

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.

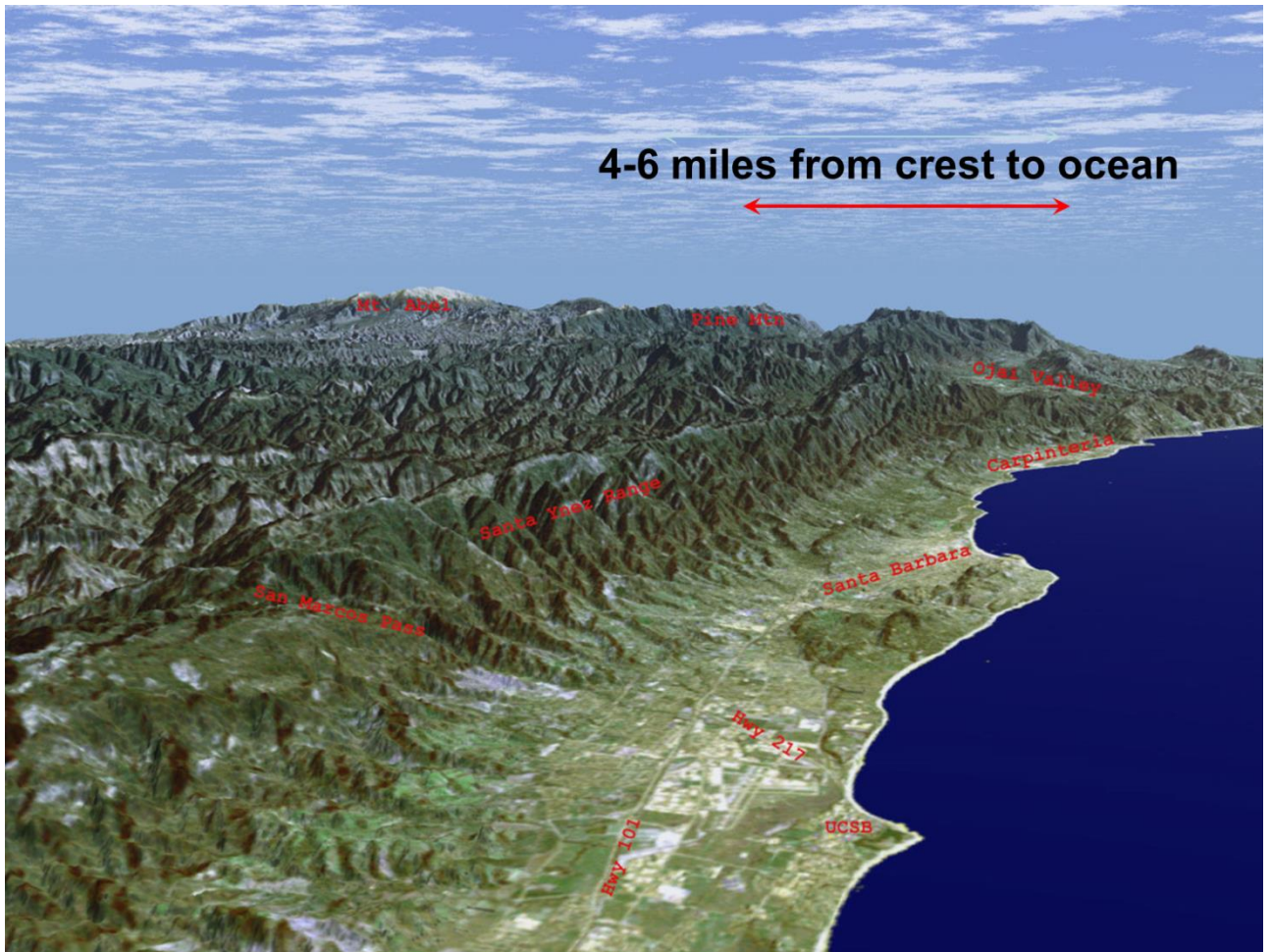


'NEST EGG'

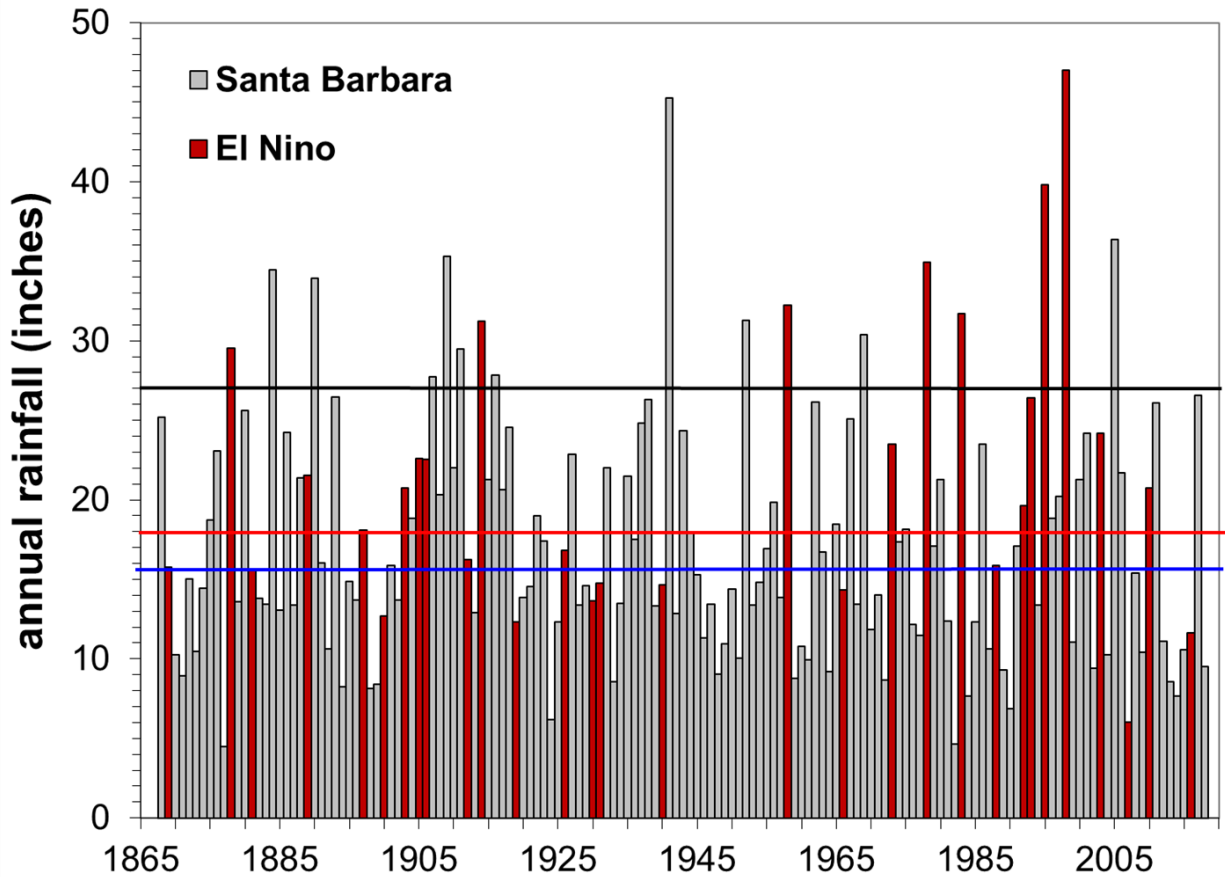
"For in creating the modern west we have gone a long way towards ruining this magnificent and fragile habitat. And as Marcus Aurelius said a long time ago, *what is bad for the beehive cannot be good for the bee.*"

Wallace Stegner

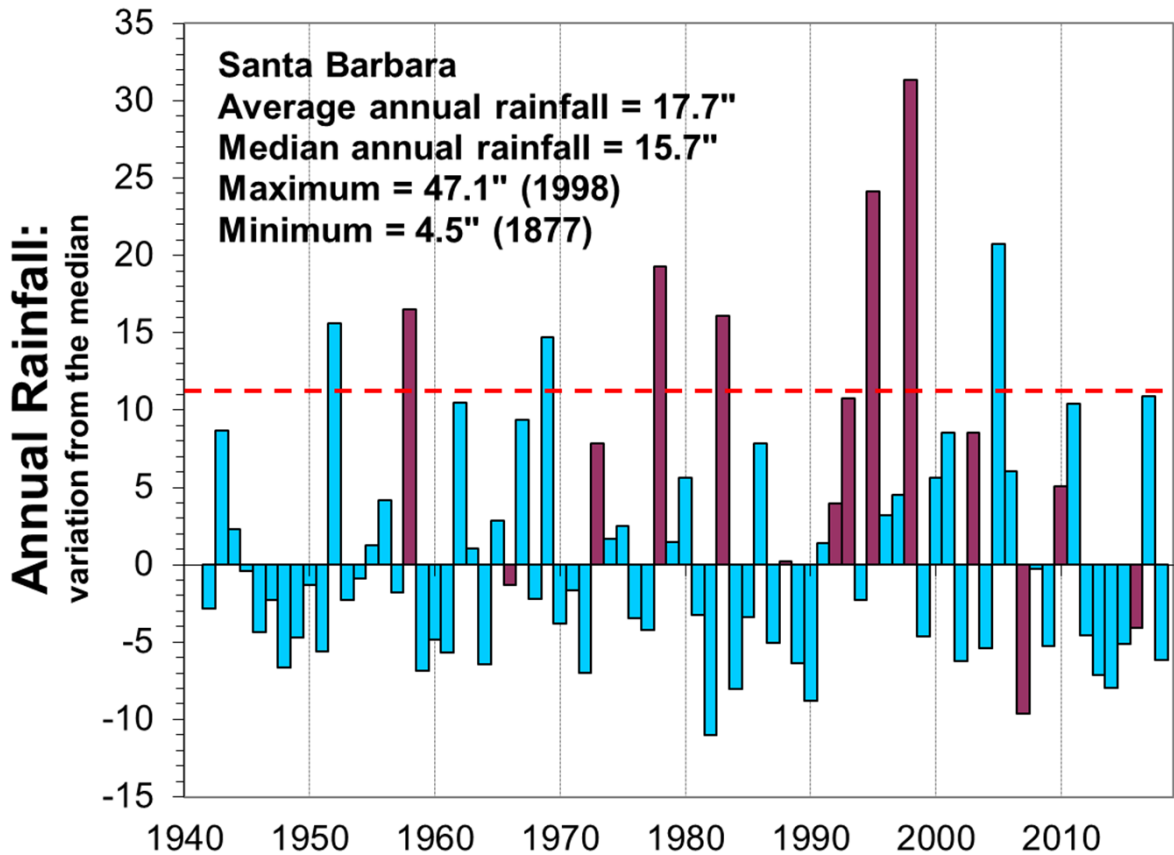
Forget recycling or donating your annual twenty bucks to Greenpeace or the Sierra Club. If you really want to help your generation to a better future think about pushing your grandparents down the stairs.



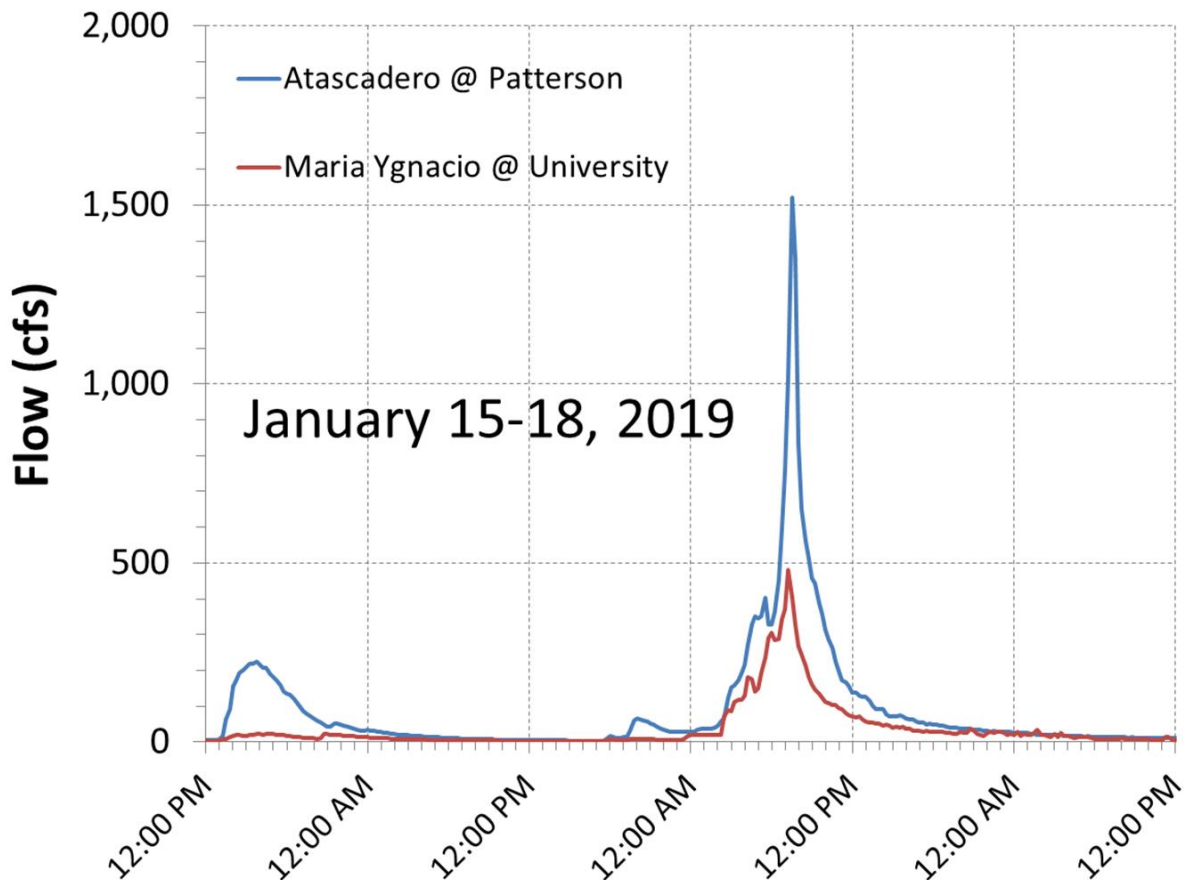
Topography is fate. Streams in this area are short and extremely steep. The mountains are made up of relatively recent, easily eroded, marine sediments. Storms produce flashy runoff: flows rise and fall rapidly – and are heavily sediment laden. (If you have any doubt, think “Montecito.”) The climate 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 agricultural runoff (enhanced groundwater flows from excessive irrigation) and urban nuisance waters. These days, if there’s water in a creek during summer someone put it there.



Streamflow is produced – and the character of a stream determined – when rainfall is added to topography. The graph shows annual (water-year) rainfall in downtown Santa Barbara from 1868 to Oct. 2018 (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 can be considered 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 (and 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.



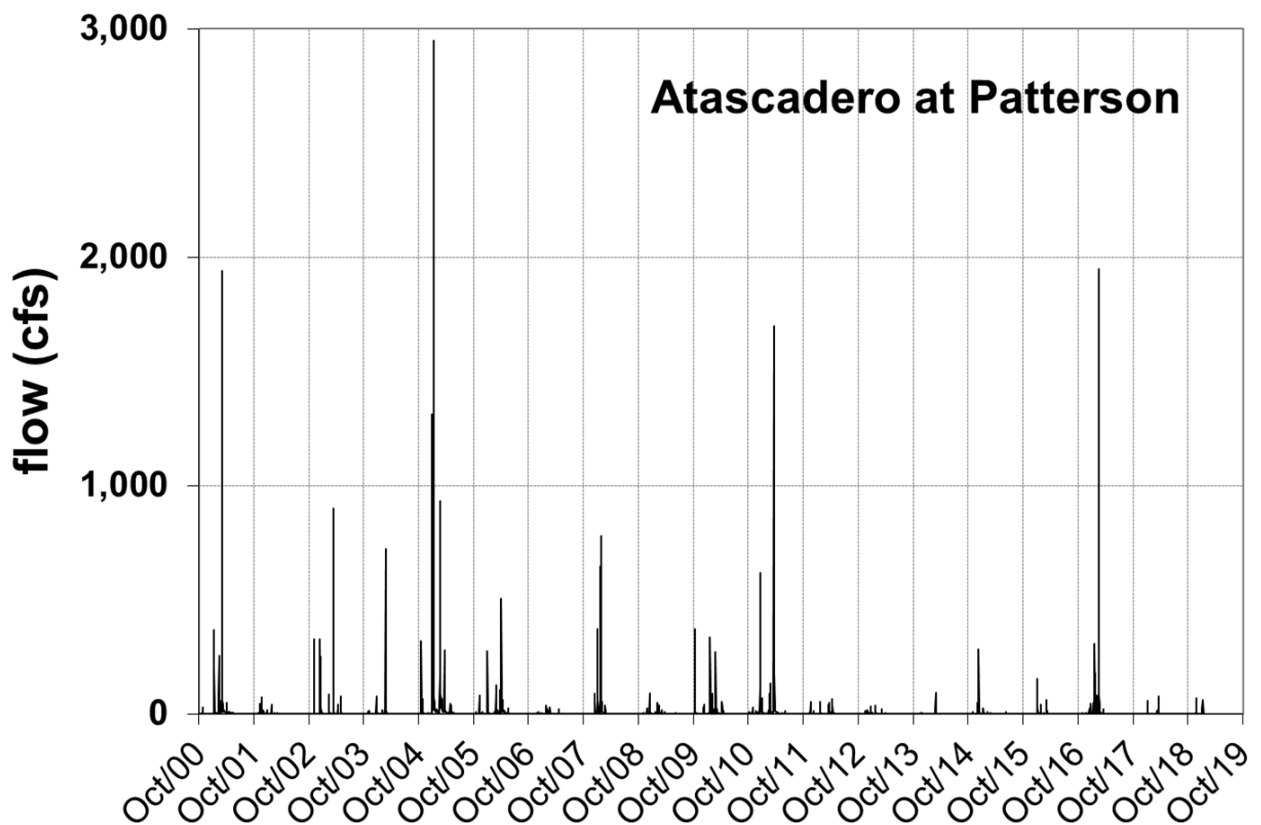
Another, and perhaps more meaningful, way of looking at annual rainfall (1942-2018): by indicating how far below or above the long-term median each year's total was. (The median, with half the years measuring greater rain and half less, is a better estimate of the most likely or expected rainfall than 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 the **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 the largest storm we had in January. To add some perspective, since few of us think in cfs, this storm caused water levels to rise roughly two and a half feet under the Patterson Bridge.

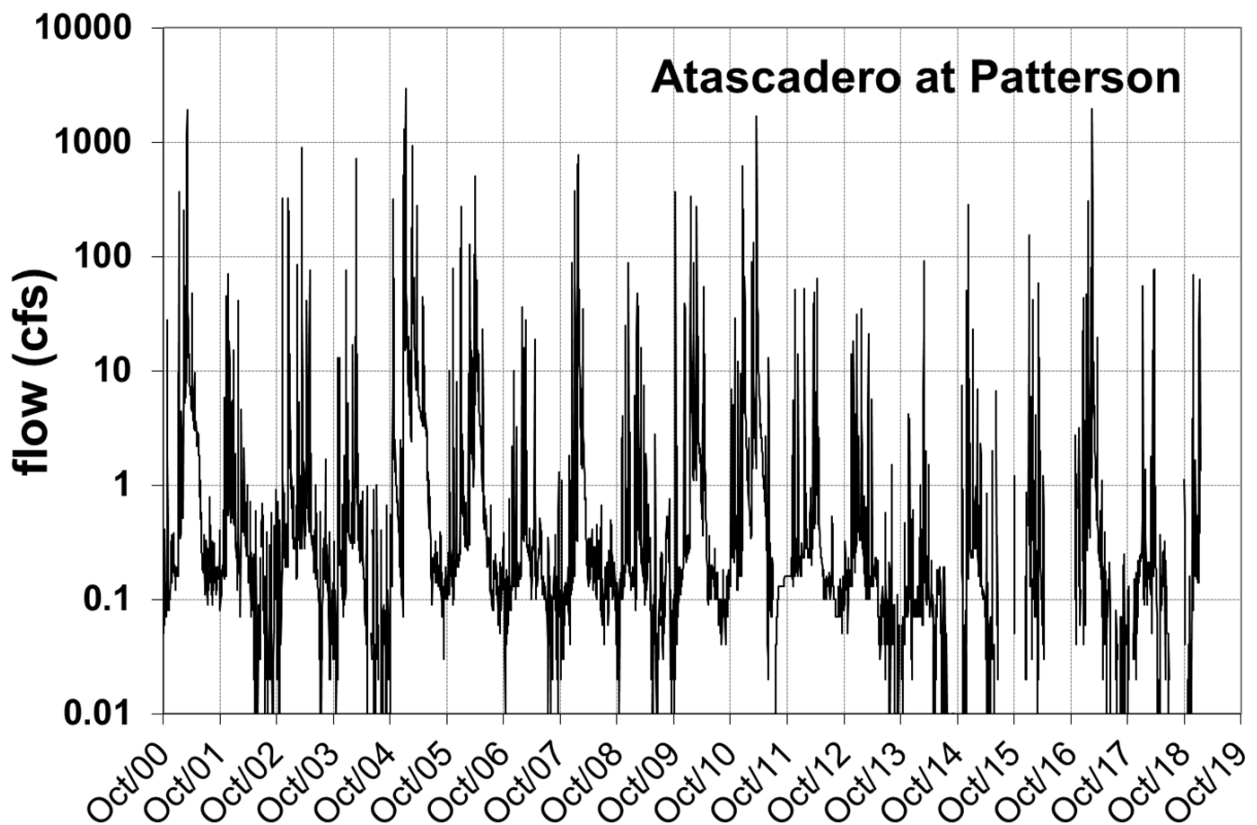
I've also shown the hydrograph for Maria Ygnacio Creek at University Drive. Maria Ygnacio is the largest Atascadero tributary, and its watershed above University comprises more than 1/3 of the total Atascadero drainage area. However, while it contributed roughly that amount to the peak flow on Jan. 17, there was no contribution during the earlier, smaller rainfall.

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 runoff, and less of the total rainfall going towards groundwater recharge, thus lowering subsequent dry-season streamflows.



Here's an expanded Patterson hydrograph. It includes more than 18 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.

Again, 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 as shown on the previous page, 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.

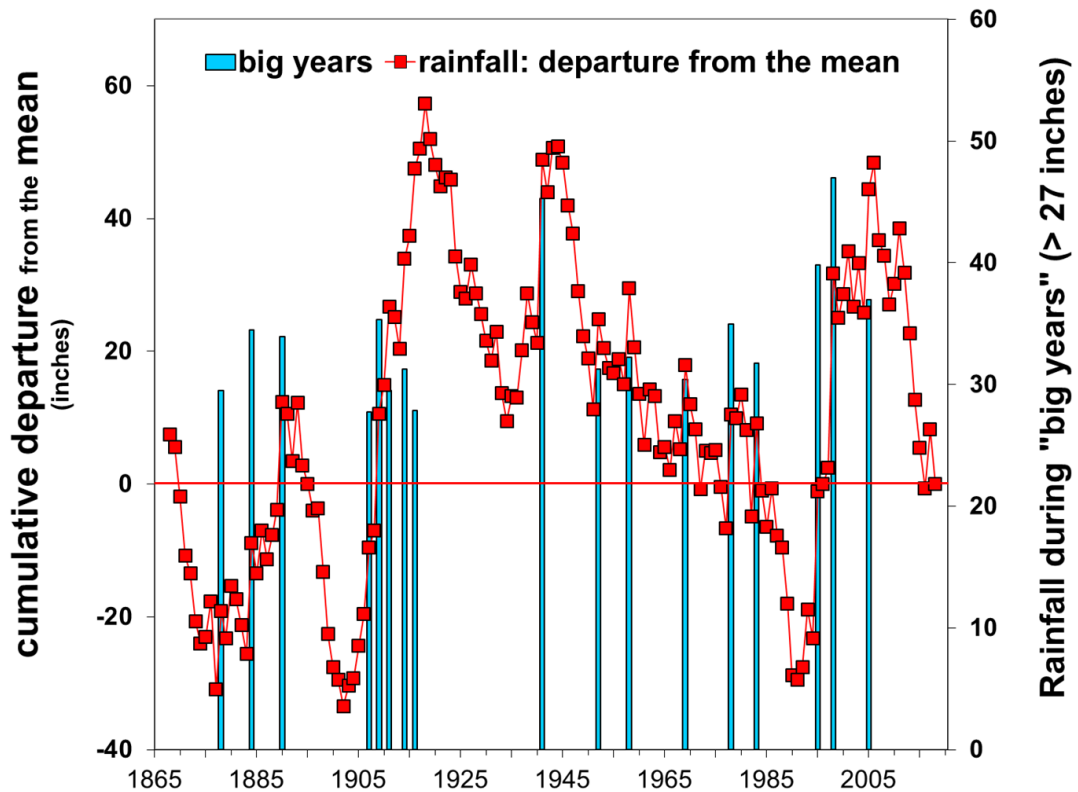


at Puente Ave.

at Patterson Ave.

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

Here's what the contrast between dry-season flow (after the really, really good winter of 2004-2005) and storm runoff looks like on the ground.

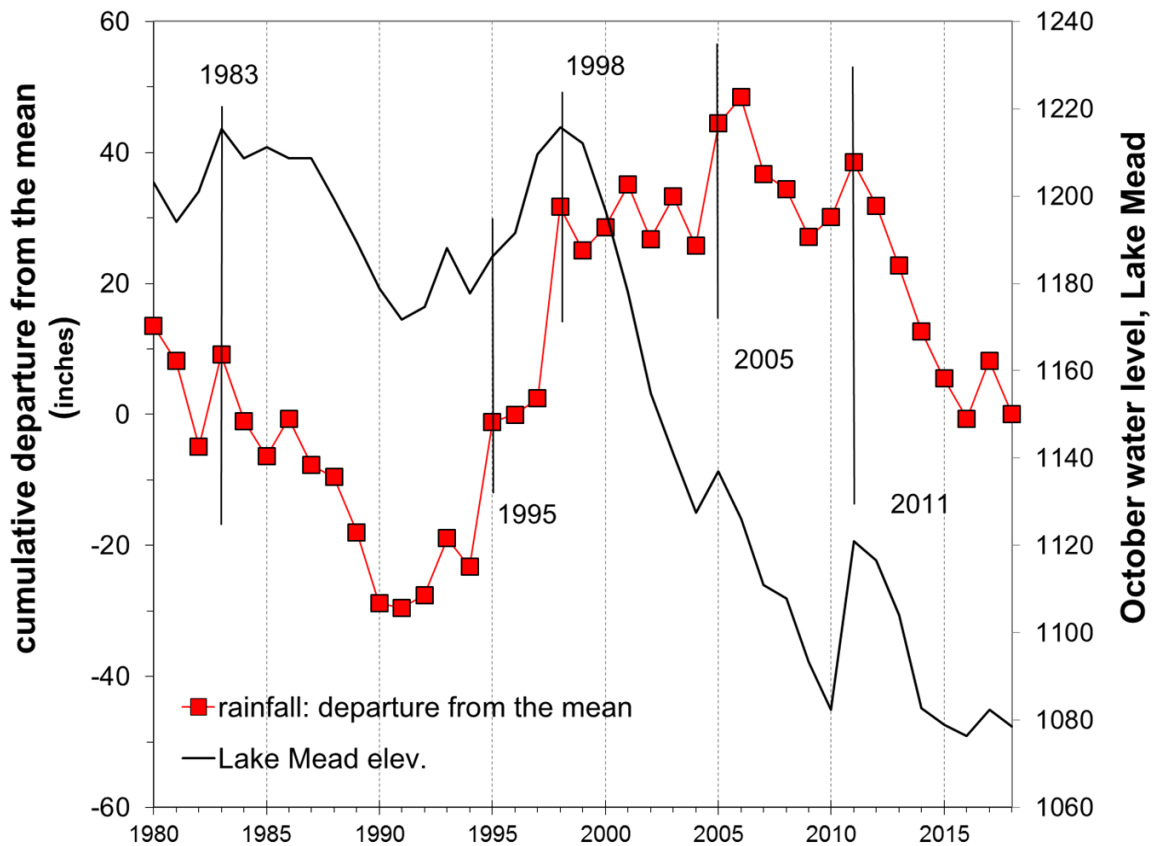


We know that annual rainfall varies, but the big question is whether or not that variation is random. Are the five years of drought we've recently gone through no different than tossing 5 heads in a row, or is something else at work? One way of deciding is to look at the cumulative departure of rainfall 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 annual differences from the mean. The graph of these running totals 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).

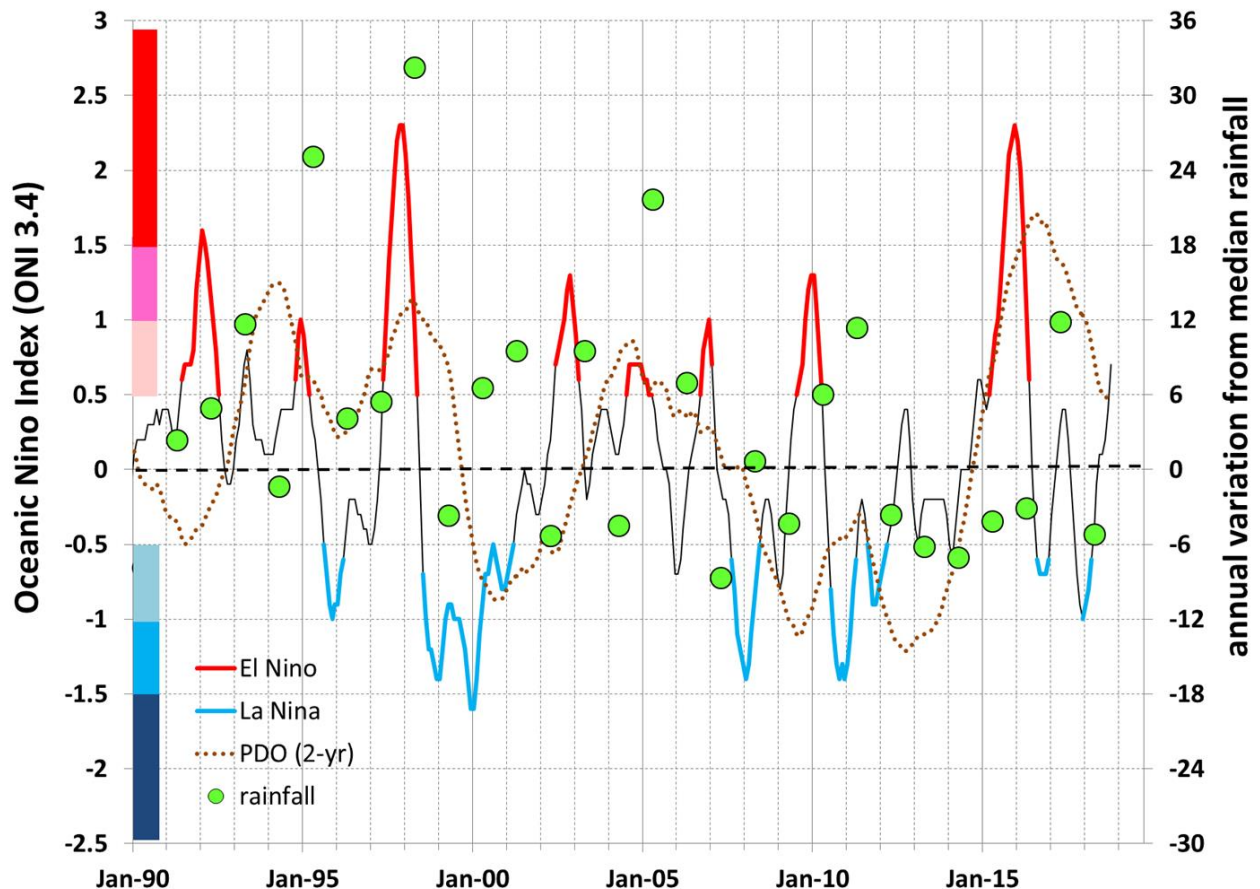
There are two patterns in the Santa Barbara data: The first, the big pattern, is produced by something called the Pacific Decadal Oscillation (PDO): a roughly 50-year cycle of alternately cold and warm waters that abruptly shift location in the eastern Pacific Ocean. The “cold” PDO phase moves the jet 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 Niño events). If we define a “big” year as having rainfall at least 150% above the average (>27 inches), the blue bars represent 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 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.



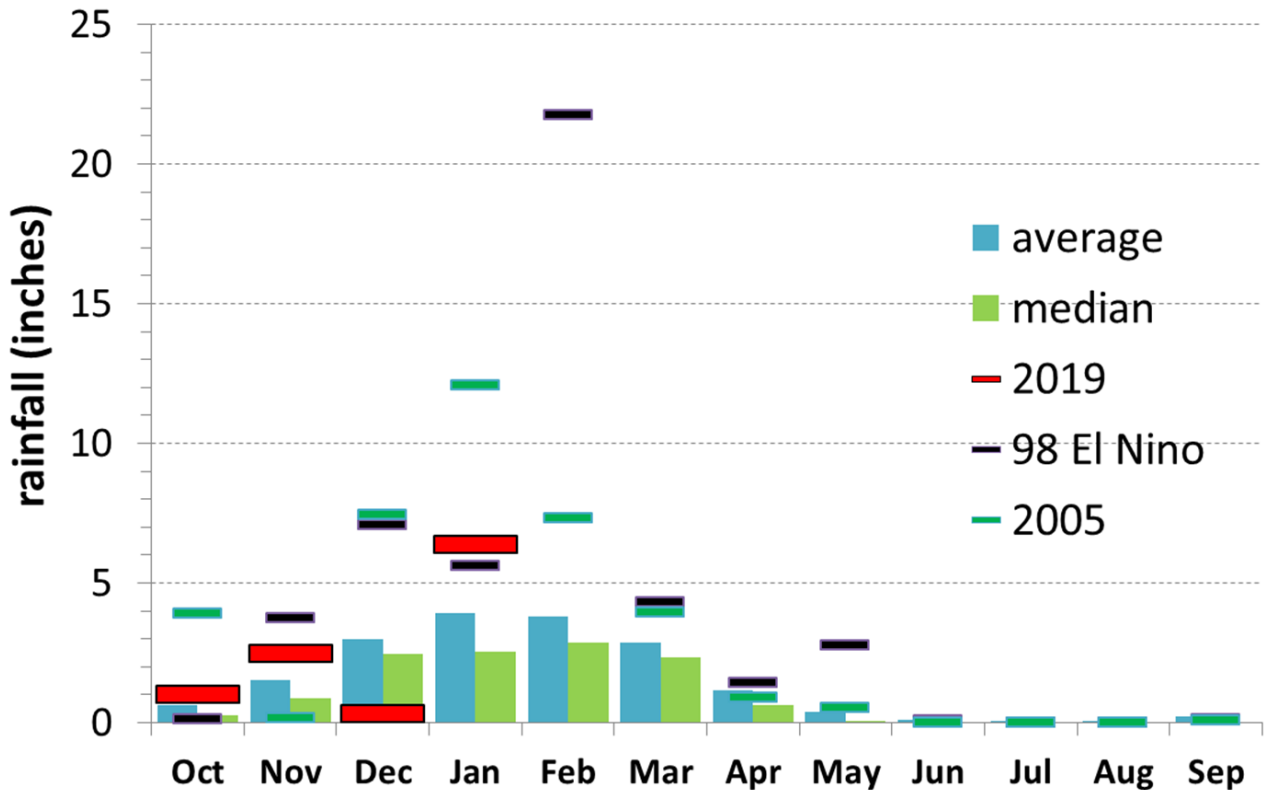
This is again the cumulative departure of Santa Barbara rainfall from the mean (red squares). Plotted with it are October water levels at Lake Mead (measured at Boulder Dam on the Colorado River). The point here being that rainfall in the west is most often caused by big frontal storms coming out of the Pacific. And rainfall in Santa Barbara is usually well correlated with rainfall throughout the western 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 extent by which we have overwhelmed the capacity of the Colorado River and are now heading towards disaster in terms of water availability and power production in the southwestern US.



El Niño or La Niña events are defined as 5 consecutive overlapping 3-month periods when oceanic sea surface temperatures (SST) in the Niño 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 index line mark official events since 1990, and the color scale to the left indicates their intensity. Also shown is each year's rainfall (through 2018) and a 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. 2017 produced a weak La Niña while the PDO remained positive, i.e. a mixed signal. Theory says a strong PDO should weaken the impact of any La Nina. And it seemed to work out—we had reasonable rainfall. This year, despite the early January drama, the situation is looking rather grim: no rain from October through December, another La Nina, the PDO trending negative, and only a couple of likely wet months yet to go. But as you can see, long range weather prediction is 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 done so. 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 may not really know for some 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.

Santa Barbara Monthly Rainfall

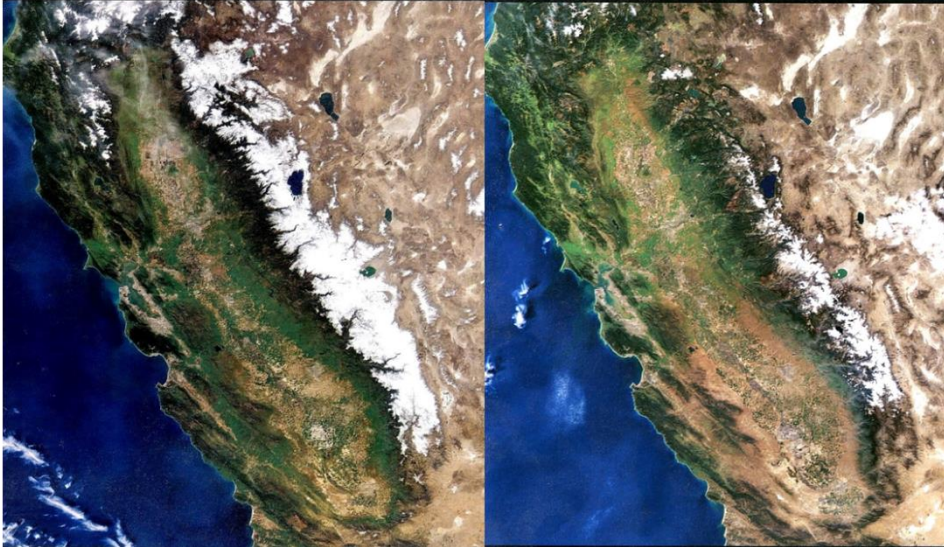
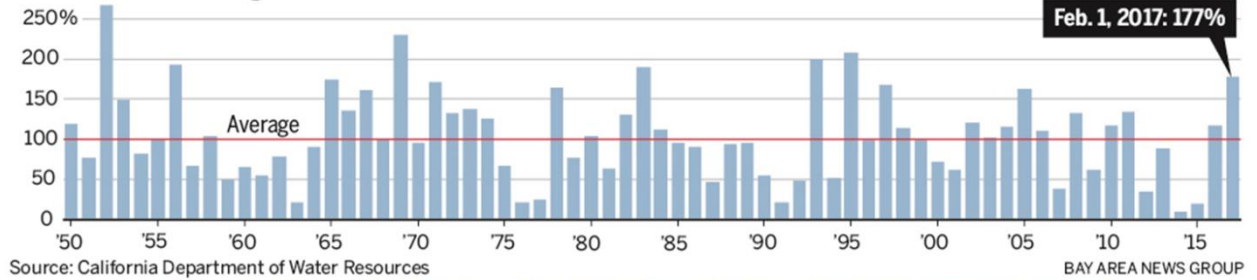


A closer look at where we are today: This is downtown Santa Barbara rainfall for this year as of the end of January. As you can see, although we had a dry December the other months have been above both the median and average. A good start for anyone wanting lots of rain. However, we're still below the kinds of rainfall we saw in our two most recent big years. The graph, presenting a comparison, shows what happened back then. 1998 was a truly impressive El Nino year. We got 22 inches in February of that year, 47 inches in total, almost 3-times the annual average. February is traditionally our deciding and biggest rainfall month so we have yet to see how it all plays out this winter.

SNOWPACK BURIES AVERAGE

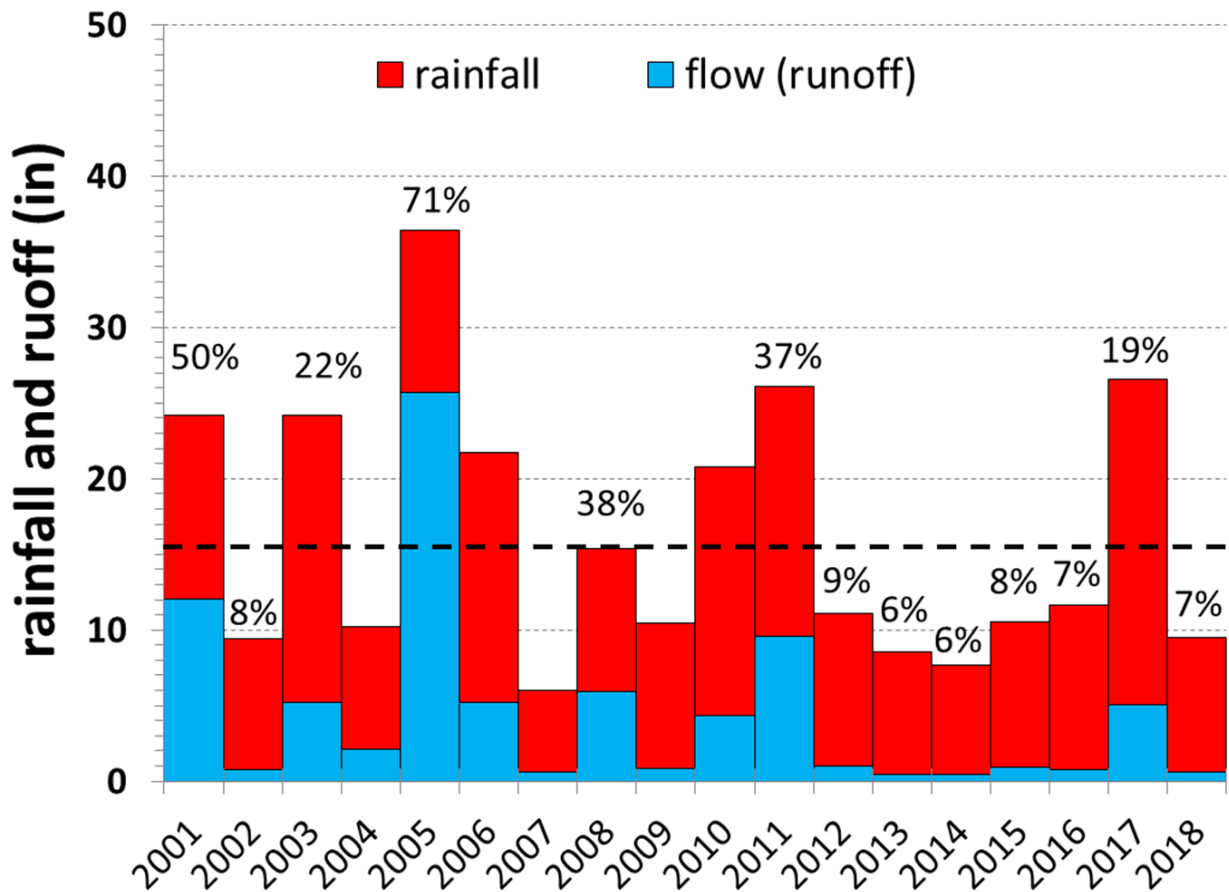
The statewide Sierra Nevada snowpack is 177 percent of the historic average, the largest in 22 years.

Percent of historic average on Feb. 1

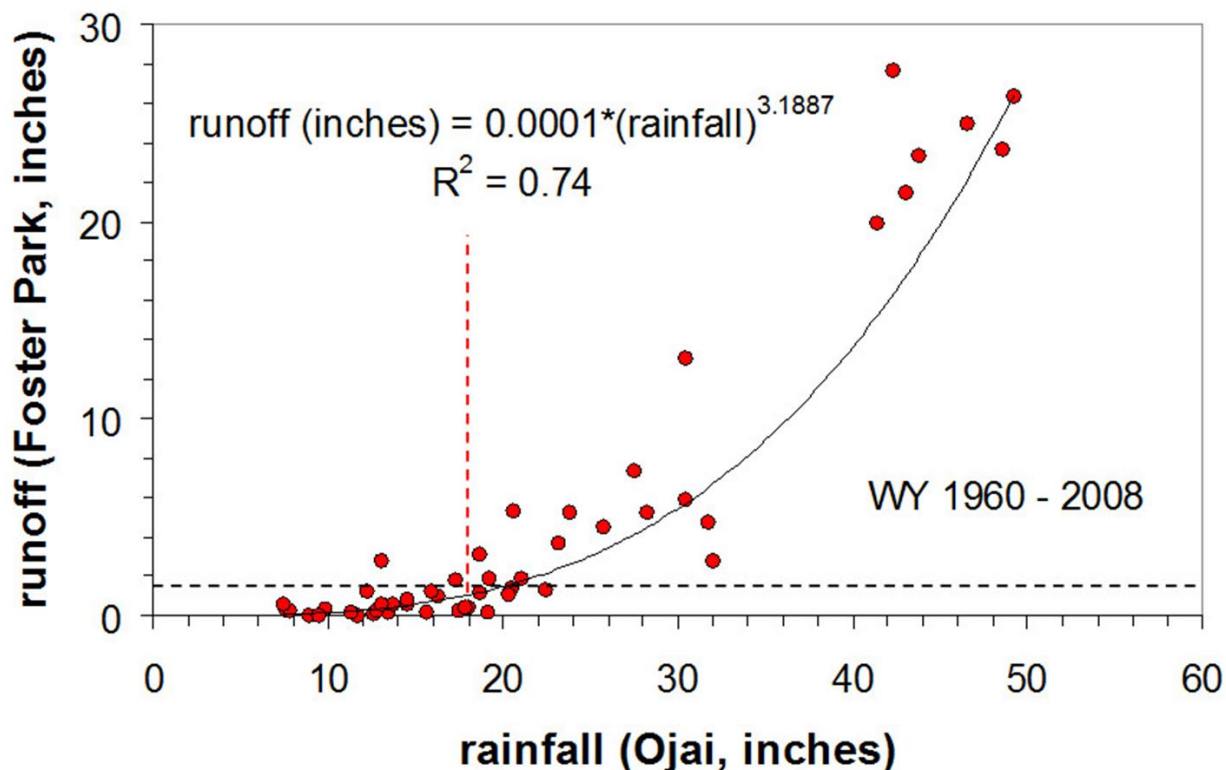


The key to California's water supply is not rain but snow, more precisely the snowpack in the Sierra Nevada. Rain produces quick runoff which rapidly fills reservoirs, and there's the rub. California reservoirs are designed to not only capture water for dry-season use, but to prevent floods, and, as such, cannot be allowed to completely fill until very late in the rainy season. Capacity must be retained so as to capture potential flood runoff from late season storms. Indeed, late 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.

The satellite photos, March 27, 2010 on the left (April 1 is considered the beginning of the melt season) and March 29, 2015 on the right, show the contrast between business as usual and a horror story for a state water system designed around snowmelt. Luckily, in 2017 the snow did arrive (as the graph, showing conditions as of Feb. 1 compared with past years indicates). The question remains: was this a return to normal or simply a reprieve? Currently (at the end of January 2019), the state's snowpack is a little bit above average for this date.

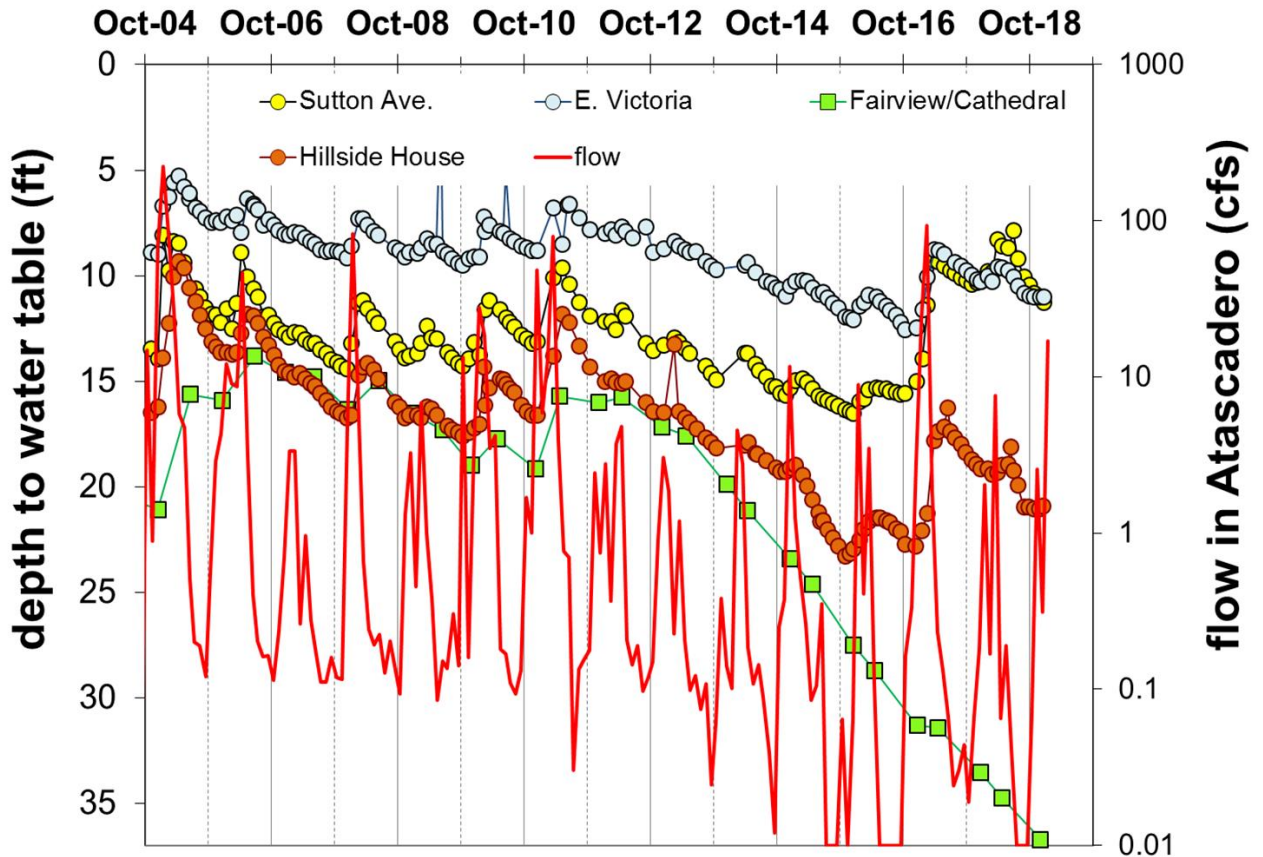


There's an obvious connection between rainfall and streamflow (or runoff), but it's not linear. Watersheds both retain (mainly as groundwater and soil moisture) and utilize (via plant uptake and evaporation) rainfall. Most rainfall does not end up in the stream; only the biggest years have lots of runoff; 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.



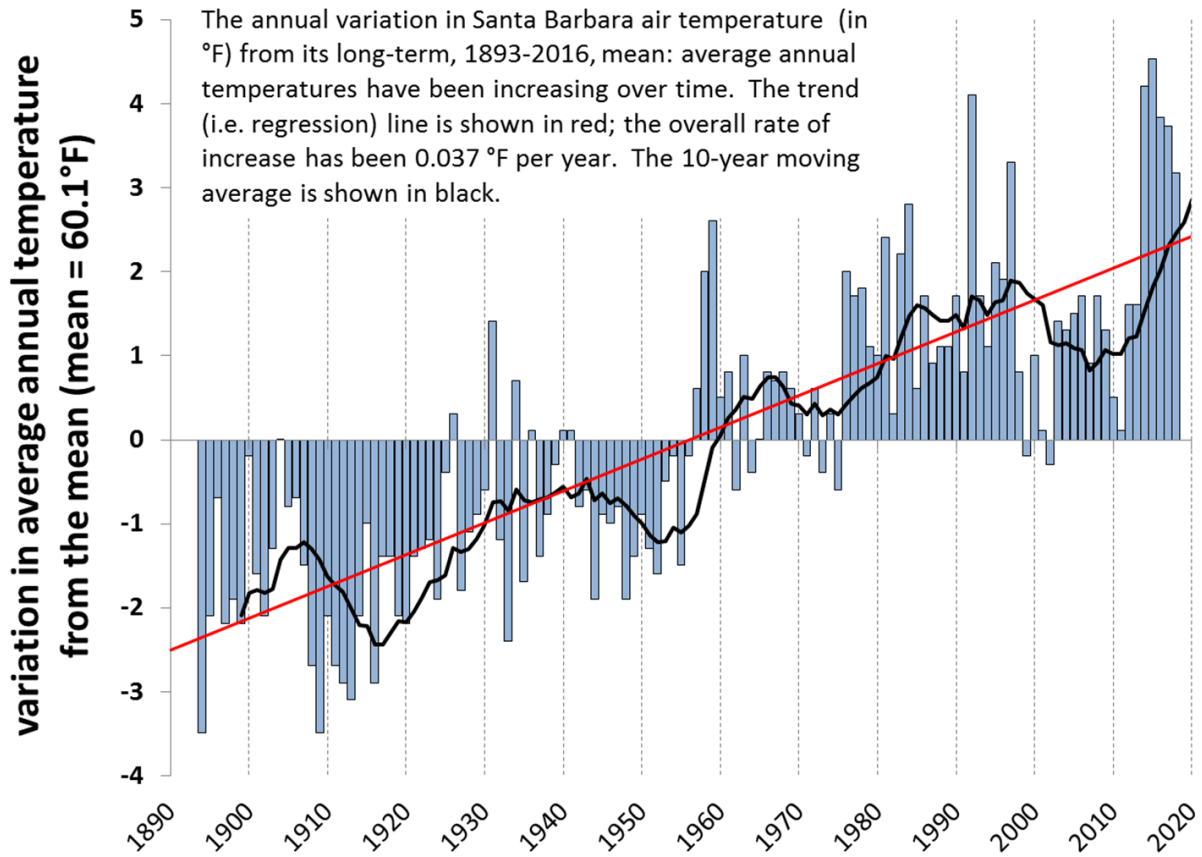
Let's shift to the Ventura River, a larger but similar stream just south of us, and explore this point further: In the graph Ojai rainfall represents the number of inches that fell upon the Ventura watershed in a given year (Ojai is about halfway up the catchment and a good proxy for average watershed 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, marks the magnitude of 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, aside from 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).



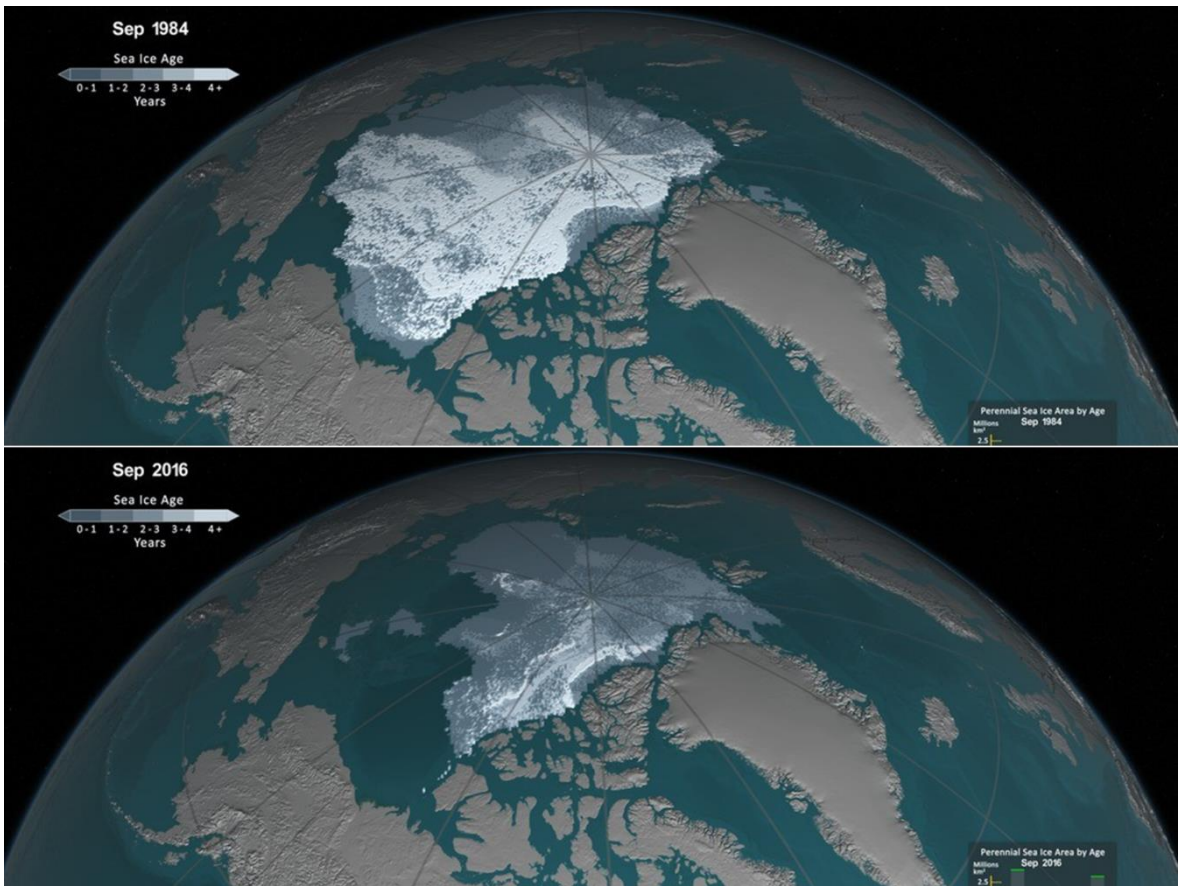
There is also an obvious connection between rainfall and changes in groundwater storage. This is a graph of average monthly flows on Atascadero Creek (monthly flows remove much of the rainstorm spikiness seen in daily or hourly hydrographs) and the depth to groundwater for two shallow wells (Sutton & 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. Hillside House is near Veronica Springs, adjacent to Arroyo Burro Creek. Groundwater levels in these 3 wells are closely correlated with streamflow, although Hillside seems to have been more affected by the drought—perhaps due to pumping at a nearby City well. The Fairview/Cathedral well is in upper Goleta, near the foothill transition. It too fluctuated with streamflow until the drought, during which it showed a steady drop in water level of about 17 additional feet—lack of recharge and/or increased pumping in the agricultural areas above it, or drawdown for the city's water supply, could be explanations. All wells showed an obvious downward trend during the years of recent drought (2012-2016), and the nine dry months of 2017 appeared to be restarting that trend in spite of the uptick produced by a wetter 2017 winter (the latest measurements were taken at the end of Dec. 2018).

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 shown here and is one of main reasons it, again unlike most other creeks, almost always has flowing water.



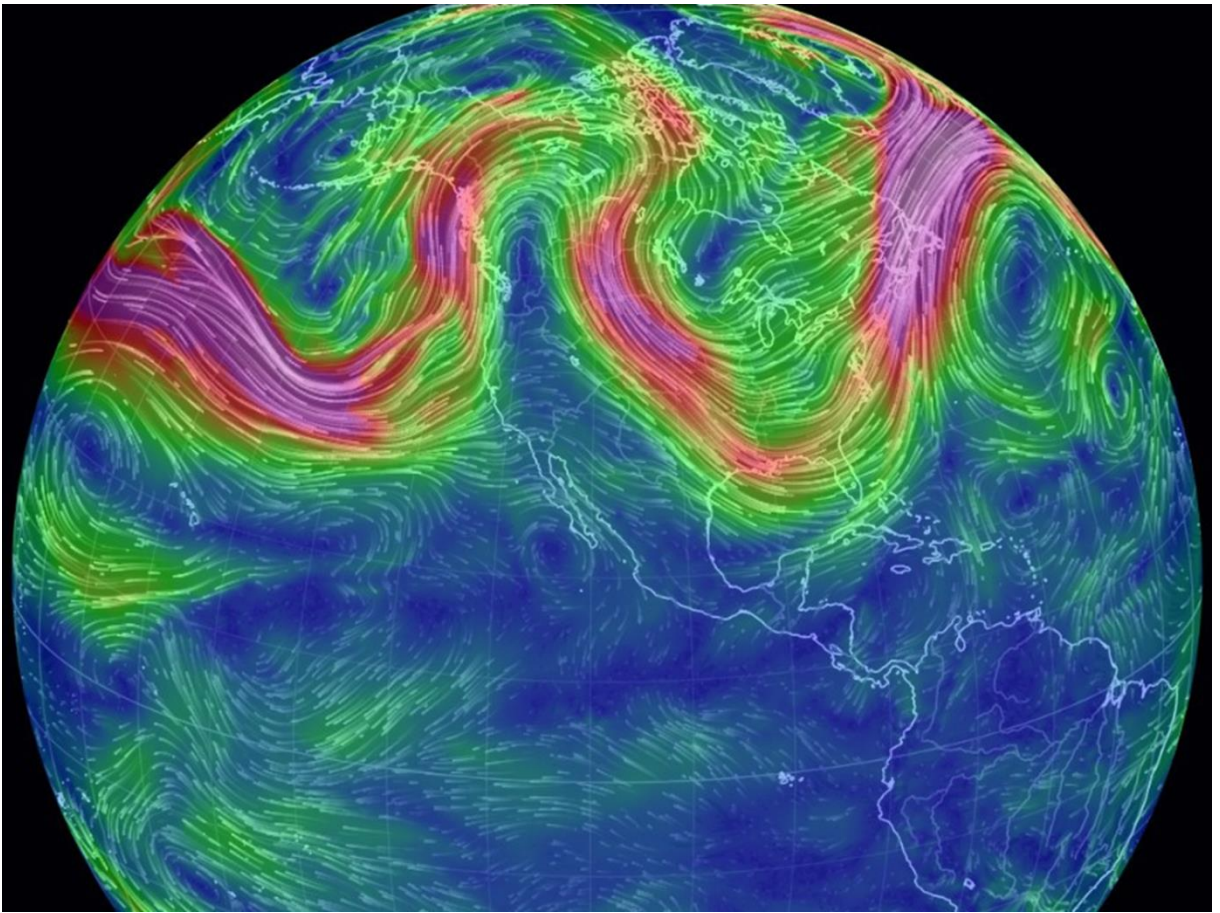
A 2014 paper, based on tree-ring studies, by Daniel Grin and Kevin J Anchukaitis (*How unusual is the 2012-2014 California drought?*) reached some interesting conclusions: Three-year droughts have not been unusual over the last millennium in California, and can occur with as little as a single year between 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 lasting between 3 and 9 years (i.e. every year having rainfall below the 800-2014 annual average precipitation). *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 year 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 these 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.



Over the past decade southern California has been experiencing rather strange weather. But the question as to whether this has been due to climate change or represents just some slightly extreme swing of a normal pattern remained open. However evidence and studies pointing to global warming have been accumulating. Not a done deal by any means, but the argument is becoming convincing. It goes like this:

The arctic is warming faster than any other part of the globe (e.g. on Dec. 30, 2015 the North Pole was above freezing). The ice cap is melting (contrast Sept. 1984 with Sept. 2016 above, the whiter portions represent older—thicker—ice, the less white newer—thinner—ice; see <https://svs.gsfc.nasa.gov/4510>). The replacement of highly solar-reflecting ice with open water causes increased heating and higher temperatures, and increases the water vapor content of the now warmer air—we tend to forget, but water vapor *is* another greenhouse gas. The positive feedbacks continue and more ice melts, and as the arctic warms, the contrast between arctic air with warmer air to the south weakens the jet stream.



And as the jet stream weakens (the slide shows the jet stream on January 14, 2018, see <http://miami-water.com/blog/3305/live-jet-stream-wind-map-of-world-radiation-fallout-usa/>) the “loops” shown here become more pronounced—less west to east, more north to south). As the jet stream becomes “wavier” it moves slower and has a greater tendency to become fixed, or stuck, in position (you may have heard words like “polar vortex” or “ridiculously persistent ridge” mentioned in weather forecasts). It also reaches further north in the vicinity of Alaska and western Canada. Major frontal systems follow the jet stream so a lot of our potential rainfall is also heading north—causing drought in the southwest. Within the upward loop warm equatorial weather is being drawn northward increasing southwestern temperatures. In contrast, the downward loop (call it a trough) over the eastern US draws cold arctic air further south, making Christmas even more Christmassy and New Englanders wish they lived in California.

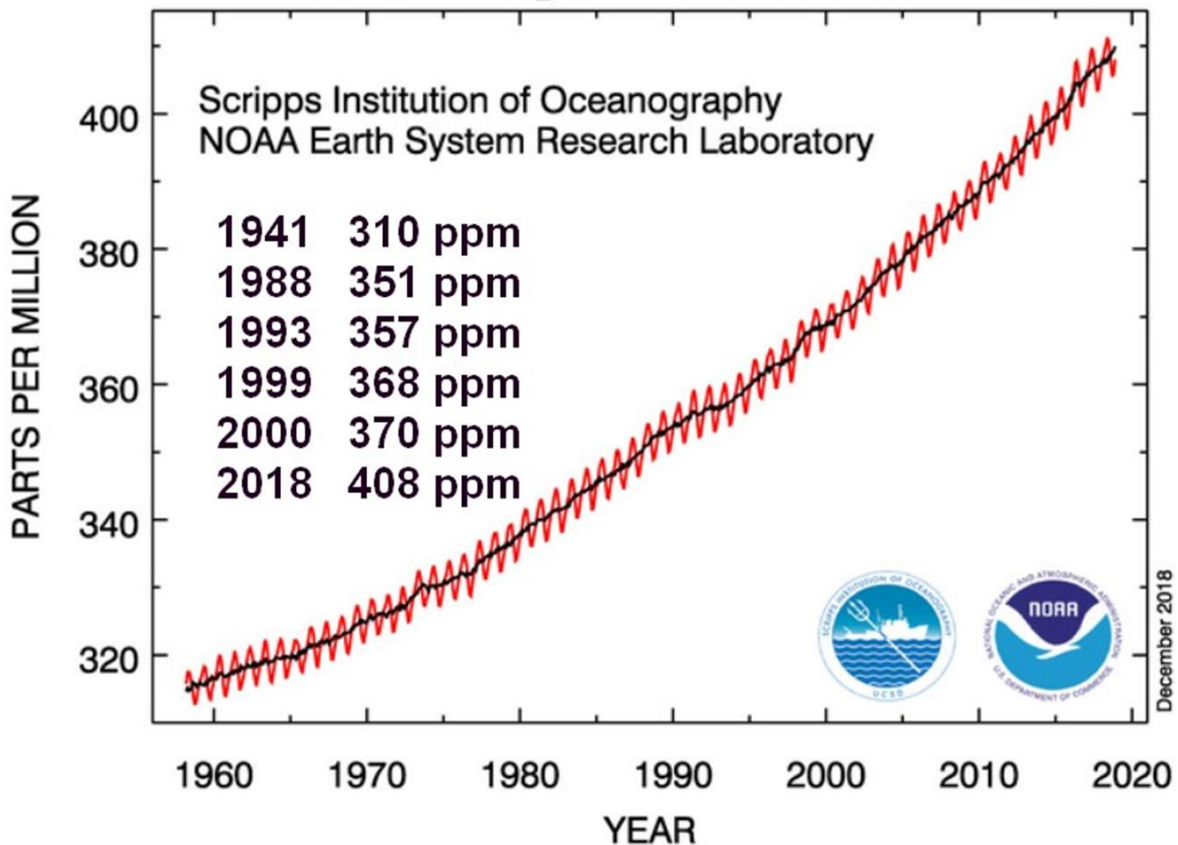
For more information Google “Jennifer Francis, Rutgers University” for some easily digested YouTube videos on this subject (e.g.

<https://www.youtube.com/watch?v=wE53Or56eNM> She’s heavily engaged in this research, and is perhaps the best spokesperson for all the recent developments.



We end up with hotter summers, and less winter rain; a year-long fire season instead of one lasting 4 or 5 months (e.g. Thomas fire in action on the slide above); a dropping water-table, dry wells, and shrinking reservoirs; and once flowing rivers and streams becoming ravines and dry gulches. The past no longer becomes a good guide to the future—as if we were entering a new country of which little is known. As Yogi Berra said, “prediction is very difficult, especially about the future.” And design is too. For what future do we design reservoirs, culverts, bridges, highway drainage, whatever . . . if the past no longer gives us much of a clue?

Atmospheric CO₂ at Mauna Loa Observatory



Let's digress a little and talk about climate change or global warming. We might as well start with an updated version of what is, arguably, the most famous graph in history, showing data likely to have the greatest impact on us, the human species – and on your future: the “Keeling” curve. We should all be this lucky when we plot data. Keeling found not one, but two patterns in atmospheric CO₂: 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 CO₂ responsible for anthropogenic global warming. (He is justifiably famous, not only for fabrication of the equipment used, but for the selection of a sampling interval that allowed him to capture both variations, and for the dogged determination with which he persisted in making these measurements for years and years.)

I've added some numbers to the graph. These mark various milestones: 1941, the year I was born; 1988, the year James Hansen first testified before congress about the danger; 1993, when I first heard the phrase: “human activities may be having a discernible impact on climate” at a scientific meeting; etc. Note that the change over the 47 years from 1941 to 1988 was 41 ppm; the change over the last 19 years was almost the same: 40 ppm. The pace is accelerating, not slowing down. Last year, 2018, saw the fastest rate of growth in atmospheric CO₂ concentrations.



"Solving the climate crisis is the greatest and most complex challenge that Homo sapiens have ever faced. The main solution, however, is so simple that even a small child can understand it. We have to stop our emissions of greenhouse gases. Either we do that or we don't."

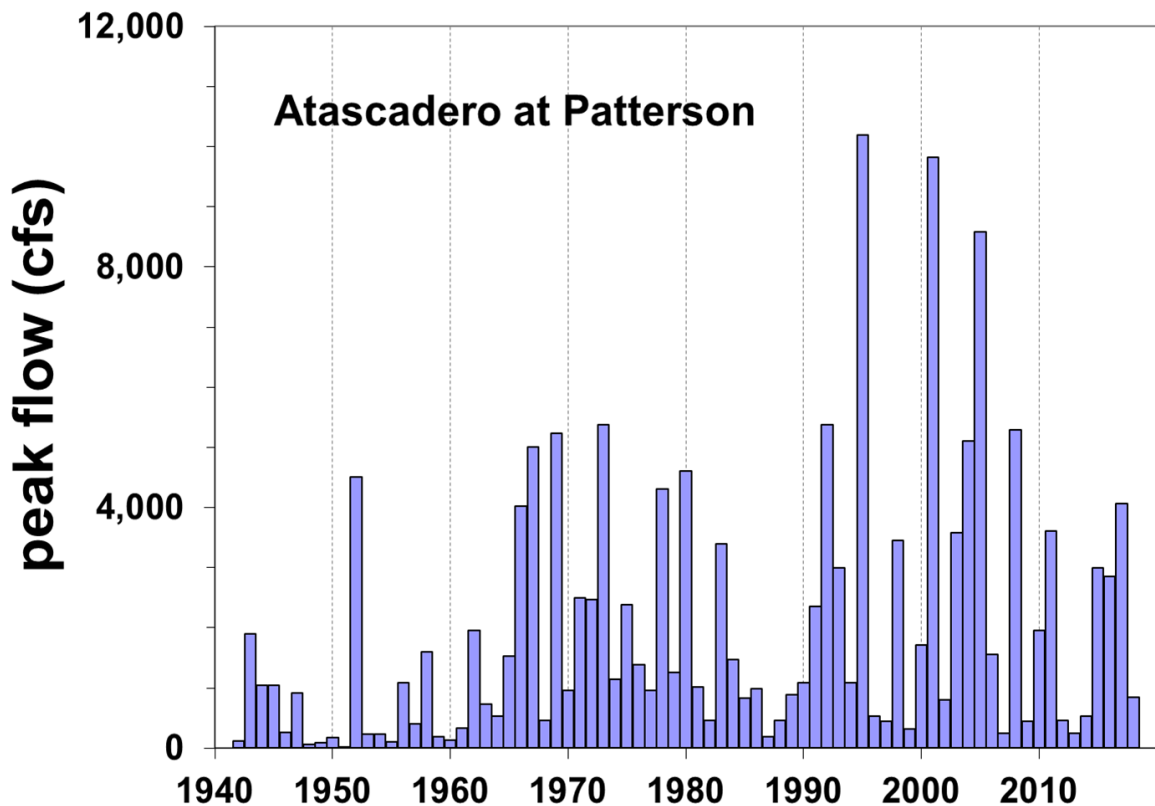
I only have one hero. She's Greta Thunberg; she's 15; she's autistic; she's a marvel. Last September she left school and began a 3-week strike, sitting outside the Swedish Parliament Building. That's where this picture was taken. She still does this one day a week.

She said all you need to know about Climate Change in a brief speech at last December's climate conference in Poland (<https://www.youtube.com/watch?v=Hq489387cg4>). As she mentions, climate change is an existential threat – i.e. a threat to human existence. And if not our existence as a species, then surely as a civilization. It's sad to know that we are now at a point where reasonable and affordable technological paths towards averting this coming catastrophe have become clear, but we seem destined to fail politically because of inattention, selfishness, and pathological greed. Societal failure is never pretty and it wouldn't be this time, but in our case it will be well deserved.

Oh, I'll miss the worst of it. A year long fire season, perhaps tens of thousands of burnt homes here and there, longer and drier droughts, warmer weather, more severe coastal flooding, perhaps some crop failures, but nothing totally destabilizing – unless, of course, I happen to become an actual victim. But the next generation, and the one after that ... *You*. What kind of humans condemn their grandkids to misery and despair? Obviously our kind.

A few Greta's can't effect change by themselves. Not even a few thousand. But a few million now . . . Spending weeks, months, or even a year or so sitting outside government buildings, marching, carrying signs; well, that might just do it. There are three hundred twenty five million of us living in the United States. The richest and most carbon dioxide contributing nation (on a per person basis) on the planet; the nation that has contributed more CO₂ to our current atmosphere than any other. You'd think it would be easy to find a few million willing to make that effort to save the future. Yeah, sure.

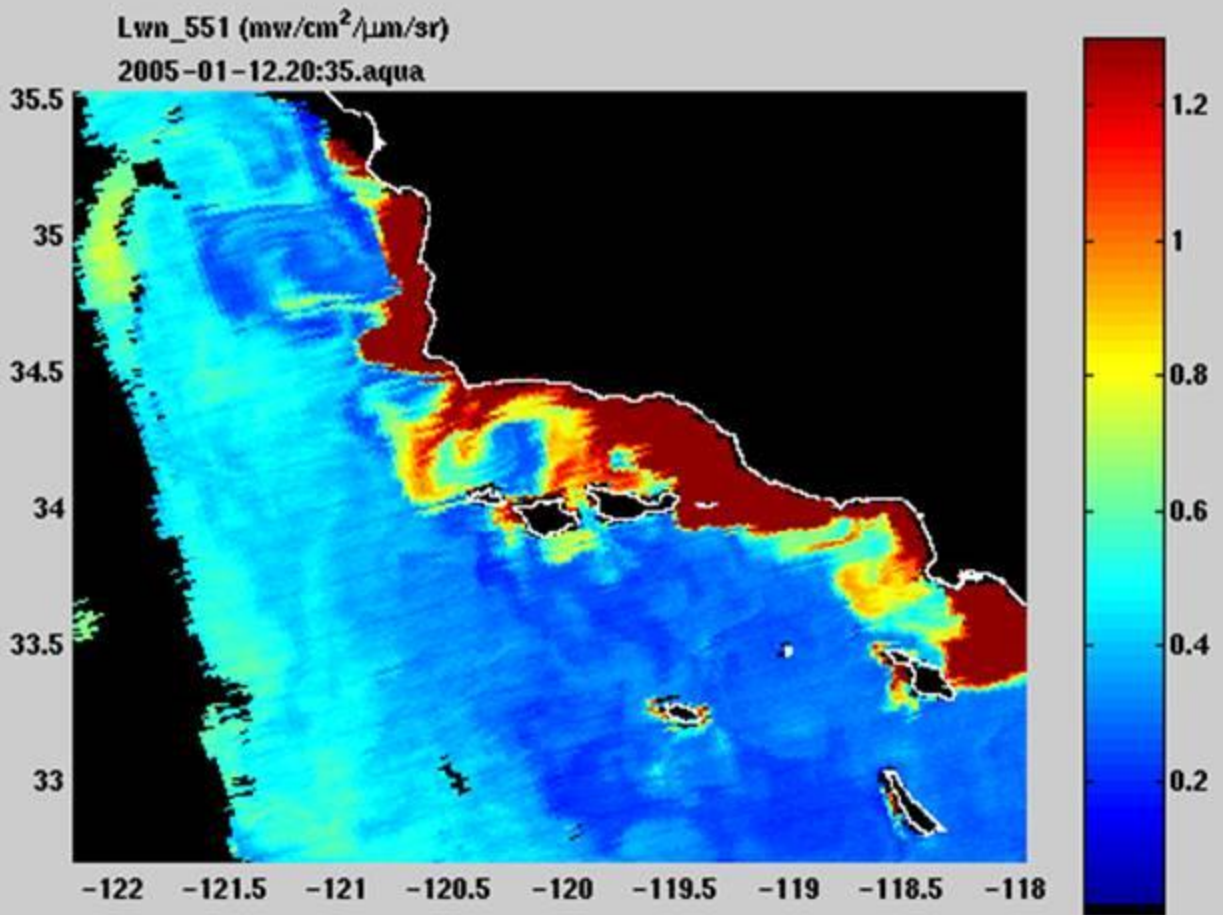
I don't know about you, but I'm shamed and humbled by her. I am not, and never was, nor could I ever be, as good a human being. Not to mention she is not even speaking in her own language. Fifteen. My God . . .



Keeping climate change in mind, let's turn to peak flow. 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 transformation and modification of the stream channel takes place. Or whether or not it 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.

(As a comparison with flows shown on the chart, as you probably sat around watching the rain on Saturday (2 Feb. 2019) peak flow was 2550 cfs.)

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 over, the faster ever increasing amounts of runoff rush directly to the creek. In hydrologist speak, the hydrograph gets flashier: steeper, higher and shorter, and more impressive. Global warming is expected to further increase peak flows in future years. Rain may come less frequently, but it will come. There will still be big years, and arguably the biggest storms will be even bigger since warmer air carries greater amounts of water vapor. Extreme events will become even more extreme.



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 by stormflows and runoff carries it downstream.



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 better show this change and functioning business we'll now focus on it.

The Ventura watershed is very similar to those in Santa Barbara & Goleta: similar geology, similar land uses, the same climate, similar rainfall. 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 the 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. All the competition for sunlight and nutrients done away with in one or two storms. And algae did dominate these open waters during the following dry-season. However, as years pass without another significant big storm the plants and trees shown in the 2004 photos returned—and why not, with water, nutrients and sunlight providing a near perfect growing environment—and 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).



from left to right

July 2001

August 2002

March 2003

October 2003

Sept. 2004

May 2005

Change doesn't just occur during a big year, modifications from year to year or even within a single 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.

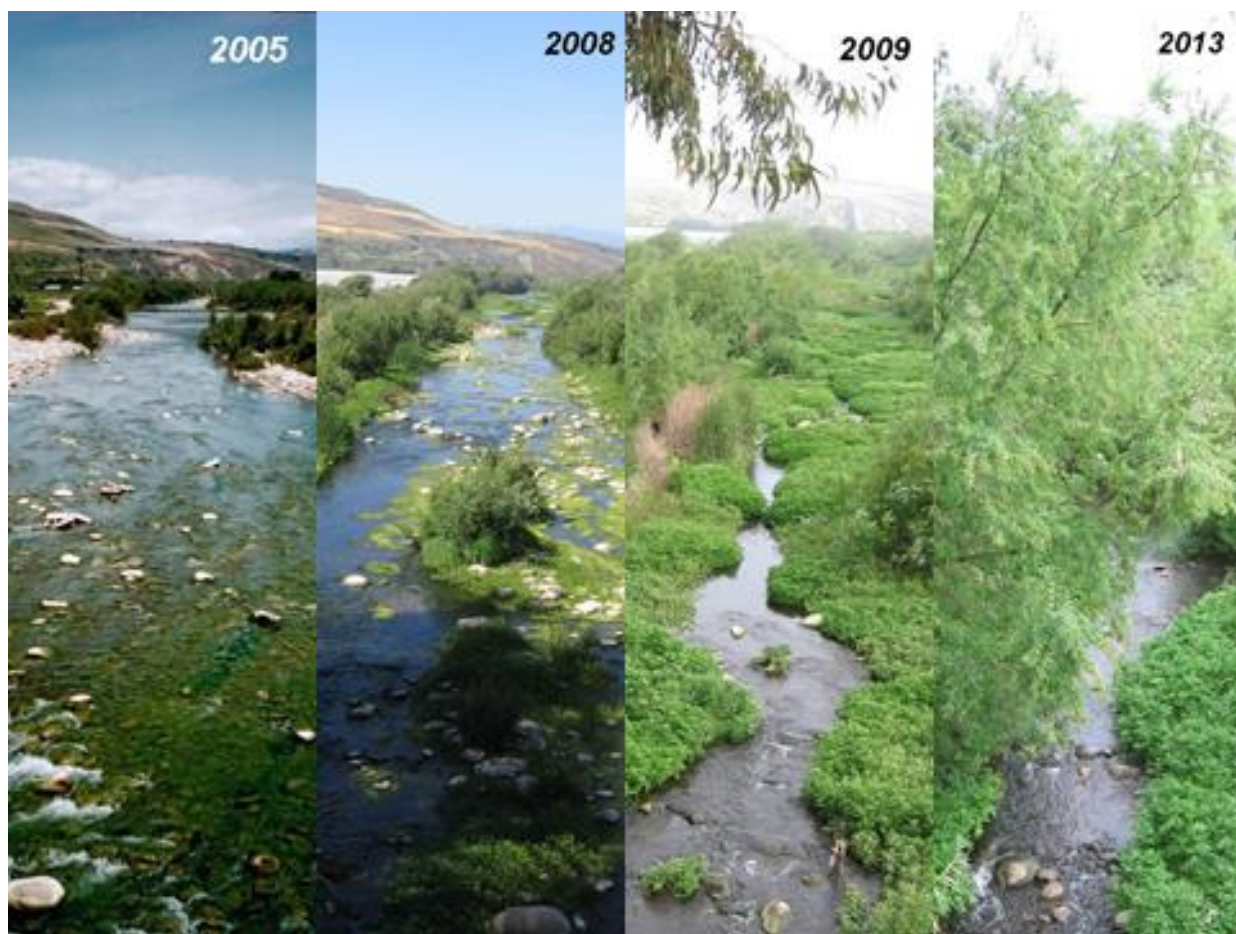


January 20, 2017: Main Street, Ventura (left), Foster Park (right)

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. During the long dry spell of this decade, there were nearly six years of low rainfall from 2011 to 2017). And its now been eighteen 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 out the river again. But the 19,000 cfs flood of 2011 was able to work very little of the same kind of 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 considerably longer passage of time would have to be extremely large. These 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.



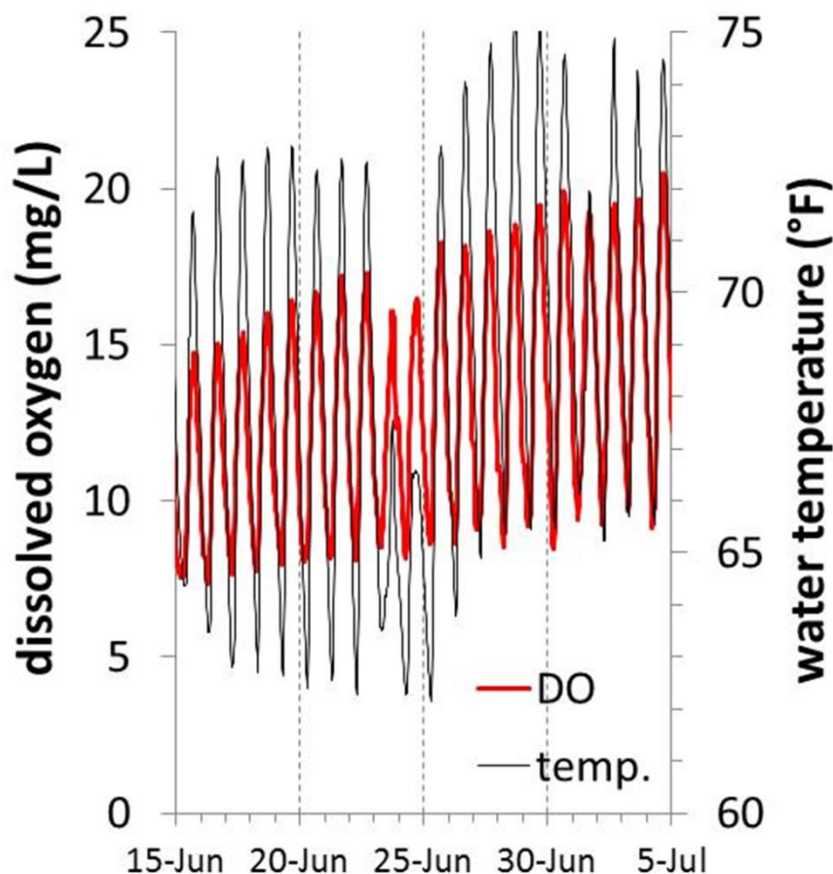
This is the same view as the one shown in the previous slide (looking upstream from the Main Street bridge), but taken on January 12, 2018, three days after the mud-slide causing storm that devastated Montecito. Peak flow upstream (at Foster Park about five and a half miles upriver) was 8,200 cfs (that's an eight foot wall of water at that location) and it had to be much higher here. Peak flow was considerably greater than the 2017 flood flows mentioned in the previous slide. Yet the riparian vegetation, including even smaller midstream plants, was relatively undisturbed.



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 pH. At high flows or in a big river, this impact is muted, but as flow decreases the 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 providing additional substrate for photosynthetic diatoms.

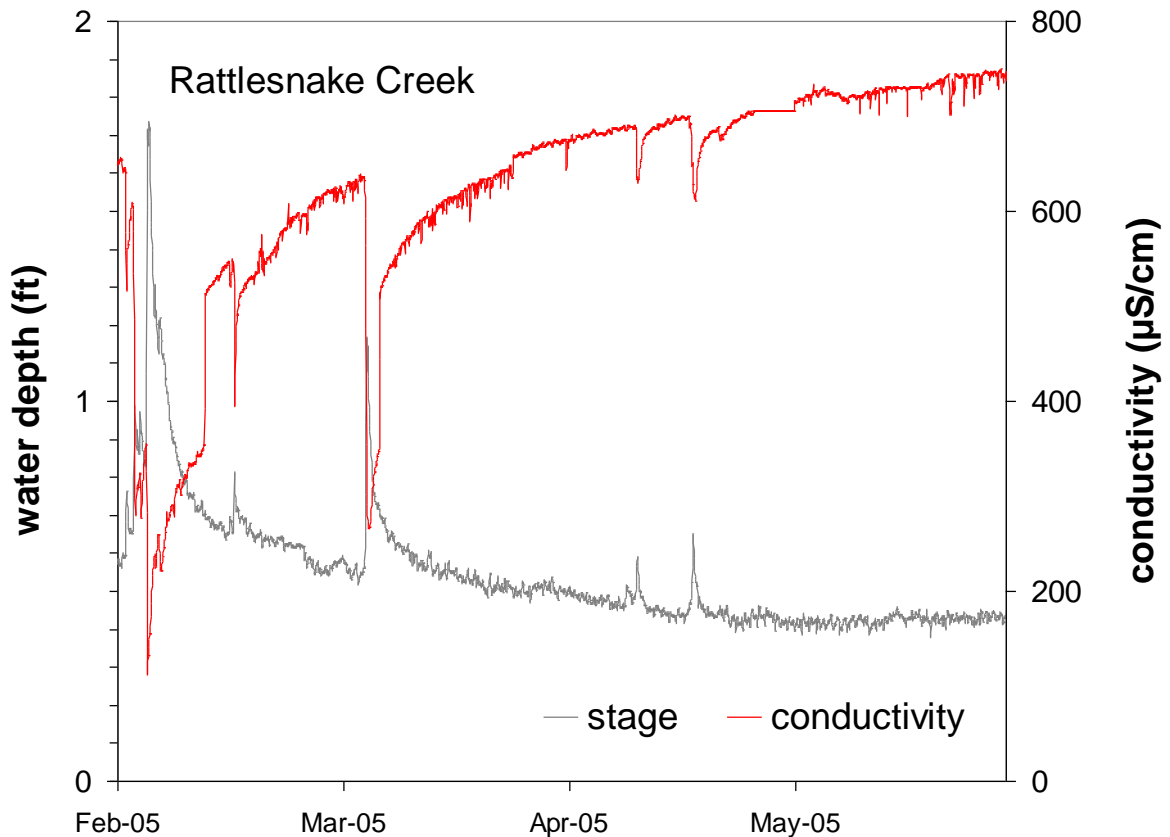
A few miles upstream of this location the Ojai sewage treatment plant dumps nutrient-enriched treated effluent into the river. Higher flows considerably dilute this loading and large masses of algae remove much of it before it reaches Main St. In low rainfall years the relative proportion of effluent 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

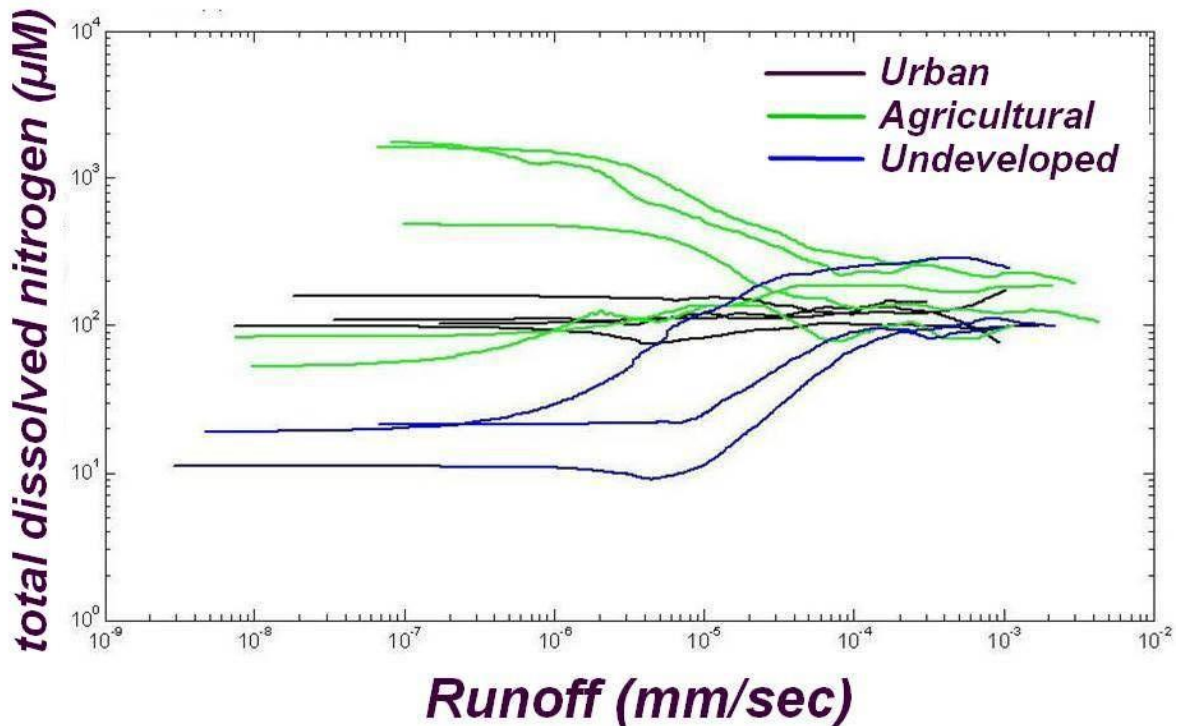
Here's an example of how much water temperature can vary in a small sluggish stream; in this case the Ventura River at the San Antonio Creek confluence during a second summer of drought. The plentiful algae present are responsible for the daily fluctuation in dissolved oxygen (pH , not shown, would vary 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 pH).

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 would 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.

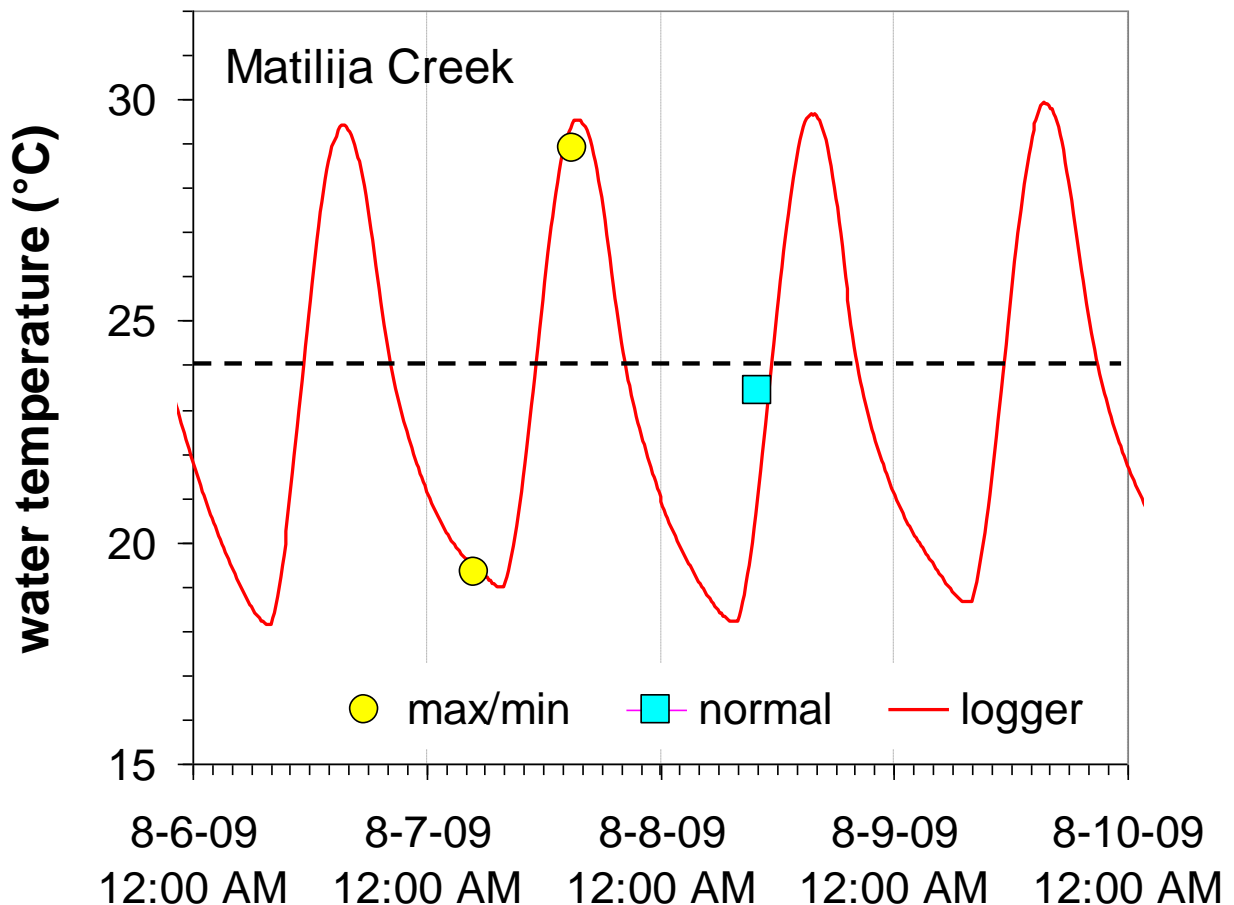
The graph shows hourly measurements of water depth (stage) and electrical conductivity on Rattlesnake Creek from February through May 2005. Notice that, except during periods of rainfall (marked by abrupt increases in water depth and decreases in conductivity), conductivity is changing gradually and 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 ($\sim 10 \mu\text{M}$; note $71 \mu\text{M} = 1 \text{ mg/L}$); urban creek concentrations are usually an order-of-magnitude higher ($\sim 100\text{-}200 \mu\text{M}$) 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 pH.

Data Collection



Summarizing data collection, here are some of the questions that need to be asked before starting:

Why do I even want to start? What's the purpose? What might I want to measure and, more importantly, why?

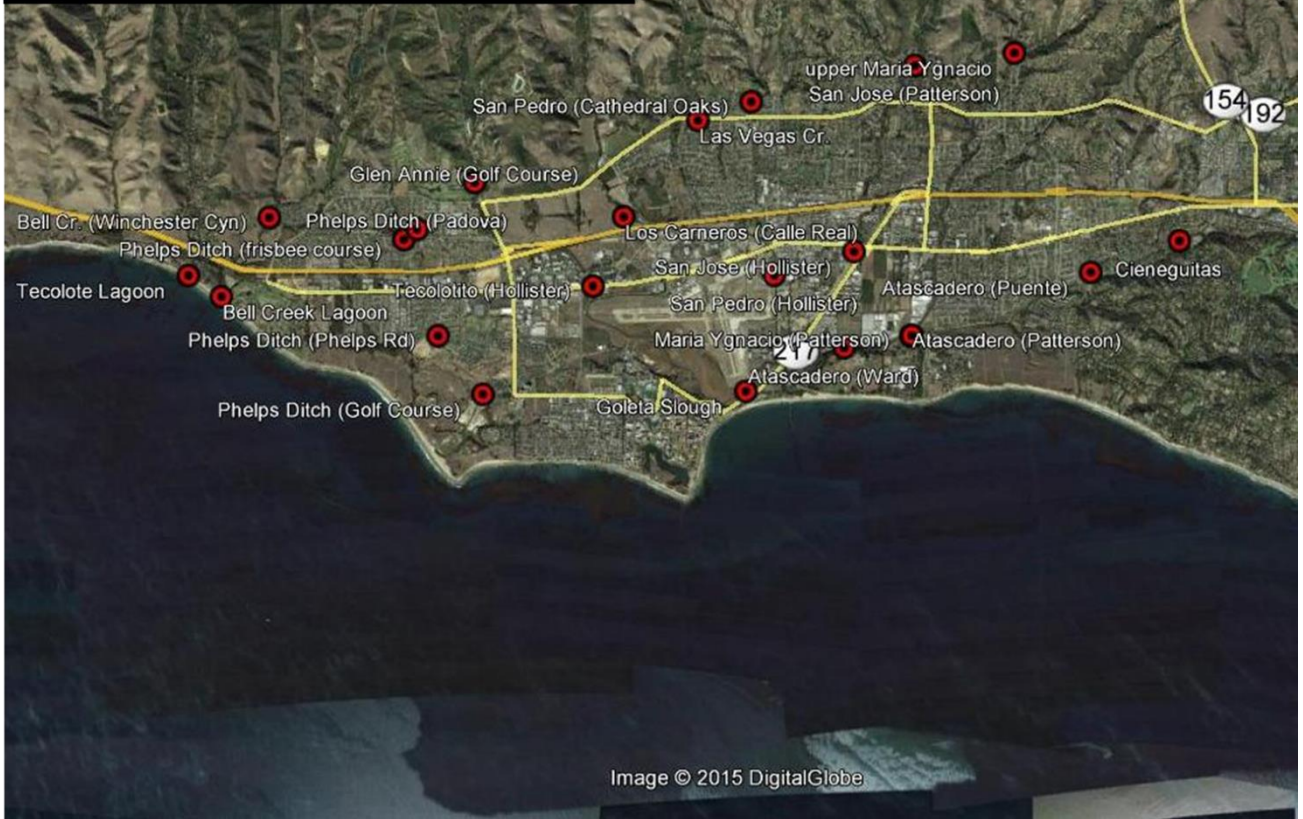
What can that particular parameter tell me and what might I expect to find? And if it turns out different, what might that mean?

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

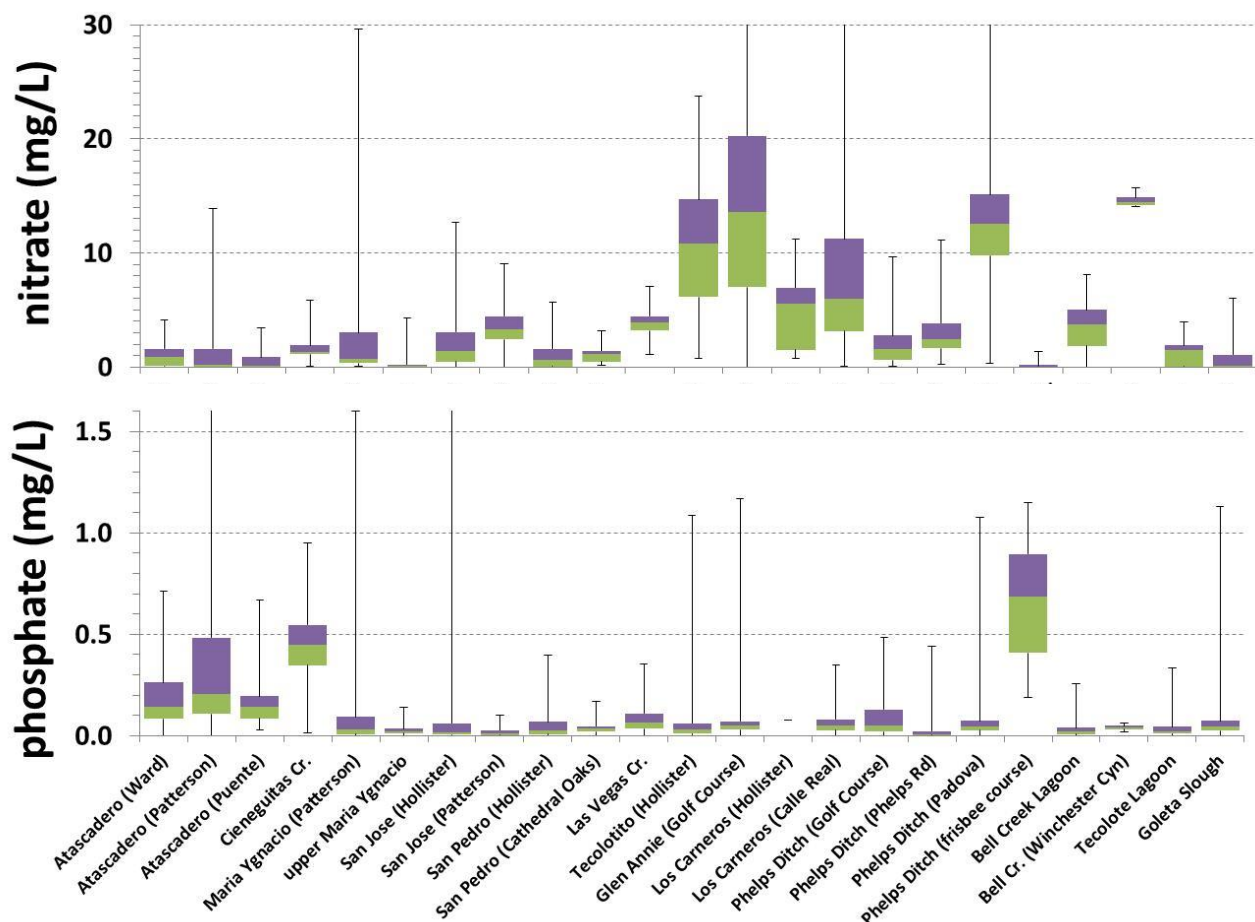
When do I sample? And how often? And for how long? How might what I'm trying to measure vary and what do I need to do to capture that variation? And if I'm wrong, will my sampling program also tell me that? After all, this is supposed to be science and not simply a confirmatory exercise in self-satisfaction.

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 referring to 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 await. Sometimes very big surprises. Be flexible and prepared to change in midstream (pun intended).

SBCK Goleta Sampling Locations



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 of summarizing large data sets.

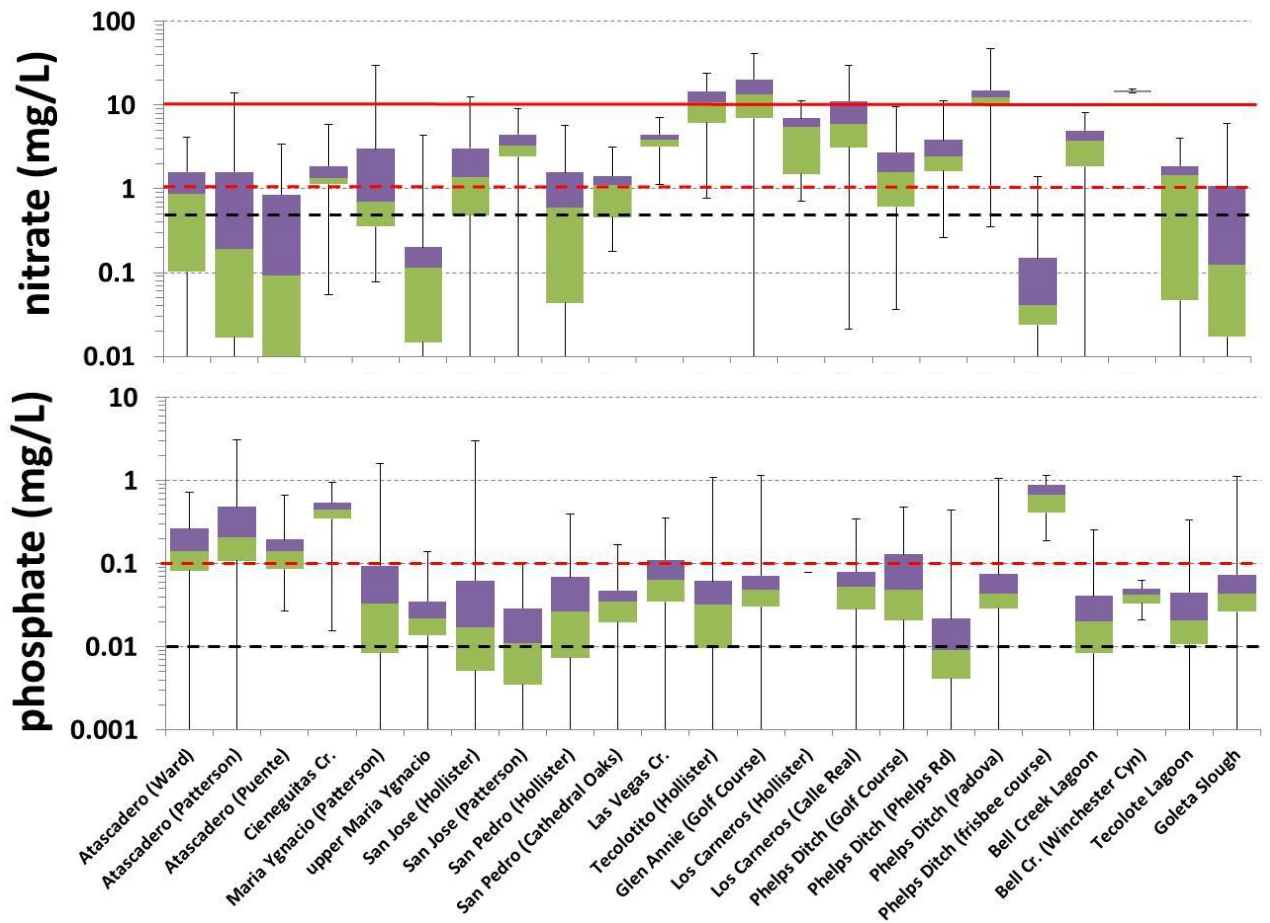
I mentioned earlier that high nitrate concentrations are a characteristic of agricultural land use, and this shows up nicely in the Goleta data. But note that phosphate in these ag-influenced creeks is low. Our geology is naturally rich in phosphorus and ranchers usually know better than to waste money 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 adjacent horse stables and arenas at Patterson and Cieneguitas.



This is a near-infrared 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, with regards to nutrient concentrations, is worse than the graphs indicate.



When I think of the vanishing species, the filth and pollution we thoughtlessly dump onto Earth and our fellow creatures, the rising desperation evident on all sides, and of us, the rich who have grown fat and sleek by plundering the resources of people in desperate places, hoarding our wealth, building walls, the whole mess of potage for which we have sold our birthright of clean air, clean water, open space, a clear conscience—when I think of all of that . . .

The quote is from Fenton Johnson in a 2017 issue of *Harper's*. I left out the first sentence, “*What can liberate us from this death spiral of consumption we have created for ourselves?*” A good question.

I don't know what the future will bring. Recall Yogi Berra's aphorism, “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) the 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.

Another appropriate aphorism would seem to be “*we learn from the past, but we don't seem to learn much.*” Our species may not be 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 weather 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.



The Basics

1. the magnitude of the nitrate concentration provides a clue to the source
2. high phosphate concentrations can indicate pollution by manure and septic tank wastes
3. high chloride concentrations can do the same
4. since most dry-season flow is surfacing groundwater, well chemistry can pinpoint the source

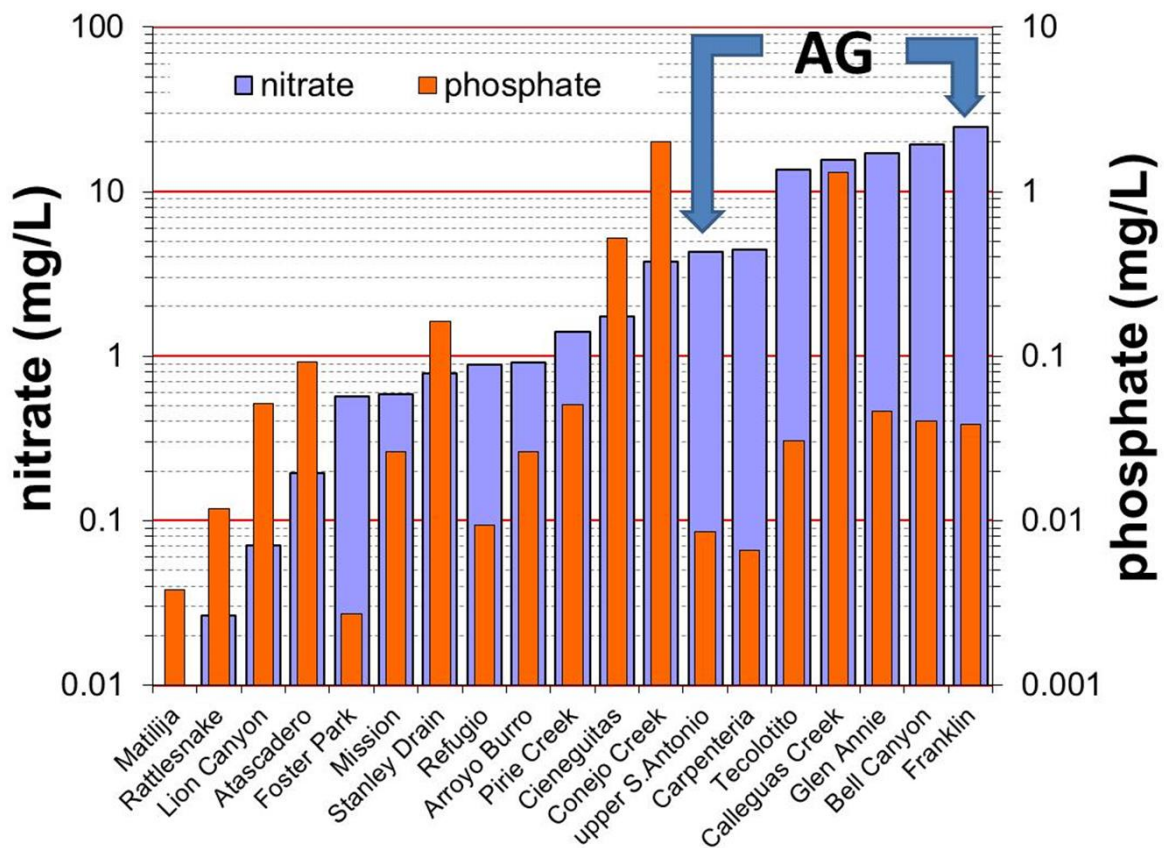
Knowing the magnitude of the nitrate concentration can, by itself, provide a clue as to the source. Different land uses typically generate nitrate concentrations in runoff and streamflow characteristic of that land use.

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 than 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.

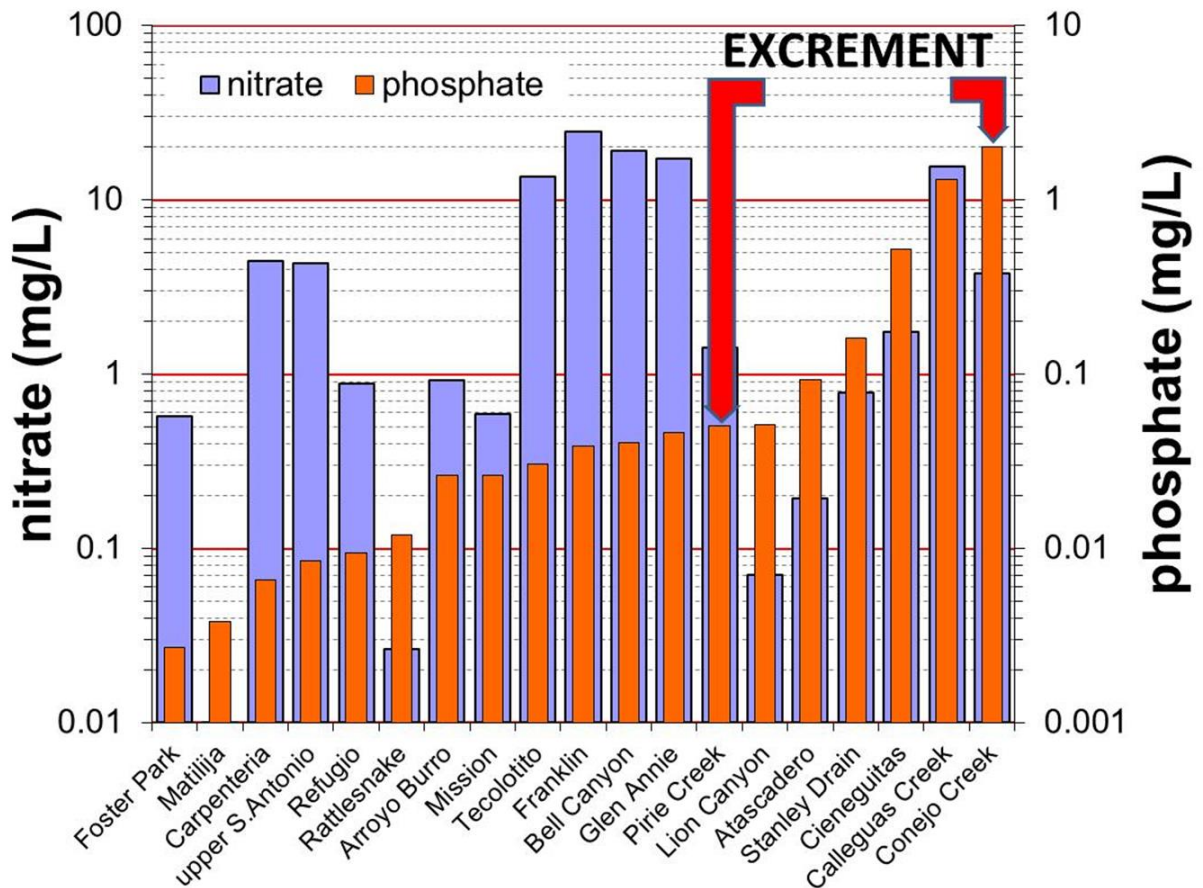
And finally, since almost all dry-season flow in our streams and rivers is surfacing groundwater (aside from wastewater treatment plant effluent, and other occasional contributions), well data and the chemistry of well water can also tell us a lot about the source of contaminants.



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 nitrate (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.

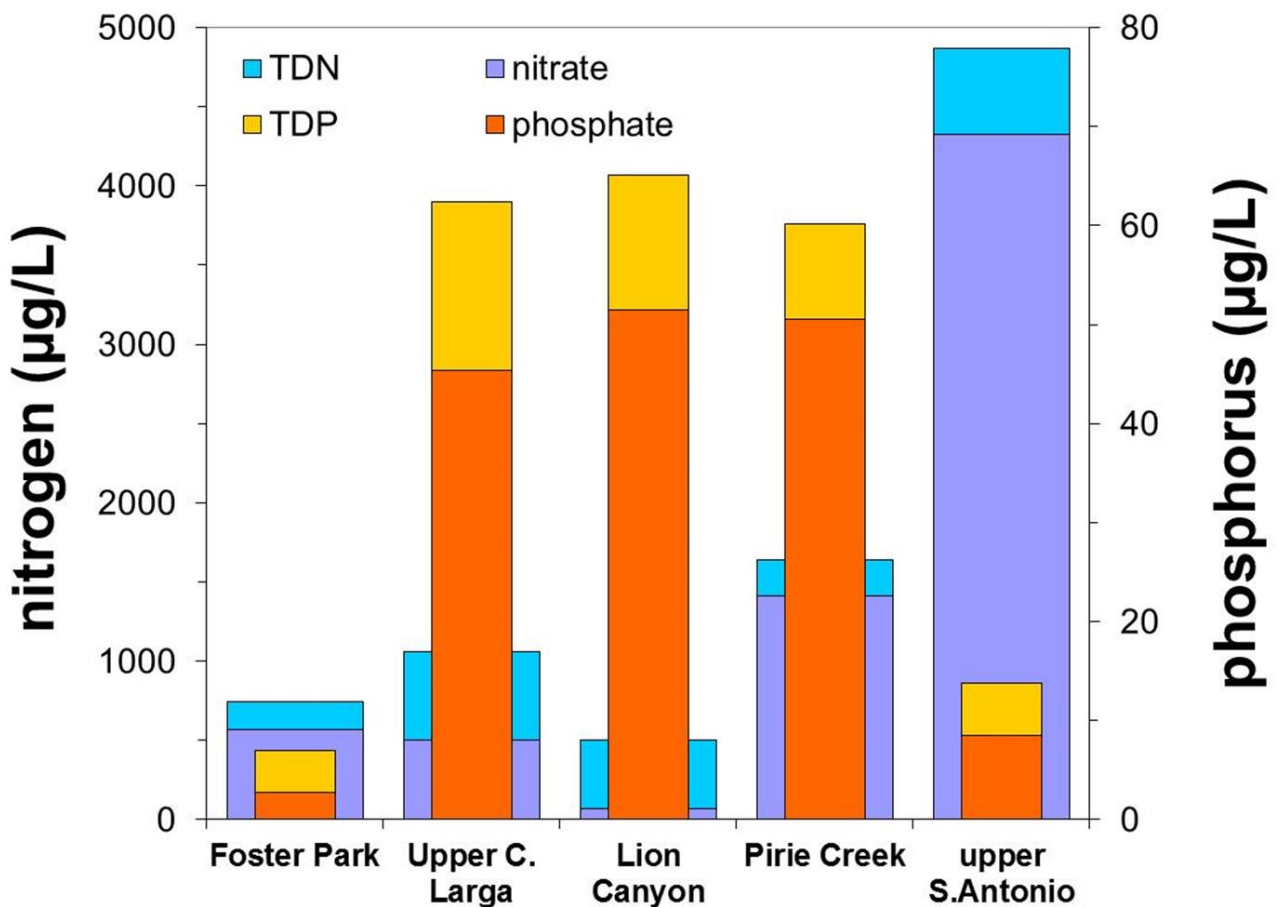
Naturally, there is some overlap. Streams monitored directly downstream of WWTPs (e.g. Conejo) or with mixed land uses (Cieneguitas—urban and horses) or with severe septic tank/leach field failure problems can fall into the urban-ag gap. Three-fold higher nitrate concentrations on upper S. Antonio compared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



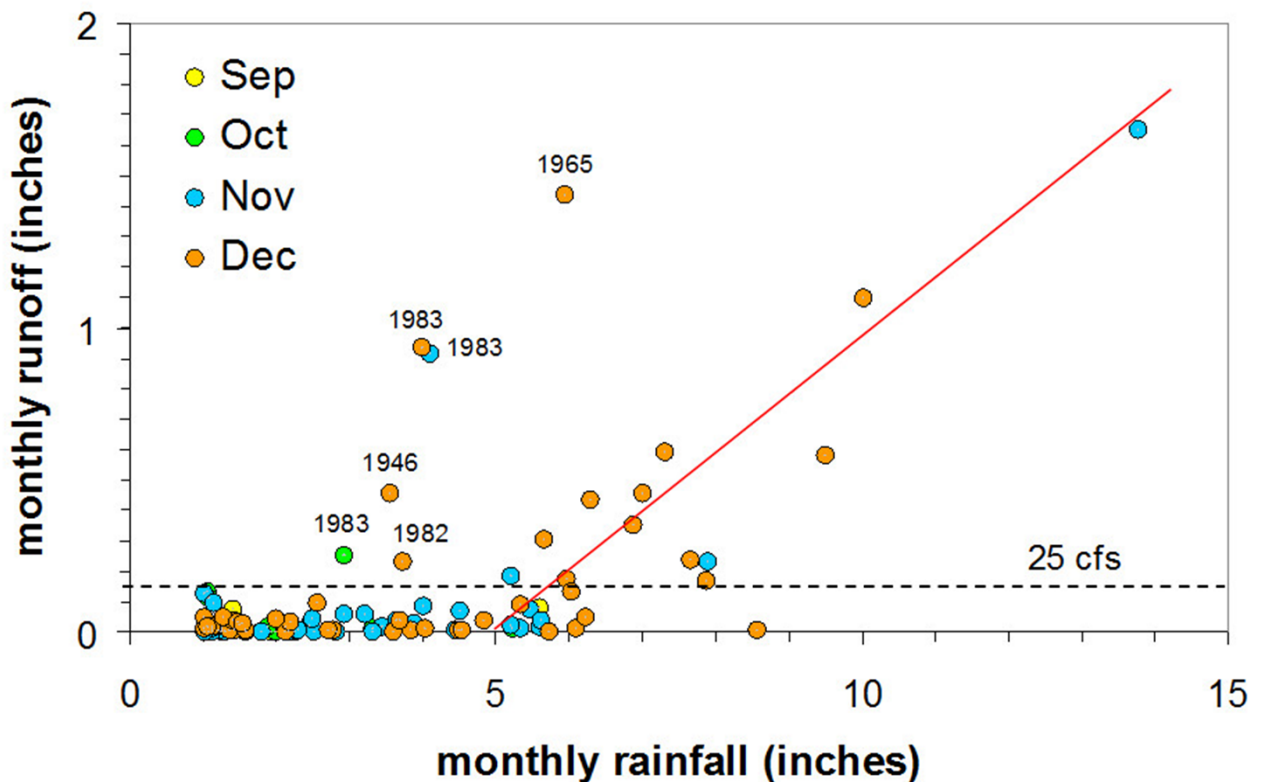
This is the same graph shown in the previous slide, except that the sampling locations are now arranged, from lowest to highest, by mean phosphate concentration. The low and middle ranges are quite mixed: near-pristine, urban and agricultural land uses are all jumbled together (the background nitrate 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 (TDN) 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.)

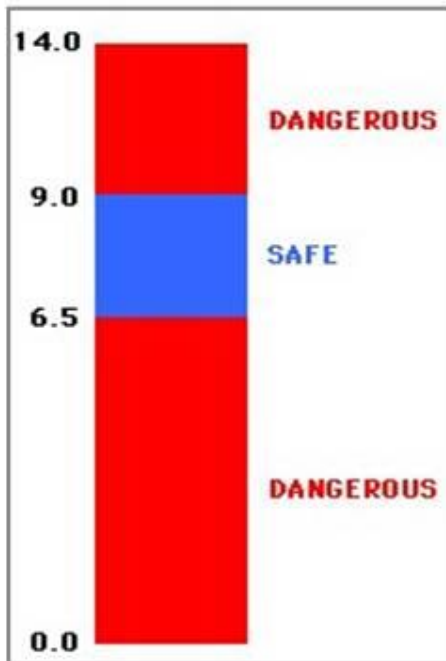


How much rainfall does it take before an entire watershed begins to contribute runoff to flood flow? Here monthly runoff (in inches at Foster Park) is plotted against monthly rainfall for the months of September through December from the Ojai rainfall record (which begins in October 1940) for months 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 (2017), 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.

pH



Dissolved Oxygen



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: pH, 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.”

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.*"