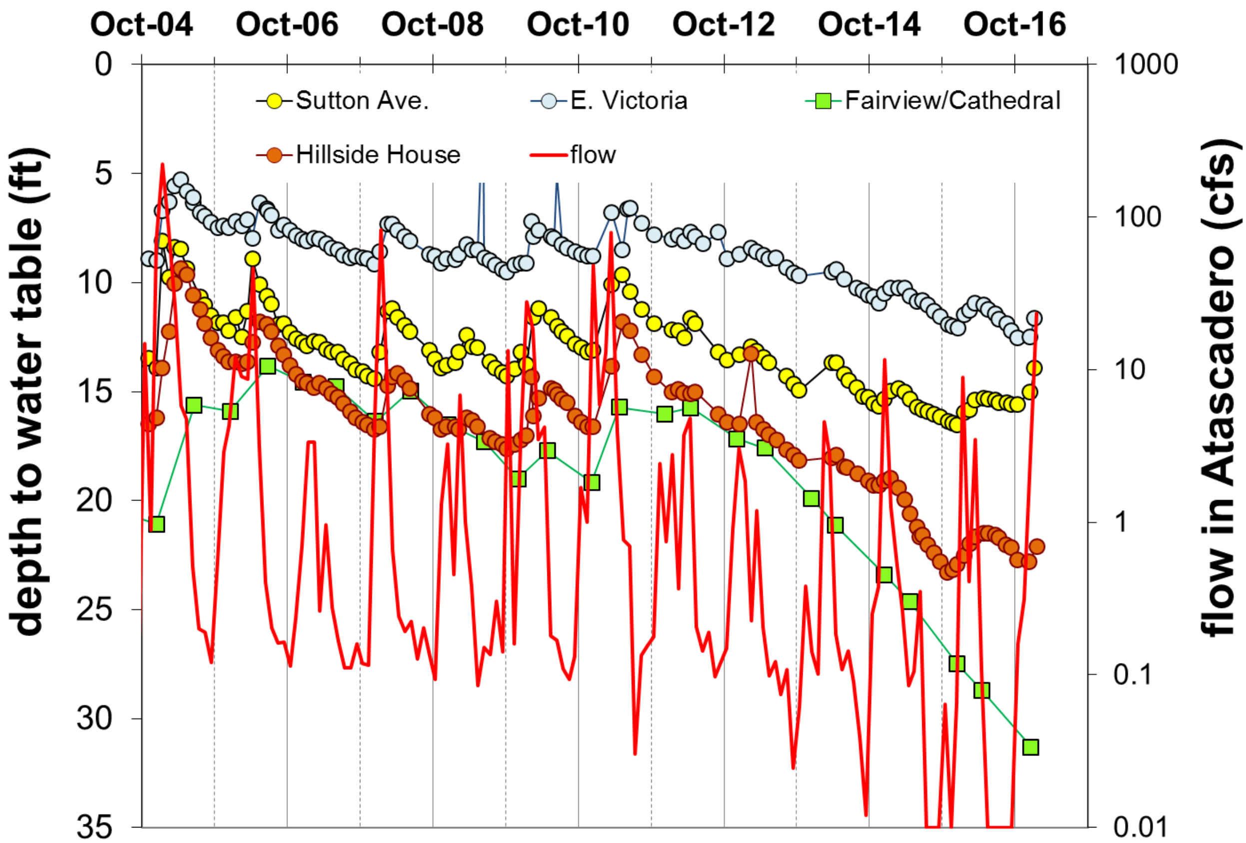


There's an obvious connection between rainfall and streamflow (or runoff), but it's not linear. Watersheds both store (mainly as groundwater and soil moisture) and utilize (via plant uptake and evaporation) rainfall. Most rainfall does not end up in the stream; only the biggest years have lots of runoff; low rainfall years have almost none. The graph shows the difference between annual rainfall and total annual flow (runoff) for Atascadero Creek as measured at the USGS gauging station at Patterson Bridge. The percentages shown above the annual bars indicate the percent of rainfall that ended up as streamflow. The dashed line marks the median annual rainfall for the watershed (15.7 inches, measured in downtown Santa Barbara): years with less than the median rainfall have very little streamflow 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.



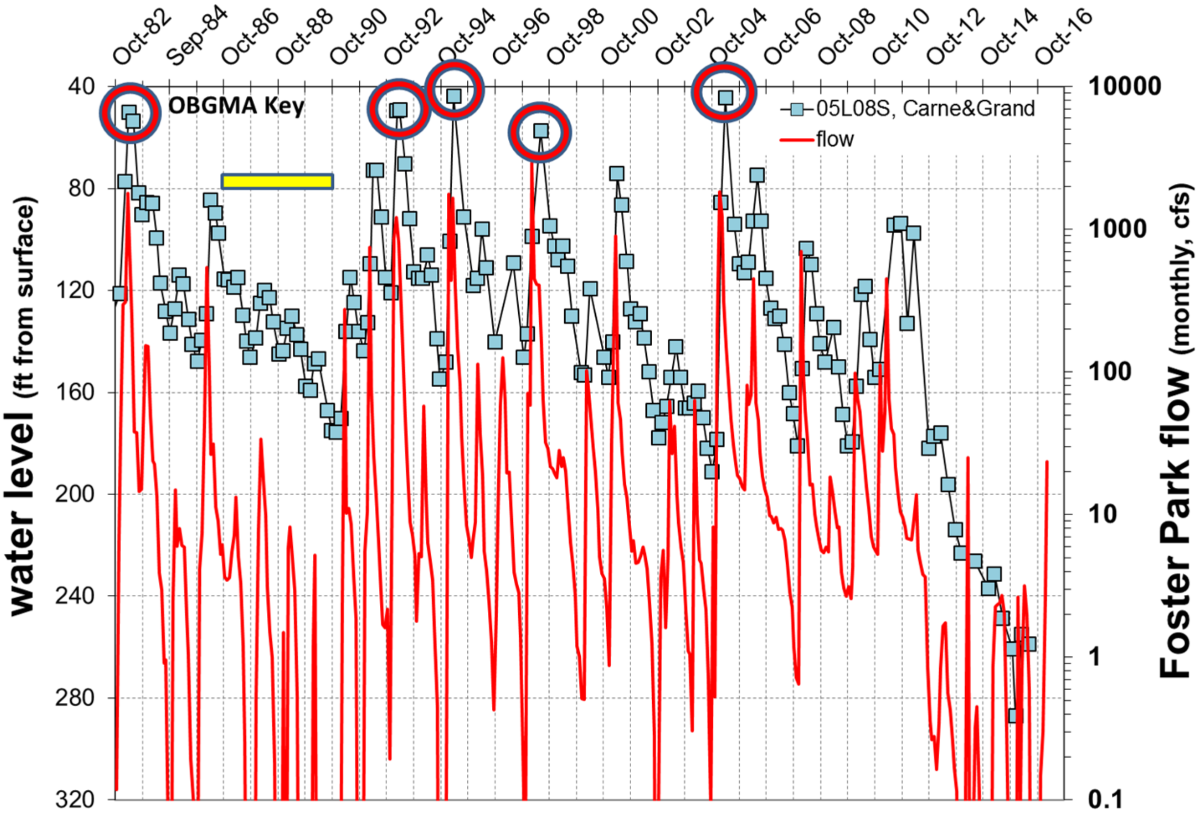
Let's shift to the Ventura River, a larger but similar stream just south of us, and explore this point further: In the graph Ojai rainfall represents the number of inches that fell upon the Ventura watershed in a given year (Ojai is about halfway up the catchment and a good proxy for average watershed rainfall). Some fraction of that total runs off down the Ventura River: so many inches in, so many inches out. How many? It depends on the amount of rainfall and you can see from the graph that the relationship is exponential – the amount of runoff increases dramatically as rainfall inches upward (pardon the pun). The exponent, rainfall to the power of 3, gives the equation this upwards leap as rainfall gradually increases; 1^3 equals 1, but 10^3 equals 1,000. It's a pretty good relationship as these things go (r-square = 0.74, which can be interpreted as indicating that annual rainfall can explain 74 % of the variation in annual runoff seen from year-to-year), but there is a lot of scatter away from the black line representing the equation. That scatter represents the other 26% of explanation, all those other reasons, besides the *amount* of annual rainfall, that may cause year-to-year differences in runoff.

The two dashed lines on the graph indicate the *most likely* amounts of annual rainfall (18 inches, shown as a red line) and annual runoff (1.3 inches, or 18.5 cfs, in black). I've used the term "most likely" since I'm referring to the *median* (as calculated from the entire Ojai rainfall and Foster Park flow records) and not the mean or average. The median represents the point in the record at which half the years had higher values and the other half lower. The annual rainfall record is *skewed* (i.e., the distribution is uneven, the median being different than the mean) but runoff is *really* skewed (mean rainfall is 21.2 inches, mean runoff 4.9 inches). In practical terms this simply indicates that in most years rainfall will be below average, and runoff a lot below average. Those occasional big rainfall years, represented by points in the upper right-hand corner of the graph, bias the distribution and cause this effect (in the same way that Bill Gates walking into a bar causes the average income of all the patrons to dramatically increase – although no one becomes better off, unless, of course, he starts buying drinks).



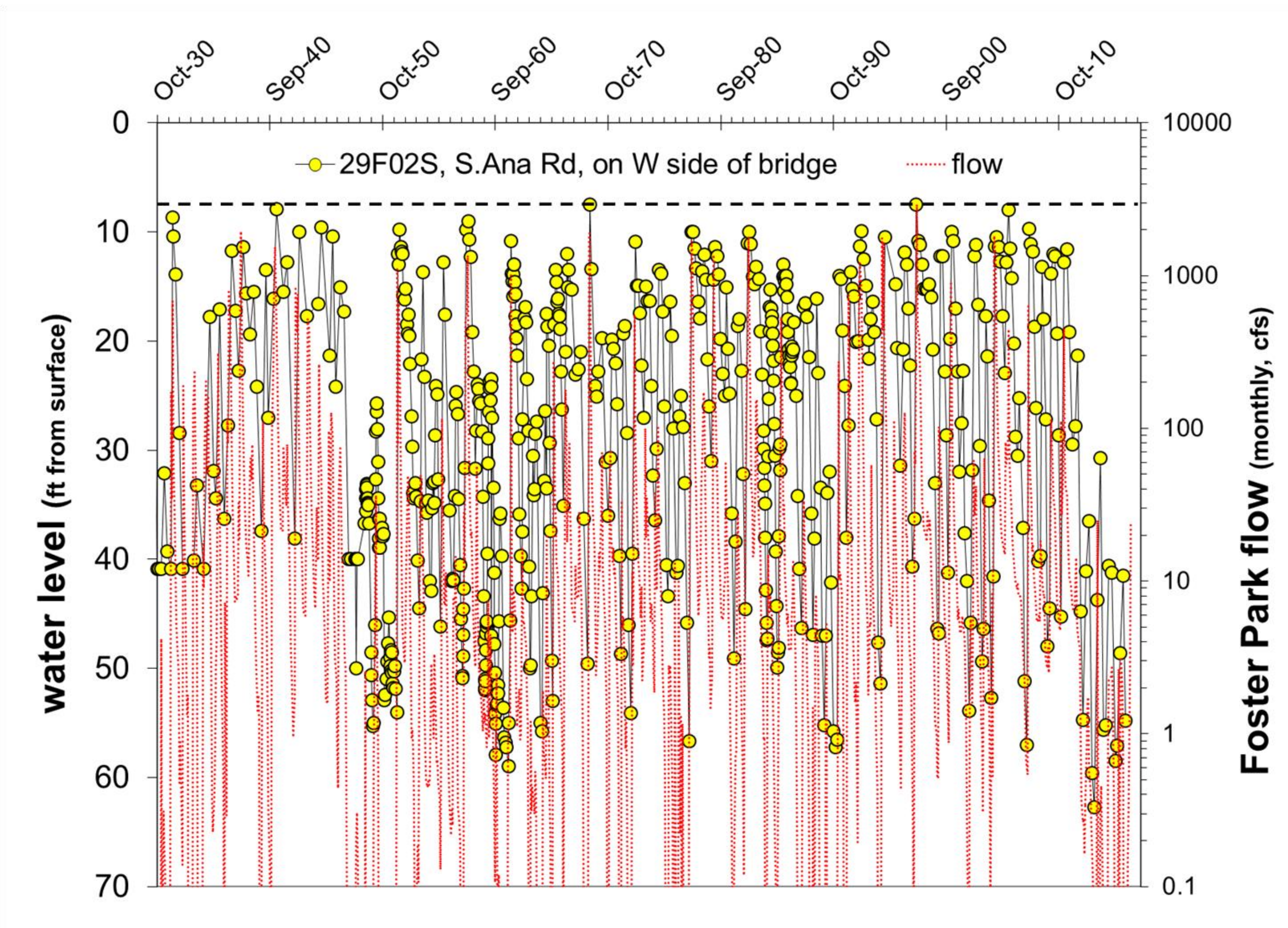
The connection between rainfall and changes in groundwater storage is also obvious. This is a graph of average monthly flows on Atascadero Creek (monthly flows remove much of the rainstorm spikiness seen in daily or hourly hydrographs) and the depth to groundwater for two shallow wells (Sutton & Victoria) in downtown Santa Barbara. Note how close to the surface the water level is (within 5 ft. during a *big* year at the Victoria well). If you've ever wanted to know why parts of downtown flood during big rainstorms, this is the reason. The Fairview/Cathedral well is in upper Goleta, near the foothill transition. Groundwater levels in these 3 wells are closely correlated with streamflow. Hillside House is near Veronica Springs, adjacent to Arroyo Burro. It too fluctuated with streamflow until the drought, during which it showed a steady drop in water level of about 17 additional feet—undoubtedly because of pumping at a nearby City well. All the wells show an obvious downward during the years of the recent drought (2012-2016) and only now are beginning to show an uptick (the latest measurements were taken in mid-January 2017).

Atascadero, unlike almost all other creeks in the area, flows for a considerable portion of its length ***parallel***, not ***perpendicular***, to the coast. This allows it to benefit from the high coastal water table and is one of main reasons it, again unlike most other creeks, almost always has flowing water.

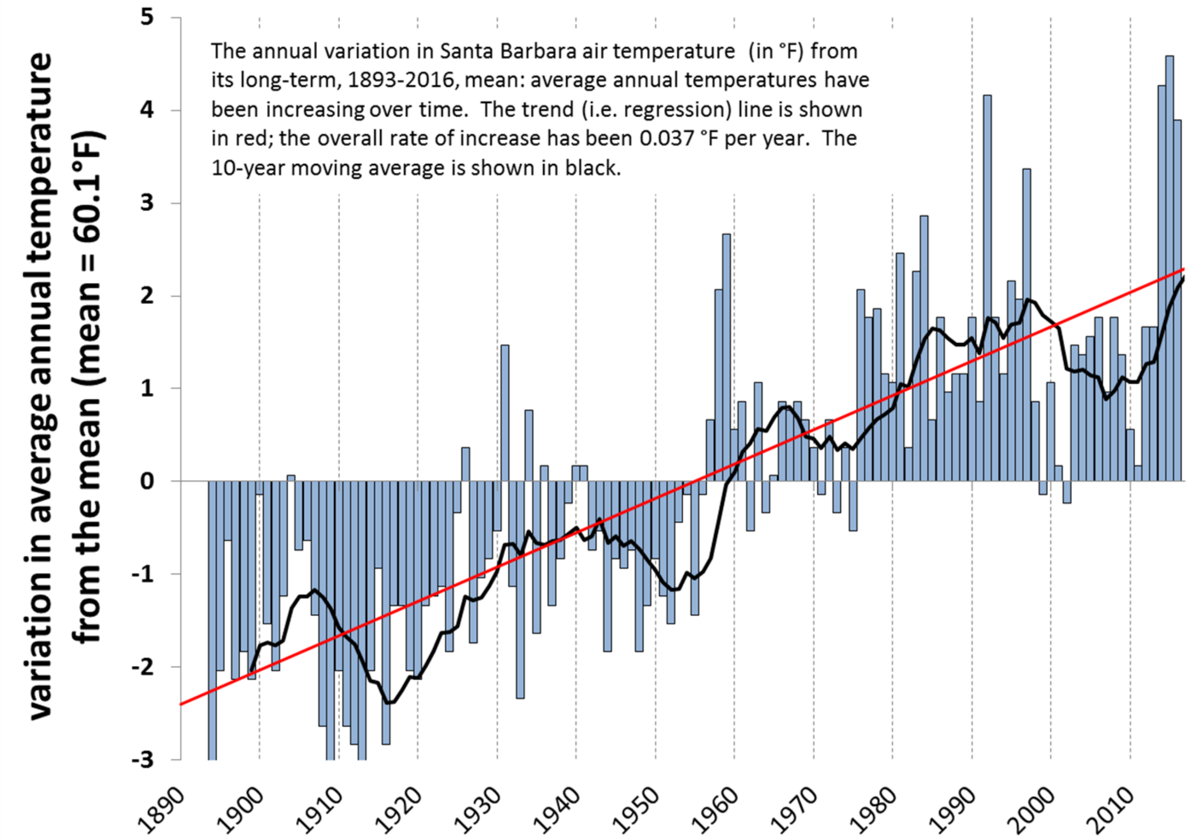


Let's look at a few more wells: The graph shows changes in depth-to-groundwater over time in what is regarded as the "key" well in the Ojai Basin along with average monthly flows in the Ventura River at Foster Park. The variation is similar, as it should be, since both are directly related to seasonal rainfall. The high points—when the water-table rises closest to the surface and when monthly flows were at a peak—represent big El Niño or Atmospheric River wet seasons: 1983, 1993, 1995, 1998 (big El Niños) and 2005 (a big Atmospheric River, i.e. Pineapple Express, year). (I've marked these with red circles—keep in mind that the water-year runs from October thru September so Oct-82 on the graph marks the beginning of the 1983 water-year, etc.). I've also marked—with a yellow bar—our longest previous dry spell: the 1987-1991 drought. We've also had other, relatively recent, dry years: 2002, 2004 and 2007.

Over time, dry-years have been increasingly lowering water levels in this well. By the end of the 87-91 drought the lowest level reached was 175' below ground. But the single dry year of 2002 lowered the water-table to 178'. It was 191' in the dry, but not quite as dry, 2004. And 181' in 2007 following two very wet years. This points to increasing groundwater withdrawals, perhaps unsustainable withdrawals, in the Ojai Basin over time. By December 2015 the level had dropped to 287'—112' below the 1991 minimum of the previous drought. In contrast, during the early spring of very wet years the groundwater table is only about 45' below the ground surface. It's not just the Colorado River that's becoming increasingly unable to meet the water demands being placed on it.

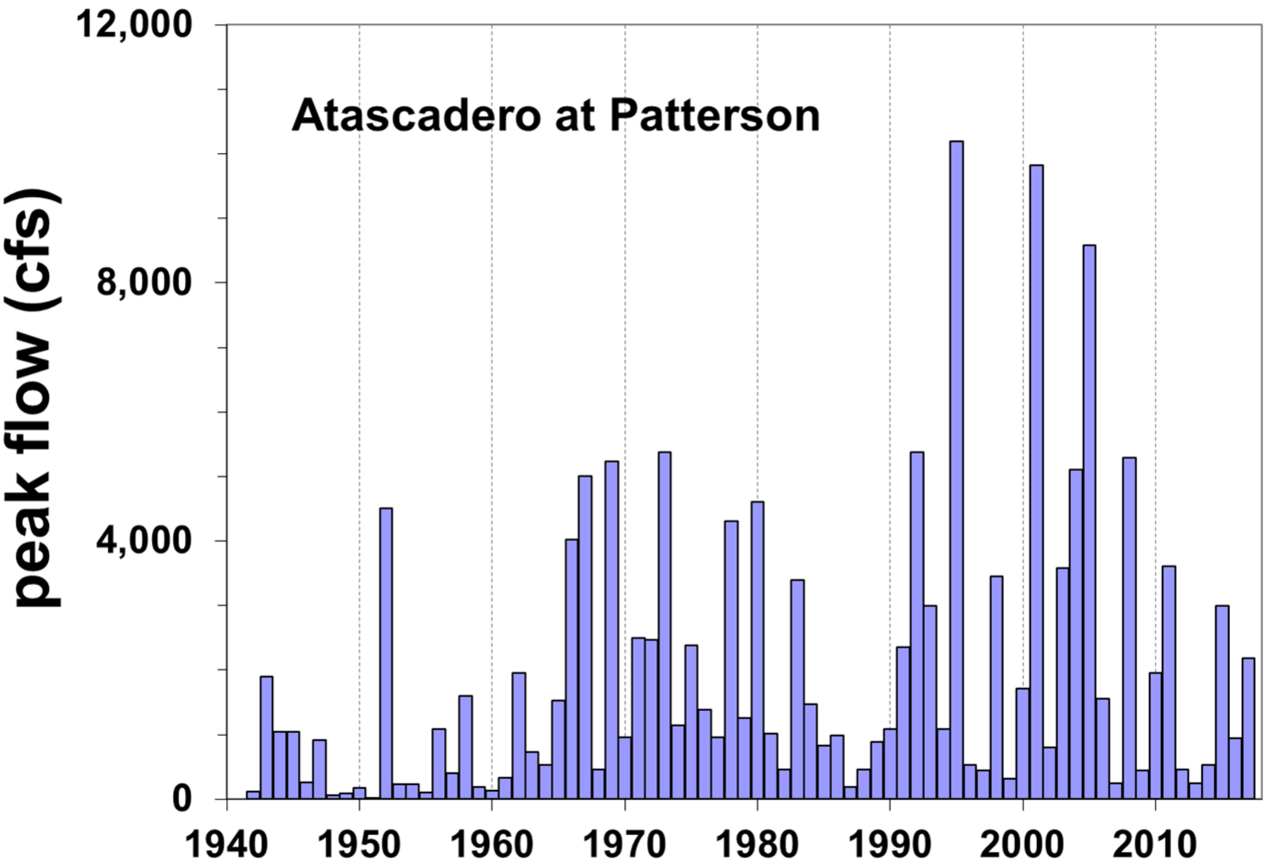


One more well graph: This one for a well sitting just adjacent to the middle reach of the Ventura River. The dashed line at the top shows the water level in the well when the river is flowing in the spring of a big year (1967, 1998 and 2005 are the more recent peak points); the level at these times is 7 feet below the surface. Note that the most recent drought has dropped the water level to the lowest elevations ever seen in the roughly 90-year record for this well. This lowest level is about 50 feet below the bottom of the river. Think about that for a minute . . . The drought was so severe that the local water table fell 50 feet below the level of the river. Or conversely, the water table must now rise more than 50 feet for there to be sustained flow in this reach of the river.



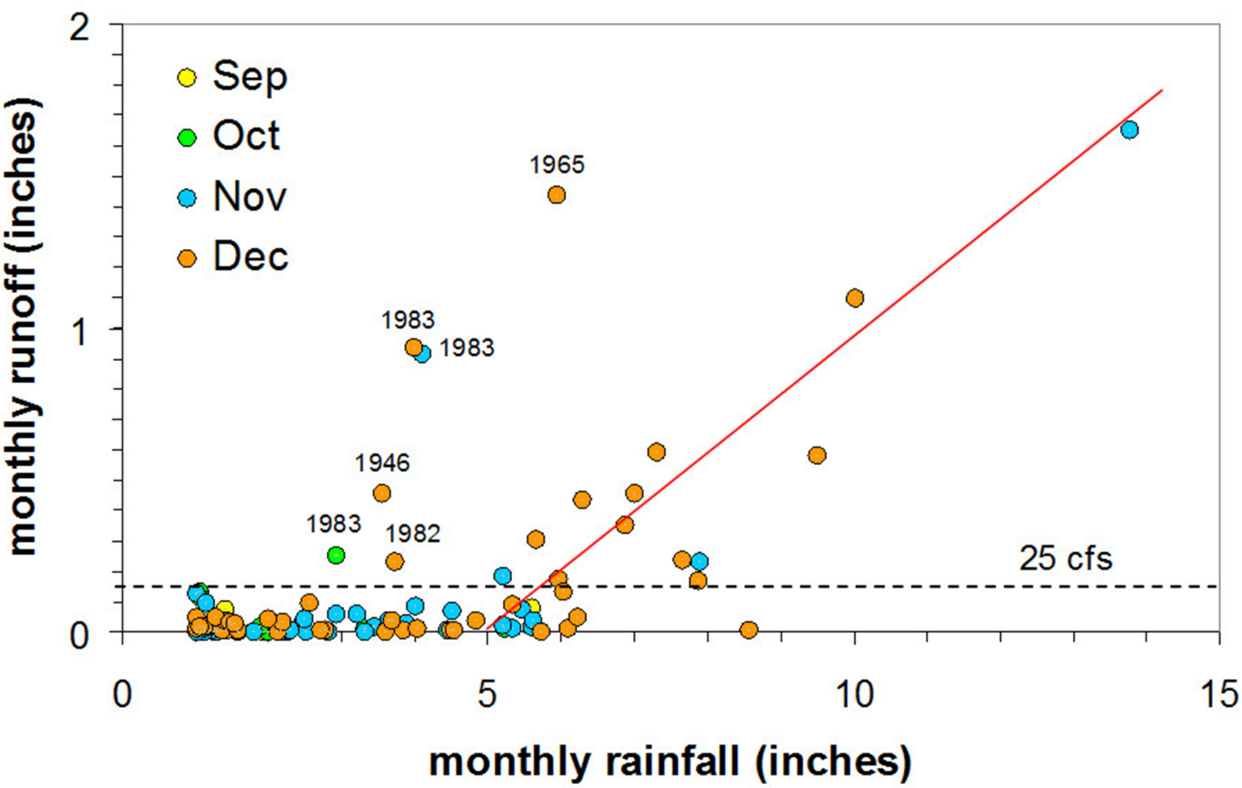
A recent paper, based on tree-ring studies, by Daniel Grin and Kevin J Anchukaitis (*How unusual is the 2012-2014 California drought?*) reached some interesting conclusions: Three-year droughts are not unusual over the last millennium in California and can occur with as little as a single year between consecutive droughts. Over the last 1200 years, they estimate that there were 37 occurrences of 3-year droughts and a total of 66 uninterrupted dry periods (every year below the 800 to 2014 precipitation mean) lasting between 3 and 9 years. *Further, that ~44% of the 3-year droughts go on to last 4 years or longer.* However the 2012-2014 drought stands out in the context of the last millennium. In terms of cumulative severity, it is the worst drought on record . . . and 2014 is the single most arid case in the last 1200 years. But the precipitation deficits of 2014 and the three-year period are not unique in the paleoclimate record. I quote, "*A simple modeling exercise, calculating the average Palmer Drought Severity Index with observed vs. climatological mean temperatures, suggests that temperature could have exacerbated the 2014 drought by approximately 36%. Based on these complementary lines of evidence, we infer that the severity of the 2014 drought is a result of both anomalously low—yet, not unprecedented—water year precipitation and record high temperatures.*"

The graph shows the change over time in the average annual Santa Barbara temperature (as the annual difference from the overall 1893 through 2016 mean). The change, since Grover Cleveland was President, has been almost 4°F. If Grin and Anchukaitis are correct, all future droughts will be worse than any similar past drought, because of increased temperatures. This brings global warming home with a vengeance. An earlier graph showed the difference between rainfall & runoff, most of that missing water goes to evapo-transpiration, and as increased temperatures magnify evapo-transpiration, we can expect even lower flows in our region's creeks and rivers.

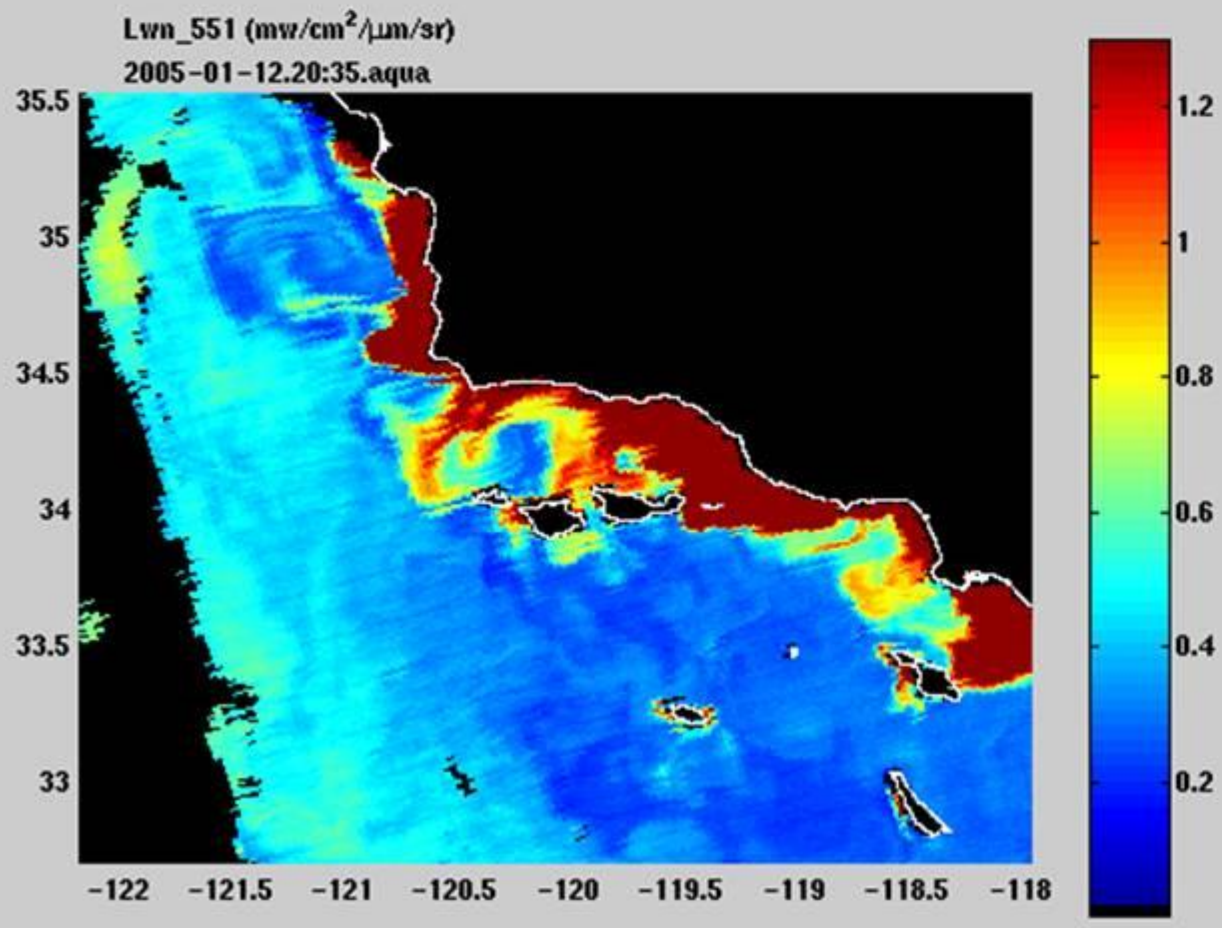


And finally, while the amount of annual rainfall is important, so too is the ***size*** of the biggest storm of the year (the graph shows annual peak flows in Atascadero Creek, measured at Patterson Avenue). The size of that storm determines how much modification and transformation of the stream channel takes place. Or whether or not any takes place at all. Big storms are important because they transform the stream channel and its ecology. Thus affecting its chemistry. Really big flows occur very rarely, usually, but not invariably, during *big* years. And major sediment moving events may occur only once every thirty or so years.

Note that the size of the big annual flood has been increasing over the years – in general, the biggest floods have occurred relatively recently. This is the cost of urbanization. The more you pave and roof, the faster ever increasing amounts of runoff rush directly to the creek. In hydrologist speak, the hydrograph gets steeper, higher and shorter, and a hell of a lot more impressive.



How much rainfall does it take before the entire watershed begins to contribute runoff to flood flow? Here monthly runoff (in inches at Foster Park) is plotted against monthly rainfall for the months of September through December from the Ojai rainfall record (which begins in October 1940) for months with more than 1 inch of rainfall. I'm using only months at the beginning of the rainy-season because we're looking for the amount of rainfall that gets everything started – what it initially takes to get runoff flowing from all over the watershed. Once this happens, the watershed thoroughly soaked and its dry soils saturated, it's another story, a story that usually happens in later months. Two lines are shown on the graph. The one drawn at 0.15 inches per month simply converts that awkward unit into 25 cfs at Foster Park; for context, 25 cfs is the median (i.e. most likely) March flow at Foster Park. The second is hand drawn through months that produced appreciable runoff, months when most of the entire watershed had to be contributing to flow. Note its intersection with the rainfall axis occurs at ~5 inches, i.e., at least 5 inches of rainfall in one month, in one storm or combination of storms, is required to generate runoff from Ventura's upland and mountain areas. Thus anything over 5 inches occurring in approximately one month's time at the beginning of the rainy season will set the stage for a sizable flood; if not in that particular month then in one of the months that follow. This year, after almost 3 years of negligible or no flow, the Ventura finally began to flow at Foster Park on Jan. 20; the amount of rainfall in the preceding 20 days had been 5.28 inches. But before congratulating myself, I need to mention that the watershed was so dry that it took 5.2 inches of prior rainfall in Oct., Nov. and Dec. to prepare the ground for the January appearance of flow.



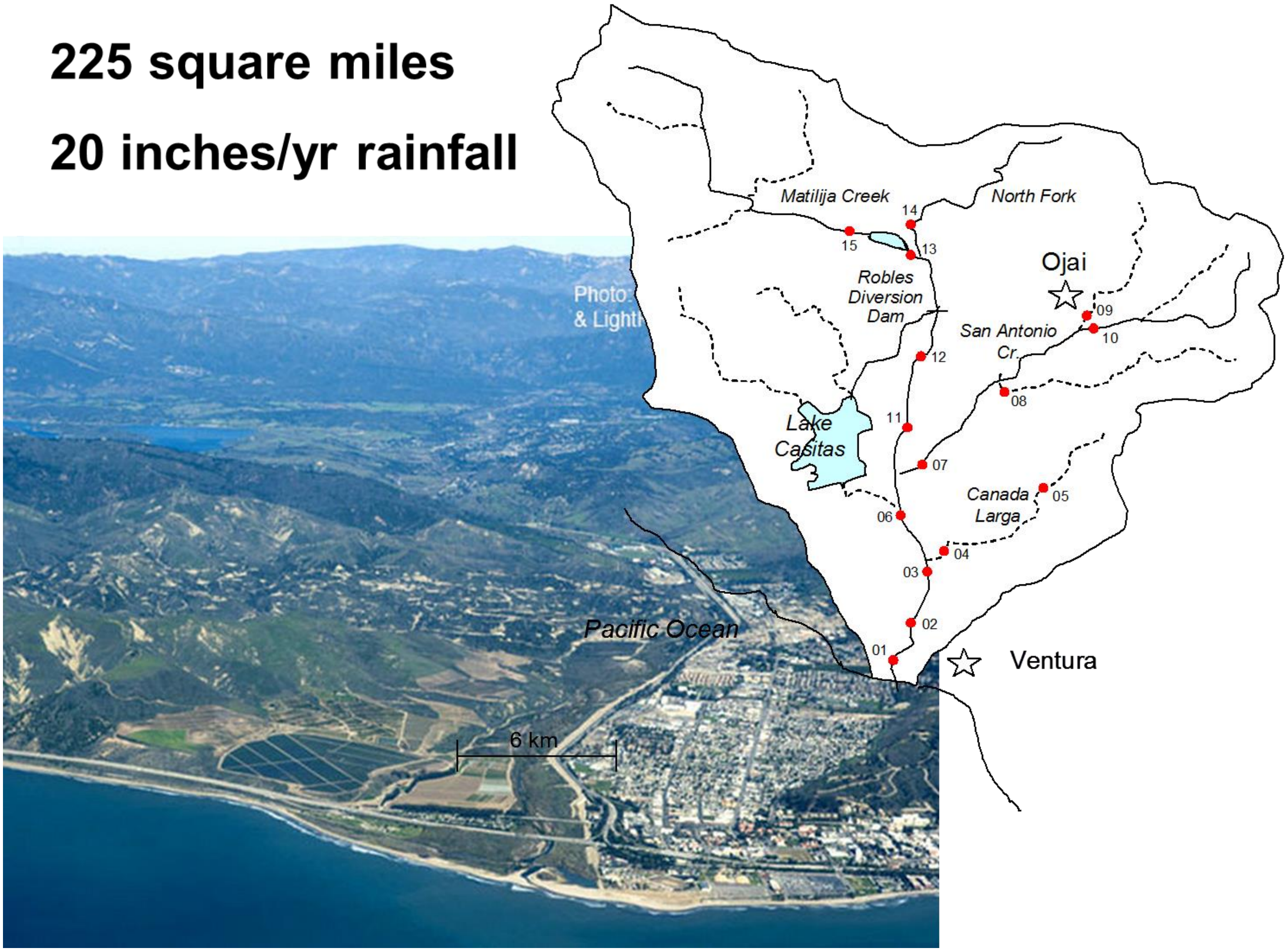
How impressive is a *big* year flood after the post dry–season soil moisture deficit has been made up? The slide shows a satellite view of sediment plumes in the Santa Barbara Channel (increasing concentrations of sediment are marked by color changes of yellow to red to brown) on Jan. 12, 2005 (this was two days after the peak of that year's big storm. In the image the plume extends out as far as 25-30 miles from the coast. Only very large storms are able to impact the Santa Barbara Channel to this extent – or move this much sediment. Downtown Santa Barbara had 37 inches of rain that year. 2005 was, up to now, our last "big" year. We have not had a year this big, or a storm as big as this one, since then.

This is a satellite image taken on January 11, 2005 (a day before the image shown in the previous slide). I've labeled the major river and creek contributors to sediment flows (and pollution) from the adjacent California coast to the Santa Barbara Channel and the Pacific Ocean. As you can see, very little is coming from the Santa Barbara area. This is not a sign of our higher moral virtue and greater ecological conscientiousness, simply a result of our local streams being so short and puny.

The big contributors are not just contributing sediment, but nutrients and trash, and even stuff we hardly ever think about these days, like DDT (banned since 1972) or PCBs (banned since 1979) which are still found in the soil and are released as soil is reworked and storms carry it downstream.

225 square miles

20 inches/yr rainfall



The variation in annual rainfall and streamflow, and in the intensity of the peak annual storm, produce dramatic changes in the appearance and biological functioning of the region's streams. Although I've mentioned the Ventura River previously, to show the change and functioning business better we'll now focus on it. Channelkeeper also has a monitoring program on the Ventura and the map shows the monitoring locations.

The Ventura watershed is very similar to those in Santa Barbara & Goleta: similar geology, similar land uses, same climate. Even the elevation change is about the same. It's just stretched out and lengthened . . . making the Ventura River much longer than your average Santa Barbara creek. And being bigger, it has greater amounts of runoff and shows change more dramatically: changes in the river and its riverine environment, and changes from year to year.

looking upstream looking downstream

From the Shell Bridge, Ventura River: Feb. 2, 2005 (above), Oct. 2, 2004 (below)

A single winter can make a big difference. The lower photos show conditions in the Fall of 2004: looking both upstream and down from Shell Bridge (about 3 miles upstream from the ocean). The upper photos show what these same places looked like four months later . . . after a very wet winter and a very big storm (44 inches of rainfall in Ojai, 16 of those inches in January alone). A “big” winter produces open water and a stream bed scoured of sediment, plants and riparian trees – perfect conditions for subsequent algal growth. And algae did dominate these open waters during the following dry-season. However, as years pass without a significant big storm the plants and trees shown in the 2004 photos will again become the major ecological players in and along the stream.

looking downstream looking upstream

From the Main Street Bridge, Ventura River: Feb. 2, 2005 (above), Oct. 2, 2004 (below)

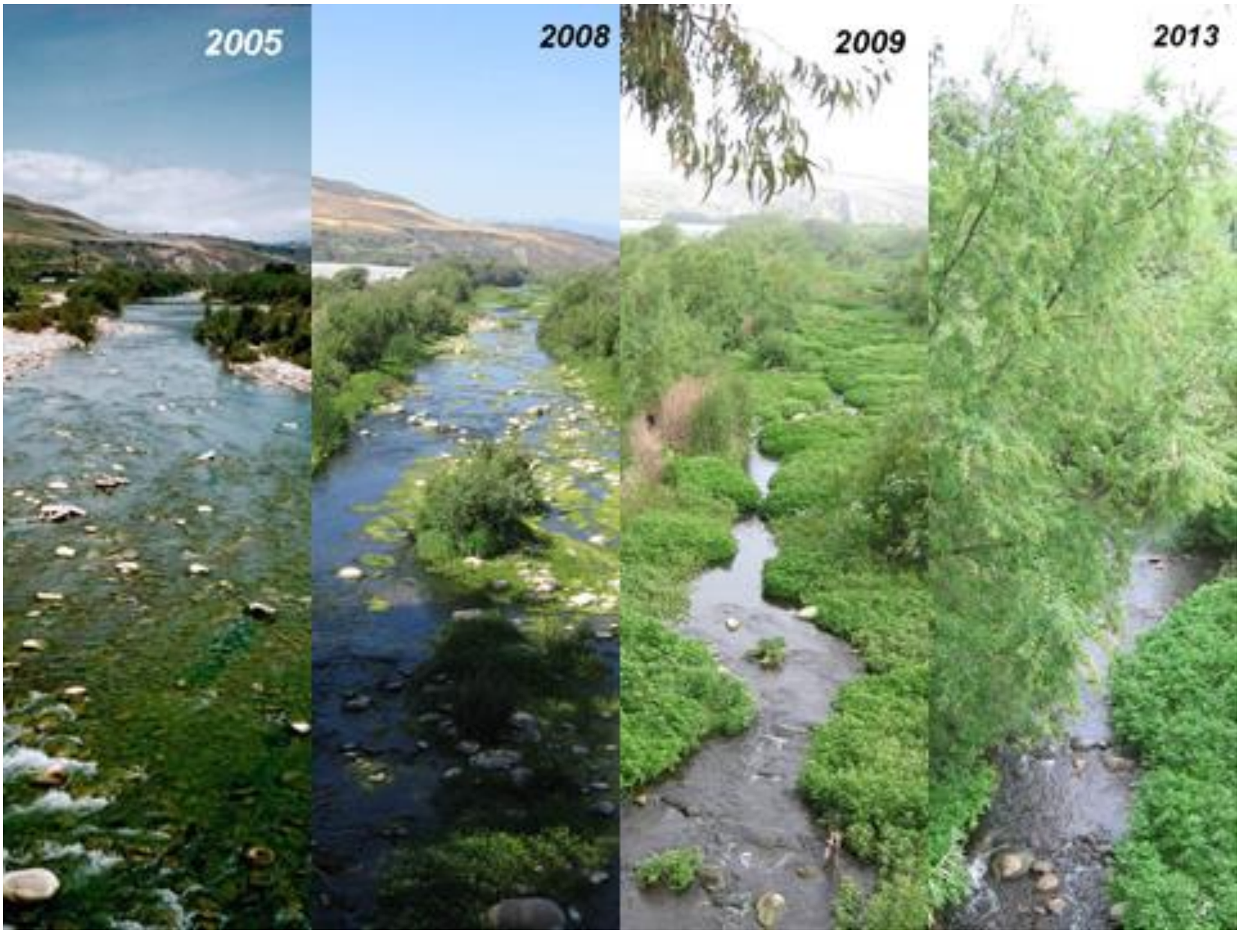
Here are more photos of the 2004/2005 change, showing peak-flow modification of the river and its ecological functioning. These photos were taken just above the tidal limit, adjacent to Highway 101. This slide contrasts the “before” (lower photo) and “after” (upper photo) stream environments bracketing a big year on the lower Ventura River with photos taken on Oct. 2, 2004 and Feb. 2, 2005. They could just as easily have been titled 1997 and 1998 (an earlier “big” year transition).

Change doesn’t just occur during a big year, modifications from year to year or even within a singe year can often be almost as dramatic. We are again looking upstream from the Shell Road Bridge (annual runoff/annual rainfall, in inches, are shown in bold face for each year): left to right, on top: July 2001 (algae dominate following a wet winter; **7.4/27.6**), Aug. 2002 (aquatic plants out-compete and replace the algae in a dry year; **0.3/7.8**), March 2003 (algae return to an open environment following a large storm; **1.1/20.4**); on bottom: Oct. 2003 (aquatic plants overwhelm earlier 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 extreme changes caused by wet-winter/dry-winter rainfall differences on the lower Ventura River are accompanied by ecological transformations: large storms = algal dominance; the absence of large storms = dominance by aquatic plants. And a winter with a moderately large storm results in algae at the beginning of the dry-season being replaced by aquatic plants during the latter months.

January 20, 2017: Main Street, Ventura (left), Foster Park (right)

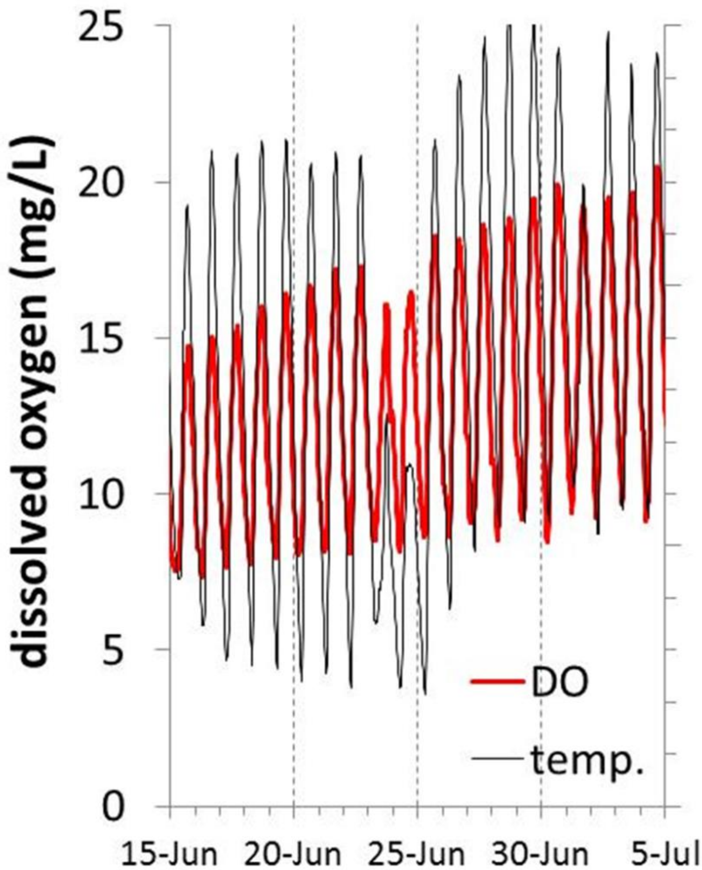
As dry-year follows dry-year riparian vegetation strengthens its hold on the river bottom: brush proliferates and grows denser and trees grow taller and more strongly rooted. We've had a long dry spell, almost six years since the last good year (2011) and twelve years since the last big year totally cleaned out all vegetation (2005). That big clock-cleaning 2005 flood had a maximum flow of 44,000 cfs. A flood of 15,000 in 2008 partially cleaned the river out again. But the 19,000 cfs flood of 2011 was able to work very little of its magic. About a year-and-a-half's growth between 2008 and 2005 vs. two-and-a-half years between the incomplete cleaning of 2008 and 2011 explains the difference. The size flood that would restore the river to its 2005 condition after what is now a considerable passage of time would have to be extremely large. The photos were taken on January 20, the first day of real flow in many years on the Ventura; peak flow was over 4,000 cfs. On the 22nd another storm increased flow to about 6,000 cfs. As you can see, neither storm removed much vegetation. In the earlier years of this century six thousand cfs would have done the job. We should be careful about how much rain we wish for.



Let’s look at how various aquatic parameters might vary with changes in ecological condition at a single location: in this case just upstream from the Main St. Bridge. First, consider what we might call the “mass” problem: the larger a volume the more resistant it becomes to change. Just as a toy car is far easier to push than a real one, small volumes (i.e. low flows) are more easily modified; and the smaller the volume, or the lower the flow, the easier and more rapid the change. Consider temperature: those who have ever taken a August swim in an Alpine lake know that however hot the summer the water remains frigid, while a small stream exposed to the sun readily warms over the course of a single afternoon.

During daylight, algae remove carbon dioxide from water, replacing it with oxygen; at night the process is reversed. This causes dissolved oxygen concentrations to fluctuate on a daily cycle, and since carbon dioxide in water is a weak acid (carbonic acid) so does *p*H. At high flows or in a big river, the impact is muted, but as flow decreases this day/night variation becomes more extreme. Organic sediments accumulating on a river bottom extract oxygen as they decay. Un-noticed at higher flows, this process can significantly lower DO as flows slow to a trickle. Aquatic plants further retard flow and efficiently trap sediment, increasing this effect as well as serving as additional substrate for photosynthetic diatoms.

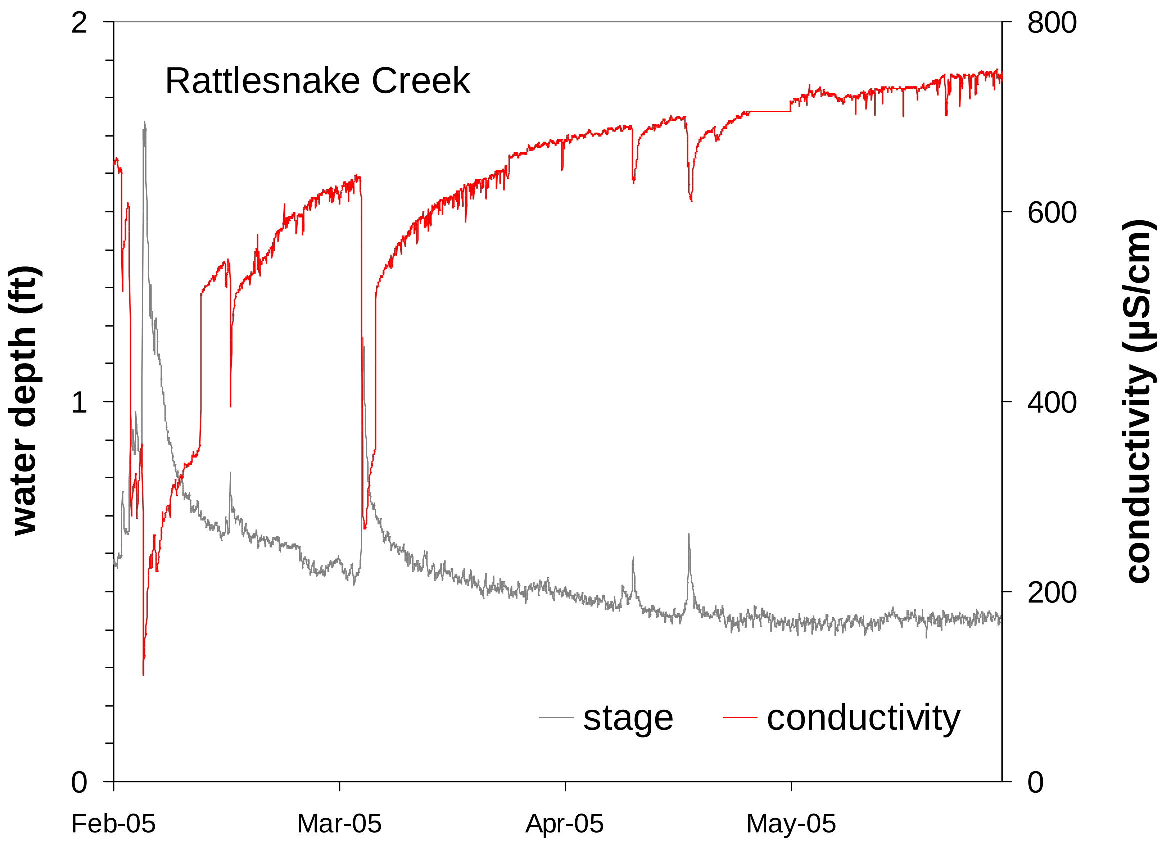
A few miles upstream of this point a sewage treatment plant dumps nutrient-enriched treated effluent into the river. Higher flows considerably dilute this loading and large masses of algae remove much of it before it reaches Main St. In low rainfall years the relative proportion of effluent increases considerably (effluent often being the only thing keeping water in the river during very dry years), but much slower flows and masses of aquatic plants increase sedimentation and dramatically reduce nutrient concentrations (with the help of those associated diatoms)—nitrate concentration being often reduced to zero.



Ventura River just above the San Antonio confluence, June 2013

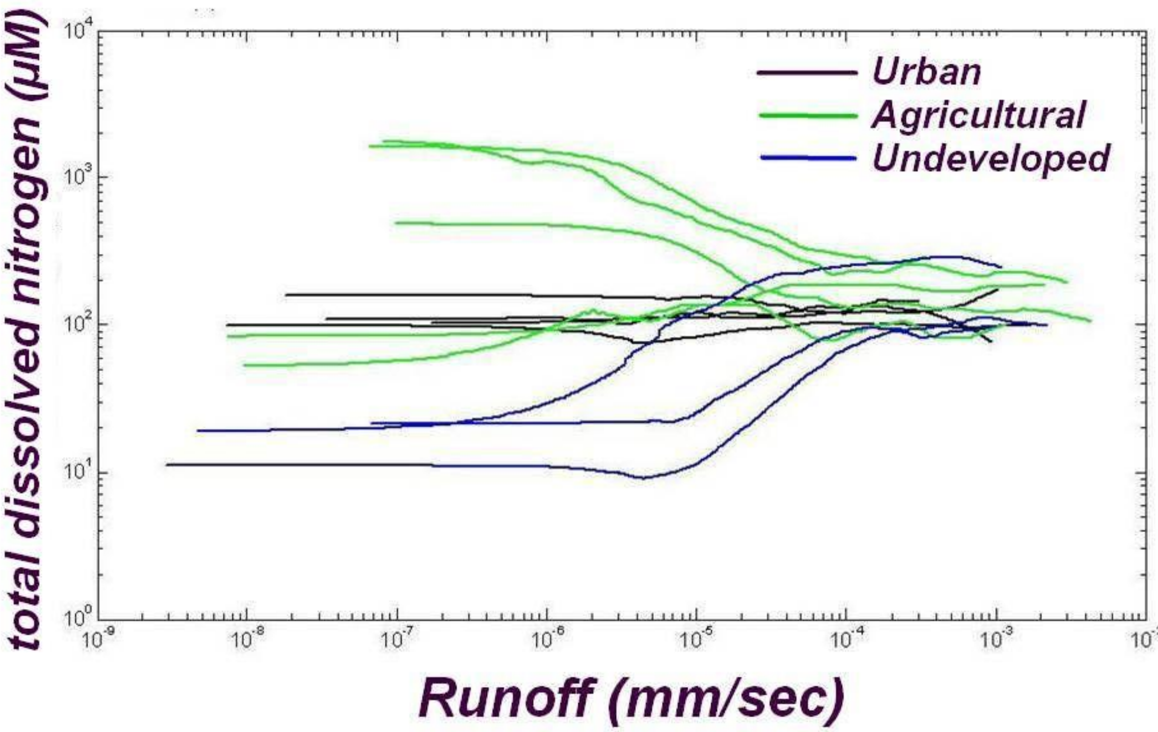
Here's an example of how much water temperature can vary in a small sluggish stream; in this case the Ventura River at the San Antonio Creek confluence during a second summer of drought. The plentiful algae present are responsible for the daily fluctuation in dissolved oxygen (*p*H, not shown, would vary in the same manner: the time of maximum oxygen production is also when maximum carbon dioxide removal is occurring, i.e., maximum reduction in acidity and, thus, maximum *p*H).

The peak in all these parameters is occurring in late afternoon, around 4-5:00 PM. The % DO saturation is around 200%, meaning that the water contains twice the amount of dissolved oxygen it could normally hold under equilibrium conditions (i.e., at the same temperature and barometric pressure). A good rule-of-thumb is that you should suspect algae as the cause whenever the % saturation climbs above 120%. (Data shown in the graph were collected at a 30 min. time interval.)



However, some parameters ***are*** relatively stable, and change is usually slow and gradual.

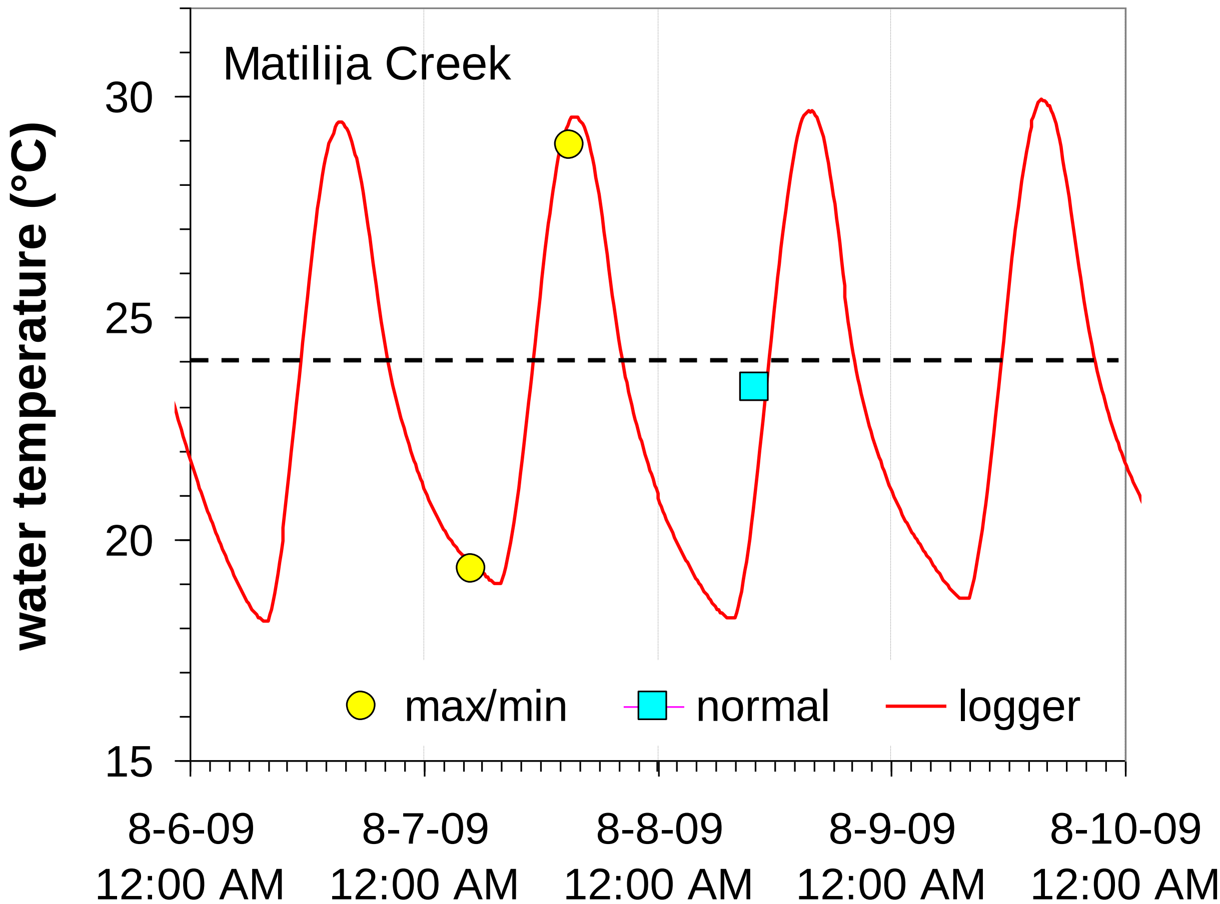
This graph shows hourly measurements of water depth (stage) and electrical conductivity on Rattlesnake Creek from February through May, 2005. Notice that, except during periods of rainfall (marked by abrupt increases in water depth and decreases in conductivity), conductivity is changing gradually and without much variation from hour to hour or from day to day. Parameters (like conductivity), relatively unaffected by stream biology, can be meaningfully measured at infrequent intervals ***as long as conditions are not dramatically and rapidly changing***. When things *are* rapidly changing, as during storms, all bets are off and you can anticipate rapid change, especially while rain is still falling and flows continue to increase.



A good example of one of these “all bets are off” occasions is what happens with nutrient concentrations during storms. This is a graph that Blair Goodridge (UCSB LTER) put together. It shows total dissolved nitrogen concentrations (TDN) on the y-axis and flow on the x-axis (measured in mm/sec; mm/sec is a strange term that translates flow in a stream to an equivalent depth of water flowing over the entire watershed surface – derived by dividing streamflow in cubic meters/sec by the watershed area in square meters and then converting meters/sec to mm/sec – its great advantage as a unit is that it eliminates watershed area from considerations of flow and allows streams of very different sizes to be directly compared).

The graph represents what happens to nitrogen (here it’s mainly nitrate) concentrations as rainfall increases on a wide variety of creeks in the Santa Barbara/Goleta area. At the beginning of the storm – and during dry-season flow in general – undeveloped or relatively pristine creeks have very low nitrogen concentrations (~ 10 µM; note 71 µM = 1 mg/L); urban creek concentrations are usually an order-of-magnitude higher (~ 100-200 µM) and creeks with large amounts of intensive agriculture two or more orders of magnitude higher (concentrations in the thousands of µM).

As runoff increases however, highly polluted creeks become less polluted, and relatively “clean” streams become more polluted. This is what generally happens with stream contaminants – rainwater and runoff dilute high concentrations of stream pollutants in our worse streams, and wash off pollutants from the land into our cleanest streams. Call it sharing the wealth.



This is an example of what can go wrong if you monitor a rapidly varying parameter under an assumption of gradual change. The slide shows 3 different water temperature measurements made by Channelkeeper during the early part of August, 2009. The blue square (normal) was the measurement made during the regularly monthly sampling program: 23.4 degrees, recorded at 10 AM. The yellow circles (max/min) were measurements made a day earlier at 5 AM and 3 PM as part of a special sampling program designed to capture maximum and minimum dissolved oxygen levels in the Ventura basin. Finally, the red line (logger) shows temperature recorded by a data logger every 10 minutes throughout this period. The black dashed line marks the maximum desirable temperature for Steelhead; above 24 degrees Steelhead mortality begins to appreciably increase.

For 8 years Channelkeeper measured water temperature at this location and never recorded anything above 24 °C. Because, obviously, they just happened to be measuring it at the wrong time. Not until 2008, with the start of min/max sampling, did this temperature problem become known. Measuring a parameter at an incorrect frequency will not only result in inadequate data (not incorrect, just inadequate), but it might be worse than not taking any measurements at all – since it may lead to a false conclusion. Let me repeat: sometimes no data is better than some data. As in this case. So if you are going to take a bunch of one-time measurements in some stream, water temperature is mostly useful only if you want to know why your feet feel cold. The same reservation can apply to DO and *p*H.

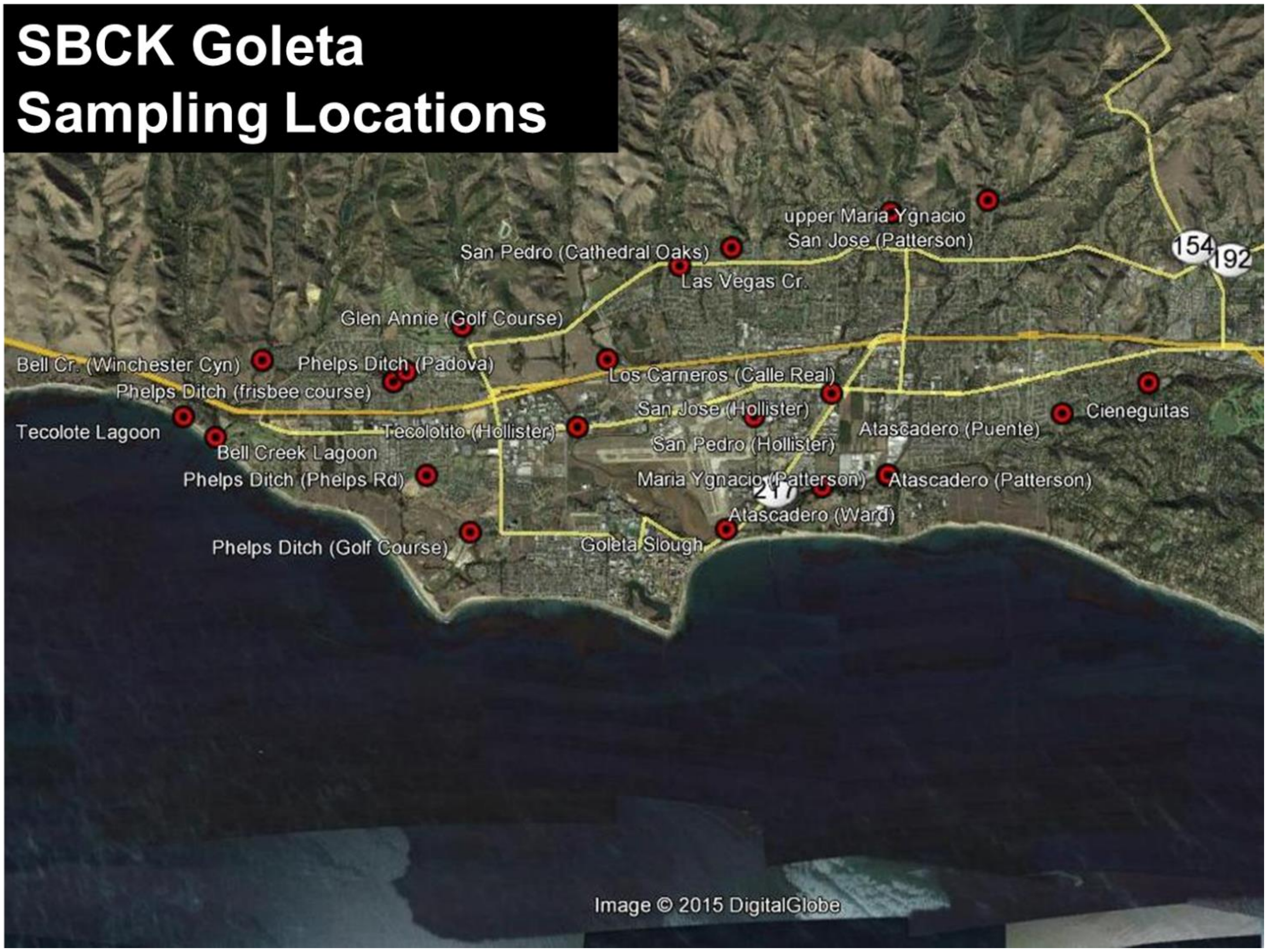
Summarizing data collection, here are some of the questions you need to be asking before you think about getting wet.

Why start? What's the purpose? What should I measure and, more importantly, why measure it. What can it tell me and what do I expect to find? And if I find something different, what might that mean?

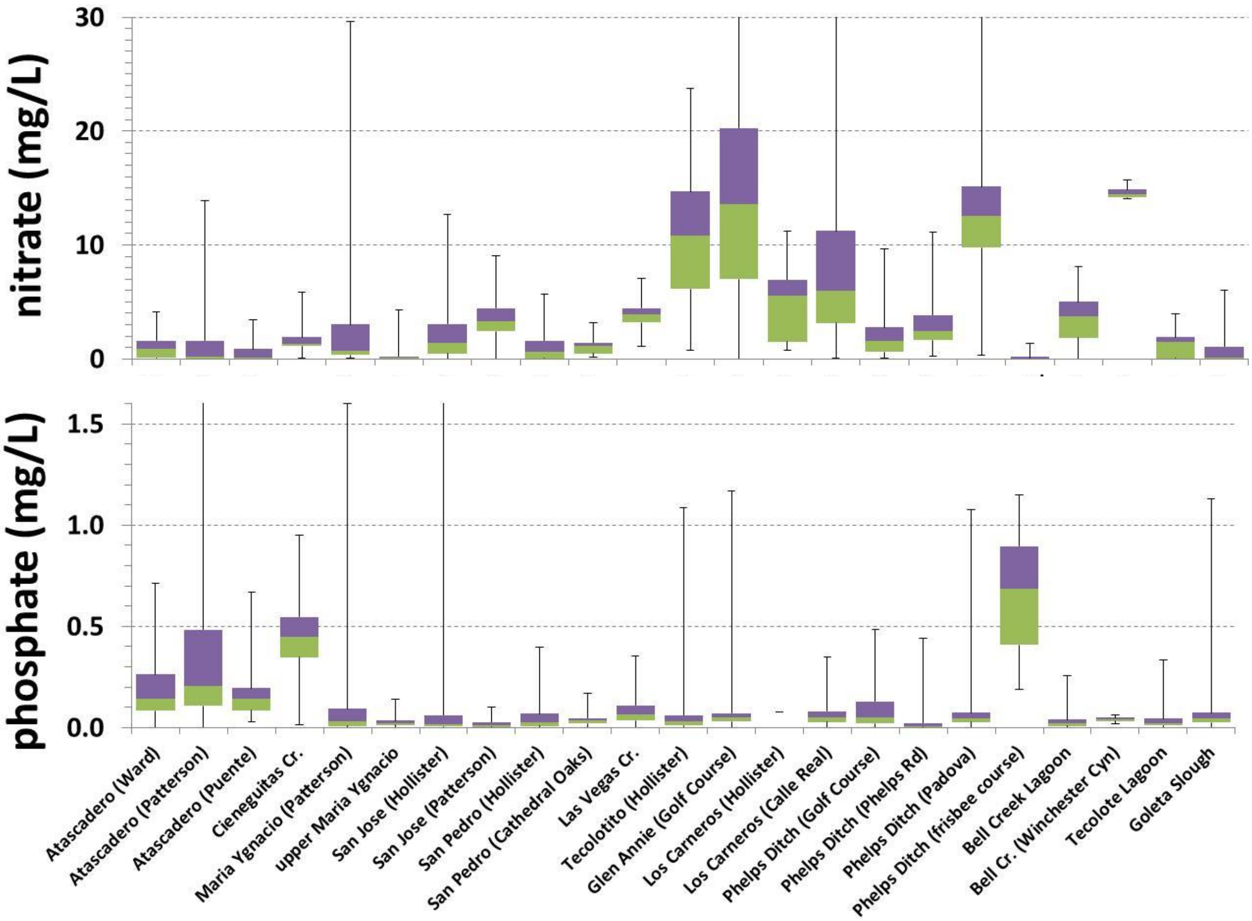
Where should I sample? And why there and not some other location? And should I be sampling at more than one location? And if so, how many more?

When do I sample? And how often? And for how long? How might what I'm trying to measure vary and what do I need to do to capture that variation? And if I'm wrong, will my sampling program also tell me that? After all, this is supposed to be science and not simply a confirmatory exercise in self-satisfaction.

My favorite UCSB Professor once told me, "Do nothing without a plan." But then he added, "But it doesn't have to be a very good plan." Perhaps he was channeling Clausewitz, who famously claimed "No plan survives contact with the enemy's main body"; or perhaps he was simply yanking my chain. But he was right, you never think of everything and surprises always await. Sometimes very big surprises. Be flexible and prepared to change in midstream (pun intended).



Santa Barbara Channelkeeper (SBCK) has a monthly sampling program originally focused on monitoring water quality in the various streams tributary to the Goleta Slough (additional sites further to the west were later added). Begun in June 2002 (Goleta Slough itself added in 2004; the Phelps Ditch locations—Devereux Slough tributaries—added in 2006; San Pedro and Las Vegas in 2008; and Tecolote & Bell creeks in 2009) the sampling continues to the present day. The locations of most of the sites presently monitored are shown in the Google image. Sampling is usually done on the first Sunday morning of the month. Feel free to give ‘em a call and participate.



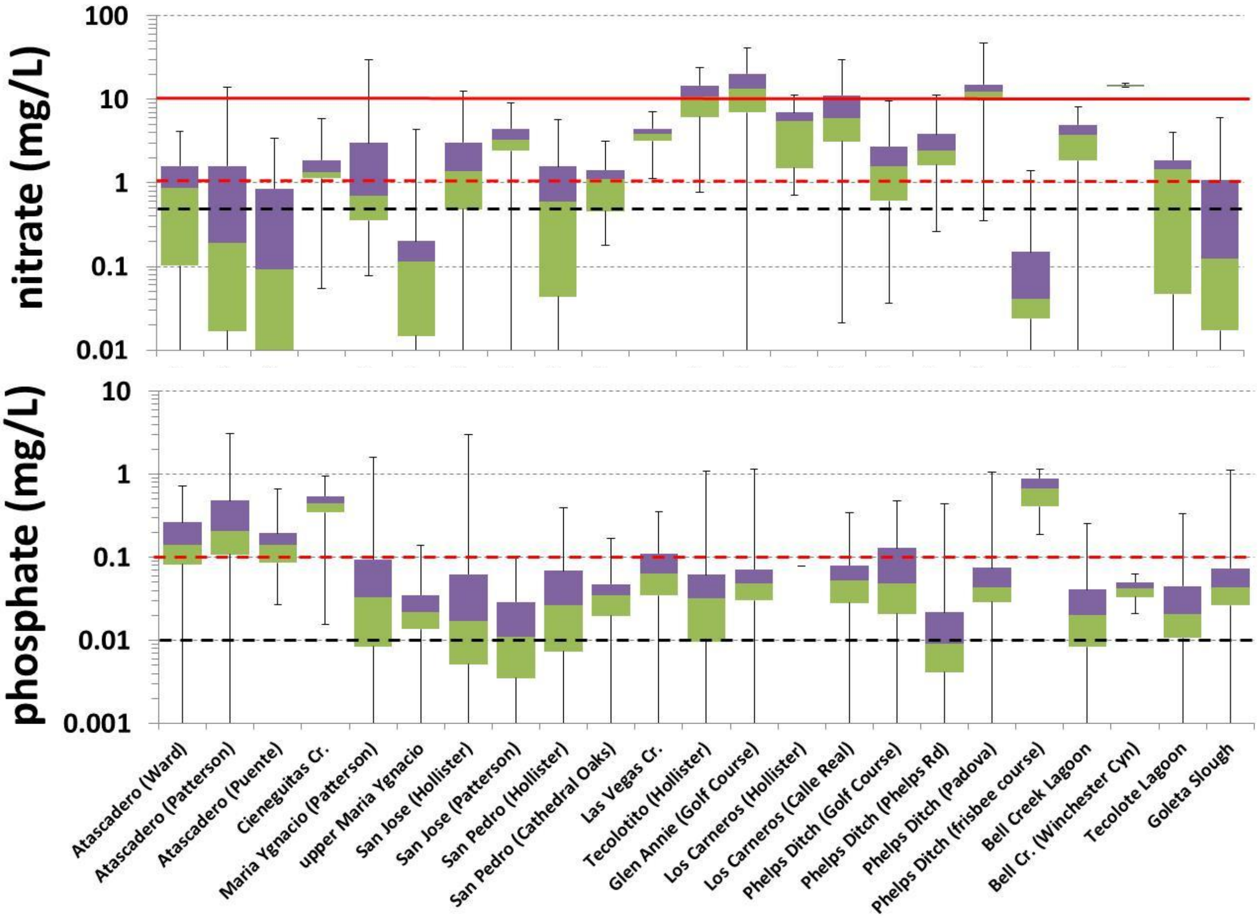
The graph shows nutrient (nitrate & phosphate) results from the Goleta sampling. These are box & whisker plots, with the median value as the dividing line in the box; the upper (purple) portion of the box represents the 3rd quartile (25% of the data—from the median to the upper quartile point); the lower portion (green) the 2nd quartile (thus the entire box represents the middle 50% of the data set—half of all their monthly measurements fall within the box); the upper whisker is the highest value measured; and the lower whisker the lowest. This is a good way to summarizing large data sets.

I mentioned earlier that high nitrate concentrations are a characteristic of agricultural land use, and this shows up nicely in the Goleta data. But note that phosphate in these ag-influenced creeks is low. Our geology is naturally rich in phosphorus and ranchers usually know better than to waste money on an un-needed and expensive fertilizer ingredient. Not so landscape gardeners and home owners to whom the cost of small amounts of fertilizer is a negligible expense—and who usually feel it's better to be safe than sorry.

As a result urban sites usually have higher phosphate, and the highest phosphate concentrations of all usually come from excrement—mostly from live stock, but also think domestic pets and humans (hopefully, from inadequate septic systems). The generally high urban phosphate seen in Atascadero is probably generously helped by the adjacent horse stables and arenas at Patterson and Cieneguitas.

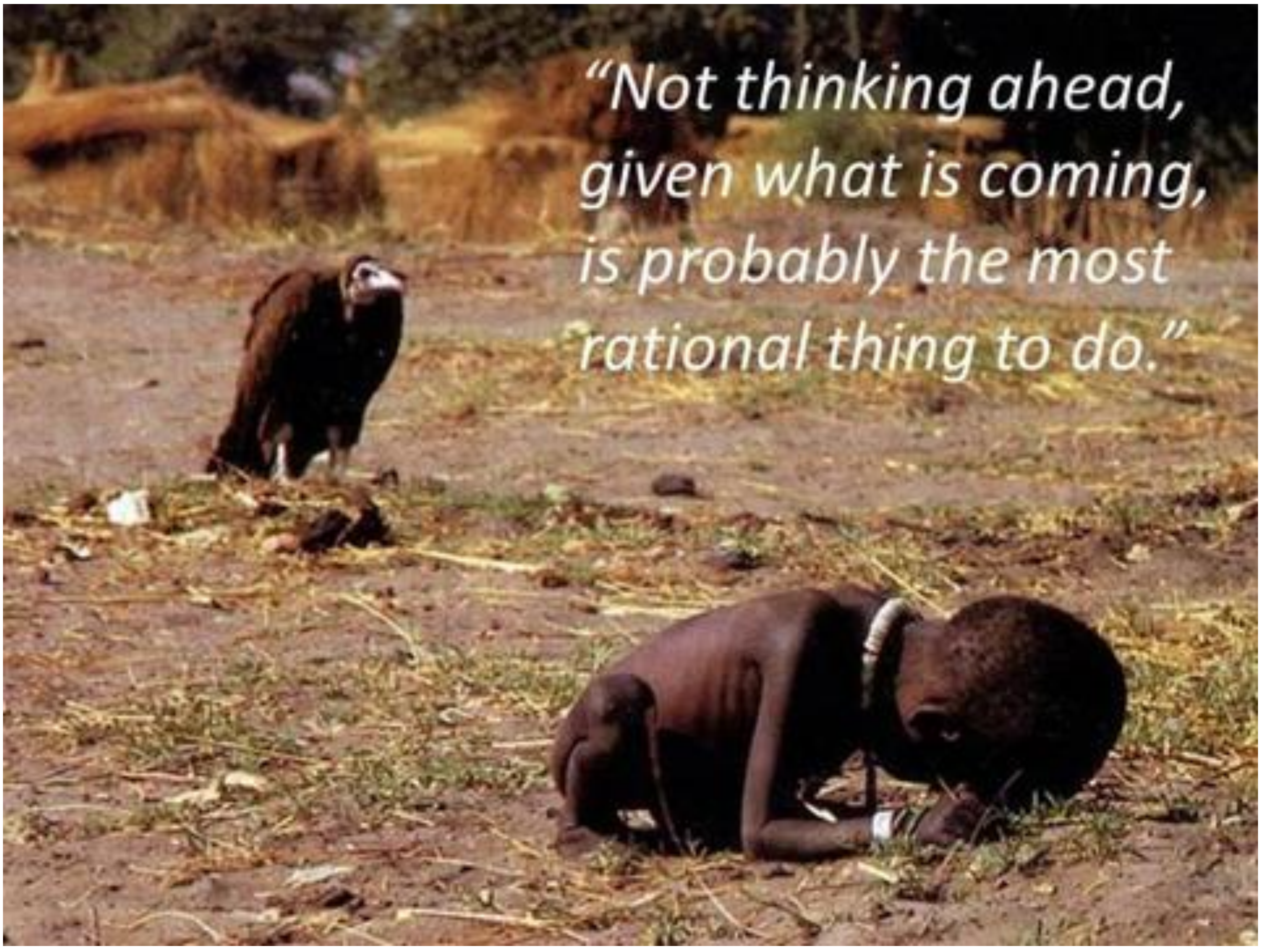
This is a near-inferred satellite image (taken May 20, 2013) of the Santa Barbara/Goleta area. This wavelength shows healthy vegetation (think well-watered and fertilized) in vivid green (e.g., the Sandpiper Golf Course near the left edge of the image, just above where it says “kelp”; contrast it with Hope Ranch and More Mesa—the brown areas adjacent to the coast on the right hand side—or the airport). The red “crosses” identify some of the Goleta sampling locations.

We don’t usually think of Santa Barbara and Goleta as being highly agricultural, but they are—especially Goleta. Usually located behind gated private roads, access to these lands is hard to come by. Note that these ranches show up as brightly as the golf courses. An interesting project would be to conduct a survey of golf course groundkeepers to find out what kind(s) of fertilizer are being used.



This is the same Goleta nutrient data shown previously, but this time using a logarithmic scale. To give these concentration ranges some perspective the lines drawn on the graphs show various Public Health and/or ecological condition limits.

The solid red line on the nitrate data indicates the 10 mg/L Public Health drinking water standard, and the dashed red and black lines ecological limits as suggested by California's SWAMP 305(b) Report for coastal streams. SWAMP limits are shown in the phosphate graph; there are no Public Health criteria for phosphorus. The SWAMP limits for total phosphorus are: >0.1 mg/L indicating poor quality, <0.01 mg/L indicating good, with anything in-between being considered fair; for total nitrogen >1 mg/L indicating poor, <0.5 mg/L, good. Notice that these are limits for **total nitrogen** and **total phosphate**. On highly polluted streams nitrate typically contributes about 80-90% of the total nitrogen, phosphate about 60-80% of total phosphorus. So the true condition of these streams is worse than the graphs indicate.



The quote is from Bruno Latour, a French philosopher, anthropologist and sociologist of science. Personally, I don't know what the future will bring. As Yogi Berra said, "prediction is difficult, especially about the future." But I suspect it will not be pleasant. As world population grows (now 7.3 billion and counting) room for error shrinks and, given our recent past, I don't believe catastrophic error can be avoided—be it environmental, societal or economic. And it doesn't even have to be error, mere inattention might just do it. Our species is probably not at risk, but the civilization we have constructed surely is. The existential threats are legion. Sooner or later even *Chicken Little* will be proved right.

Not quite the end. Over the years I've given similar programs for Sally's course. The beginning, a look at local hydrology, has stayed the same for a number of years now (but with updated data and slides), but the second half has changed depending on whatever topic arouses my current interest. Obviously, this year I'm quite taken with the drought and global warming.

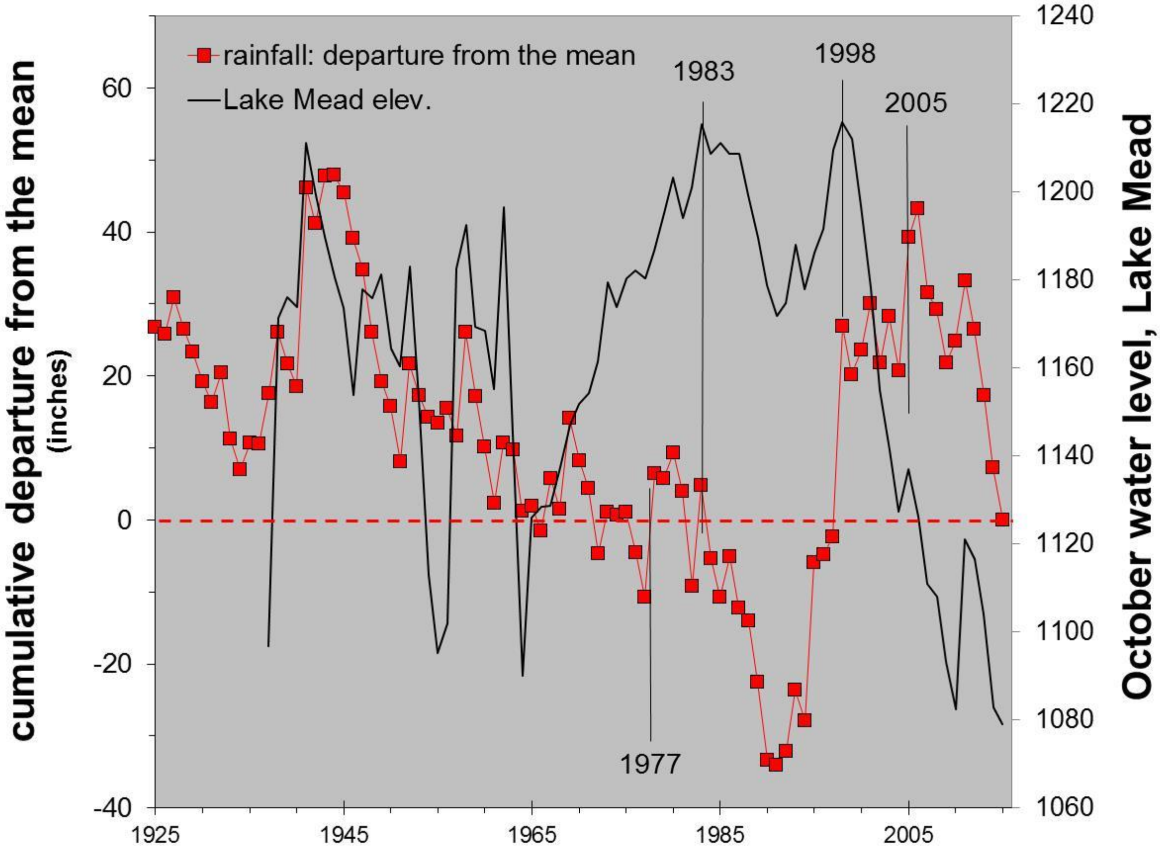
That said, some slides from past years, while no longer interesting to me, might be of interest to you and I've left them in. They follow. They mainly concern additional nutrient differences between various streams monitored by Santa Barbara Channelkeeper and the UCSB Coastal-LTER Project.

So look 'em over if you are so inclined.

And if any of you have further questions I can be emailed at

al.leydecker@cox.net

Lots of my older stuff, and more information about Santa Barbara Channelkeeper can be found on their website



This is the same *cumulative departure of Santa Barbara rainfall from its overall mean* plot shown in slide 10, except the earlier years are no longer shown. I've also plotted the annual variation in surface elevation at Lake Mead (Boulder Dam on the Colorado River) as measured every October (the reservoir began filling in 1937). Although the two plots are far from identical, there is a resemblance between them. This comes about because rainfall in the western US is dominated by major frontal systems moving across the Pacific, and although actual amounts at various locations can greatly differ the relative proportions from storm-to-storm are surprisingly similar—especially across broad latitudinal bands. And if a reservoir is large enough (requiring many years of normal runoff to completely fill) fluctuations in its water-level reflect cumulative runoff, which, in turn, reflect cumulative rainfall (given that annual loss, via evaporation and water extracted for irrigation and power production is reasonably consistent). So a really wet year in Santa Barbara usually means great skiing in Colorado, exciting river rafting in Utah, and good crops in Arizona, and visa versa.

The current level at Lake Mead is 1083 ft. (above sea-level). This is 90 ft. below its long-term average elevation, and only 7 ft. above the point where mandatory rationing will have to begin (and only 83 ft. above the pump intakes). So while continuing drought will cause problems here in Santa Barbara, it will be nothing compared with its consequences in other parts of the Southwest. Those interested can follow this adventure at http://www.arachnoid.com/NaturalResources/

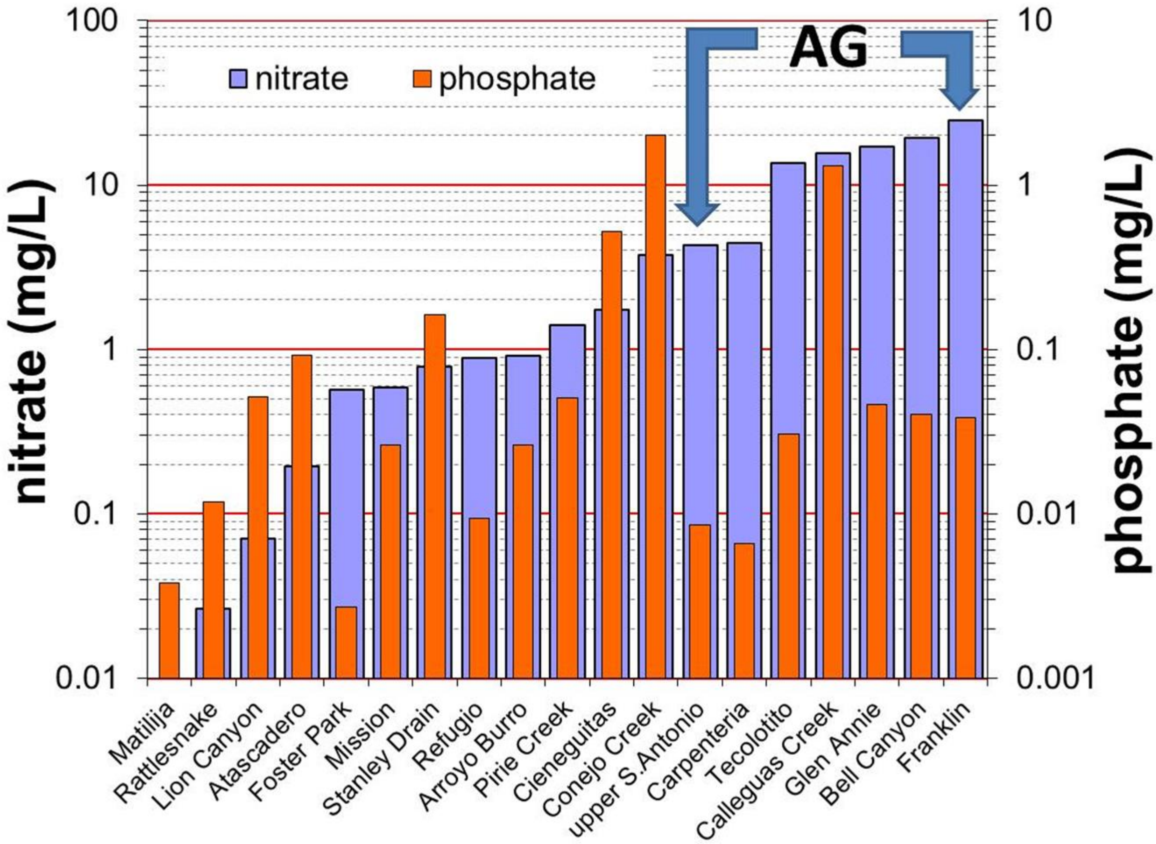
Knowing the magnitude of the nitrate concentration can, by itself, provide a clue as to the source. Different land uses typically generate nitrate concentrations in runoff and streamflow characteristic of that land use.

Phosphate concentrations can often be looked at in the same way: different land uses produce characteristic phosphate concentrations in streamflow. In our area agricultural fertilizers used tend to be high in nitrogen and low in phosphorus. In contrast, fertilizers utilized in an urban or suburban context for gardening and landscaping (and this often includes golf courses) are generally of the “let’s make sure all bases are covered” kind, much higher in phosphorus. When fertilizer is a minor incidental expense cost is rarely a concern; but cost is always a big deal for agriculturists who tend not to buy what they don’t really need.

Manure—from animals and, yes, humans (hopefully, mostly in the form of treated sewage from WWTP effluent, leaking sewers and on-site waste disposal systems, e.g. septic tanks/leach fields) is generally the cause of the highest phosphorus concentrations in streamflow. Manure is about 3-times higher in phosphorus then it needs to be for most plant growth, and the disproportion grows even higher as manure ages and highly volatile ammonia escapes to the atmosphere.

High chloride concentrations can also be an indicator of contamination by manure or failing septic systems. Aside from natural sources (geologic salt deposits, etc.), chloride can come from septic systems, wastewater treatment plant effluent, animal waste (we, and other animals, excrete chloride in our sweat, urine and excrement) and potash fertilizer (potassium chloride—potassium is a necessary plant nutrient). Disposal of water softener back-wash brine to a septic tank or to the ground can also appreciably increase chloride concentrations in catchment streams.

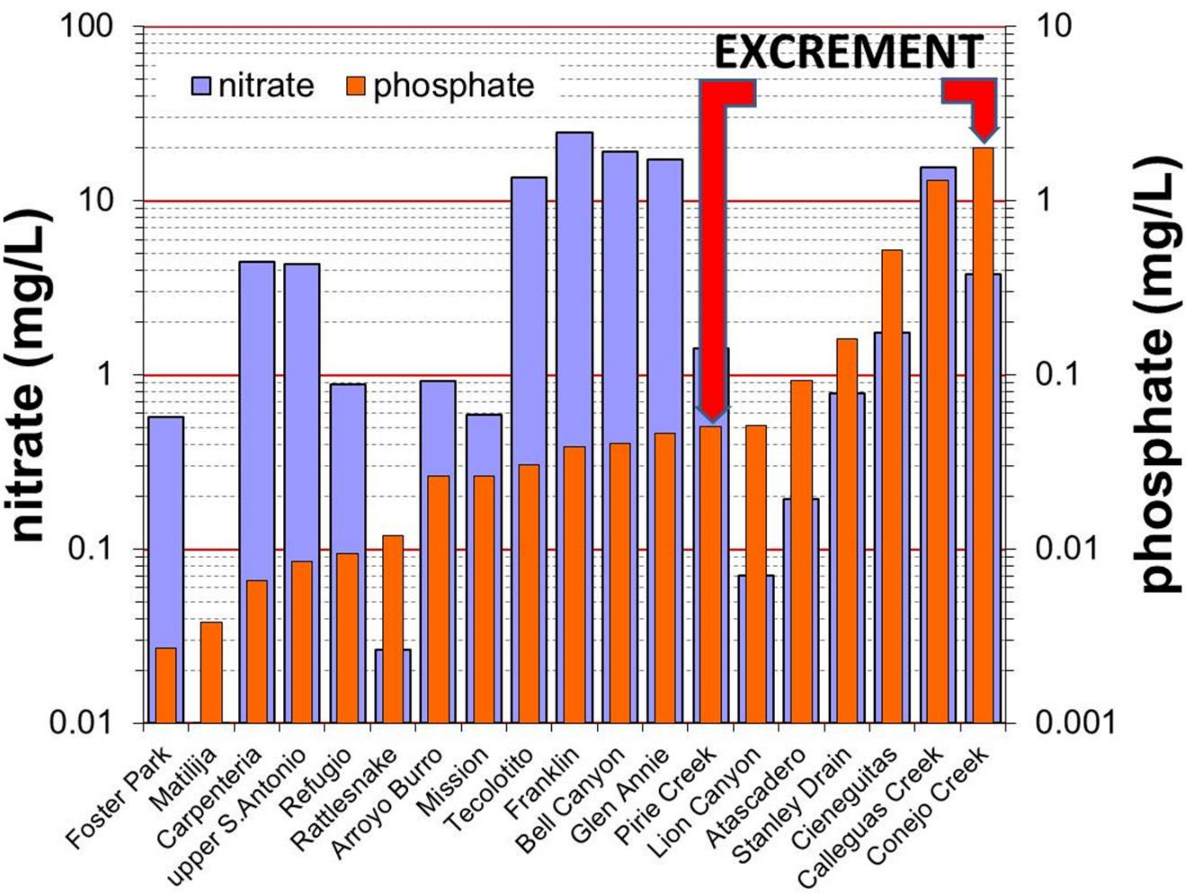
And finally, since almost all dry-season flow in our streams and rivers is surfacing groundwater (aside from wastewater treatment plant effluent, and other occasional contributions), well data and the chemistry of well water can also tell us a lot about the source of contaminants.



Mean nitrate and phosphate concentrations measured in various coastal streams in the area extending from Santa Barbara to just below Ventura are shown in the graph; they are arranged by lowest to highest nitrate values. The scale is logarithmic, so that widely varying results can be shown on a single graph. A logarithmic scale, however, makes large differences look small; the sampling location with the highest nitrate concentrations (Franklin Creek in Carpinteria) has a mean concentration *3,000-times* greater than the location with the lowest (Matilija Creek). Streams with the lowest nitrate (<0.1 mg-N/L) are relatively pristine, those ~1.0 mg-N/L tend to flow from urban watersheds, while those with concentrations above 3-4 mg/L are predominately agricultural: the more intensive the agriculture, the greater the nitrate.

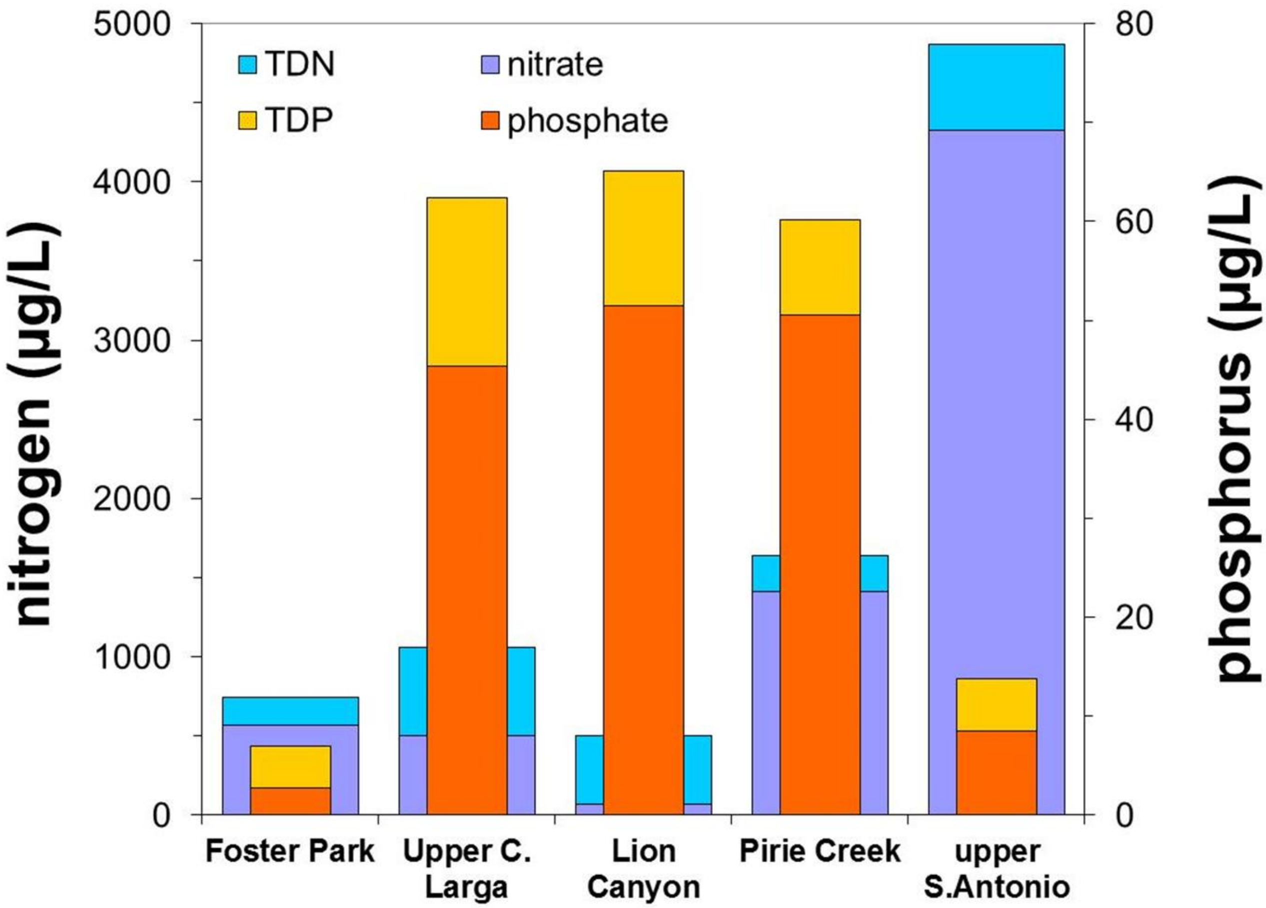
Naturally, there is some overlap. Streams monitored directly downstream of WWTPs (e.g. Conejo) or with mixed land uses (Cieneguitas—urban and horses) or with severe septic tank/leach field failure problems can fall into the urban-ag gap. Three-fold higher nitrate concentrations on upper S. Antonio compared with Pirie argue for different origins of their nitrate problems.

Note: The Ventura TMDL calls for an eventual maximum nitrate concentration of 1 mg/L (compared with a present-day dry-season mean of >4 at upper S. Antonio). This is by no means a stringent requirement: the CA coastal stream standard recommended TN <0.5 mg/L for a good quality water; the similar EPA recommendation was TN <0.52, but with nitrate <0.16 (or <0.38, depending on the exact zone). The TMDL's TN limit is 1.15 mg-N/L. The Public Health drinking water limit remains 10 mg-N/L.



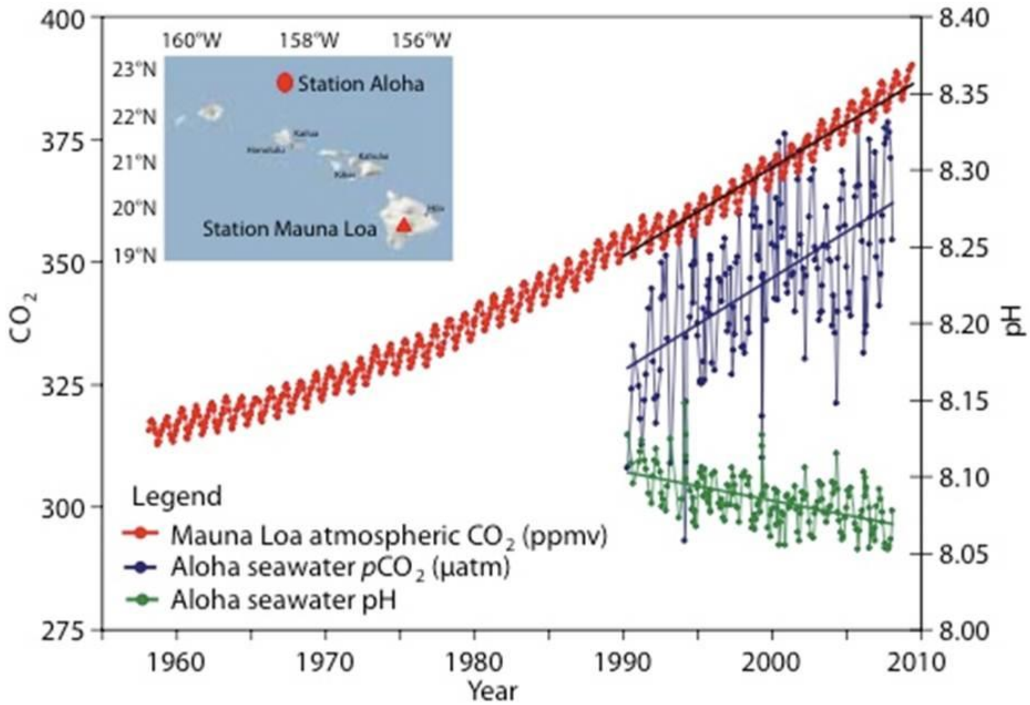
This the same graph shown in the previous slide, except that the sampling locations are now arranged, from lowest to highest, by mean phosphate concentration. The low and middle ranges are quite mixed: near-pristine, urban and agricultural land uses are all jumbled together (the background nitrate values indicate which are probably which). But the high end almost invariably represents contamination by manure or treated sewage effluent: Conejo Creek and Stanley Drain are locations directly downstream of wastewater treatment plants, Lion, Atascadero and Cieneguitas all have appreciable horse or cattle use.

The relative proportion of nitrate to phosphate can be an even better guide. The vertical scales are arranged in a 10 to 1, nitrate to phosphate, ratio (by weight). [Ten to one is pretty close to the nutrient ratio required by phytoplankton and, as such, can represent nutrient balance in a stream.] Only Calleguas Creek exhibits a ratio near this value; there is great unevenness amongst the others. Predominately agricultural streams have ratios averaging around *500 to 1* (i.e. way too much nitrogen); those with heavy animal usage, or an upstream source of WWTP effluent, a ratio around *3* (too much phosphorus). Upper S. Antonio Creek clearly fits in the agricultural catchment class with a ratio >500. The Pirie nitrate to phosphate ratio (by weight) is 28 (similar to urban and mixed use catchments).



This chart takes a closer look at some Ventura watershed sampling locations: total dissolved nitrogen (TDP) and total dissolved phosphorus (TDP) are shown along with nitrate and phosphorus (using a linear scale with concentrations in µg/L). [Mean seasonal SBCK nitrate and TDN, 2001-08, mean phosphate and TDP, 2005-08]

The contrast between upper San Antonio (very high nitrogen/low phosphorus) and Pirie Creek (moderate nitrogen/high phosphorus) is clear. That phosphorus concentrations at Pirie are similar to concentrations at upper Canada Larga and in Lion Canyon—catchments devoted primarily to animal grazing—implies a similar animal or human excrement source. That total nitrogen at Pirie is much higher than in the two grazing watersheds implies some kind of additional pollution. The N to P ratios at these monitoring locations support these inferences: >400 at upper San Antonio, 5 at Lion, and 28 at Pirie. Typical plant growth requires an N to P ratio (by weight) of about 15 (effluent from the Ojai WWTP has a median N to P ratio of 3.5). (That flow at Foster Park has an average ratio of 136 to 1 points to agriculture as a probable major source of nitrogen at that location also.)

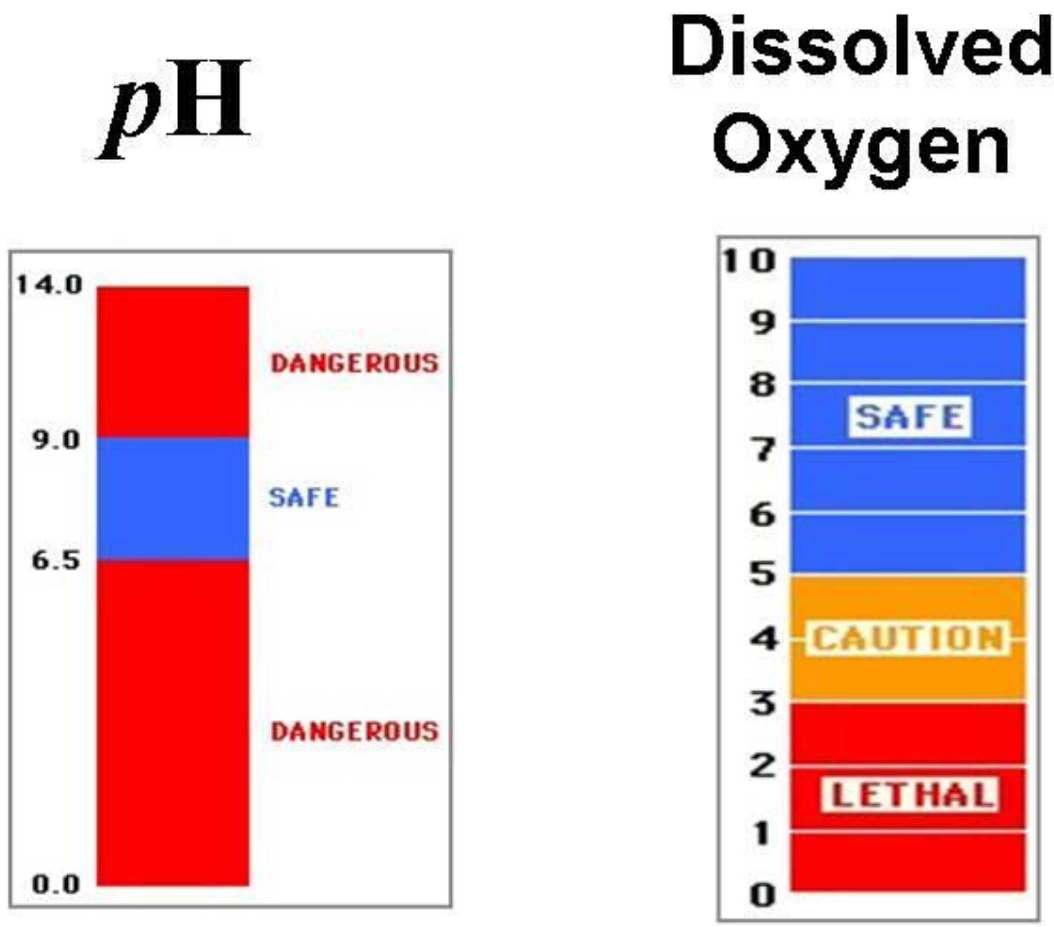


Let's talk about data. We might as well start with a slightly dated version of what is, arguably, the most famous graph in history, showing data likely to have the greatest impact on the human species – and your future: the "Keeling" curve, the foundation for all the uproar about global climate change. We should all be this lucky when we plot data. Keeling found not one, but two patterns: both an annual cycle and a long-term trend. The annual cycle is simply the earth breathing: the increased removal of carbon dioxide during the northern hemisphere growing-season by plants and other photosynthetic organisms, followed by a recovery in winter. The second trend, of course, changed history: none other than the increase in CO_2 behind anthropogenic global warming (currently at 400). (Note also the impact rising atmospheric CO_2 is having on seawater – increasing dissolved CO_2 and causing a corresponding decrease in *p*H. Very bad news indeed for the organisms at the base of our planet's food chain.)

Notice that Keeling took monthly measurements – had he taken only a single annual measurement he would have had no clue about the annual carbon dioxide cycle. And he continued taking measurements, not for years, but for decades. Had he stopped after 3, or 5, or even 8 years, especially if he had taken only one measurement a year, he would have discovered no long-term trend. Not to mention that *GOOGLE* would have had a much harder time dredging up his name.

While measurements of water quality taken at a single point in time are, more often than not, unhelpful, repeated measurements over time, measurements capable of identifying patterns or trends – and in this graph Keeling's data had both a pattern and trend – offer greater promise. If you then add the ability to compare and contrast – measuring parameters in multiple streams, or at multiple sampling locations on the same stream – sites with obvious differences (land use, location, observed characteristics, etc.) – value judgments become easier to make, and to substantiate.

My favorite UCSB Professor often said, "*Do nothing without a plan*." Not a bad slogan. He usually added, "*but it doesn't have to be a very good plan*." The combination adds up to words to live by. Especially for science. Beats the hell out of "*whoever dies with the most toys wins*."

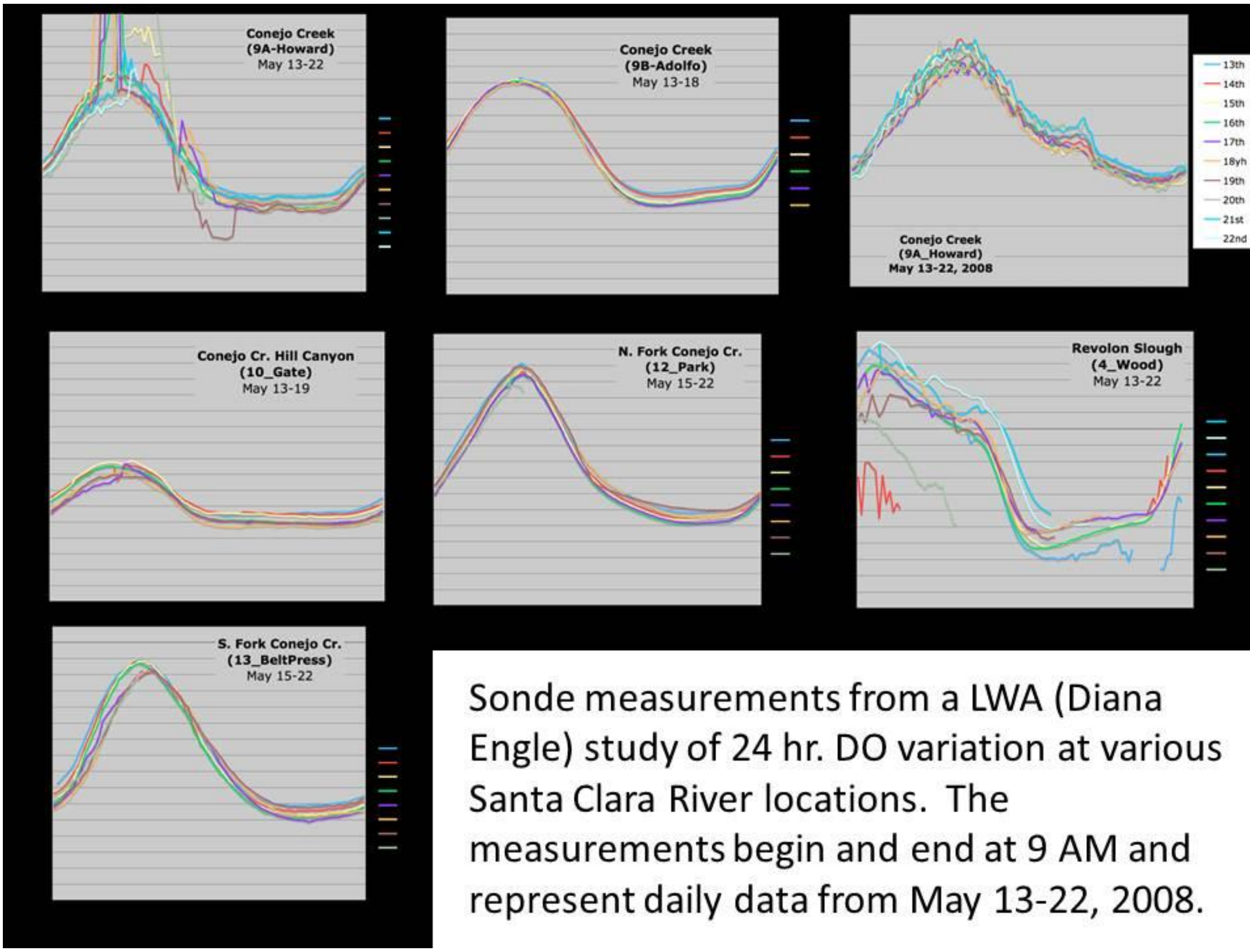


The problem with water quality testing is that measuring the usual parameters typically tells you very little.

You visit a doctor. After recording your height and weight, measuring your temperature, taking your pulse, listening to your chest and checking blood pressure she tells you “you’re 5-9, 160 pounds and not dead.”

Gee, thanks. Not much help, but it lets ‘em pad the bill to your insurance company.

Likewise, you go to a creek and measure the standard stuff, the easy stuff: *p*H, dissolved oxygen, turbidity, conductivity, whatever. You break open the book or hit on Google and this, the kind of things shown in the slide, is what you find. More often than not (actually, way, way more often than not) your measurements fall within acceptable limits. Which tells you . . . Well, it tells you the equivalent of “the creek’s not dead.”



These is some of Diana Engle’s data: 24 hr. DO measurements from 2008 from various sites on the Santa Clara River (just south of Ventura). The DO cycle, while reasonably similar from day-to-day at any particular site, varied considerably from location to location both in magnitude, in time of maximum and minimum occurrence, and in the shape of the curve between these limits. The weird data from Revlon Slough (with peak oxygen occurring at ~9:30 AM) is partly due to tidal flows at this location.

I’ll let a great scientist, Richard Feynman, have almost the last word . . .

But I’ll add that we often do . . .

This is just a reminder that our brains are optimized to find patterns . . . even when patterns are not there. God doesn’t make pancakes in the shape of Jesus, nor water stains in the image of the virgin Mary. And vaccines don’t cause autism. We like to jump to conclusions – like hardly ever reading the second half of an email. Or initially seeing nothing wrong with an Escher drawing. If we expect to find patterns in data, we usually do . . . even if there are none. So it’s important to continually remind ourselves of this tendency. To continually ask, “is this real or am I just fooling myself.” And not be all that surprised if we do fool ourselves – as we will from time to time. To quote Carl Sagan: “*we seek meaning, even in random numbers*."

But with time and further work things are usually straightened out and errors corrected. At least we hope so.

Max Planck took a cynical view of this by saying "*A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die and a new generation grows up that is familiar with it*."