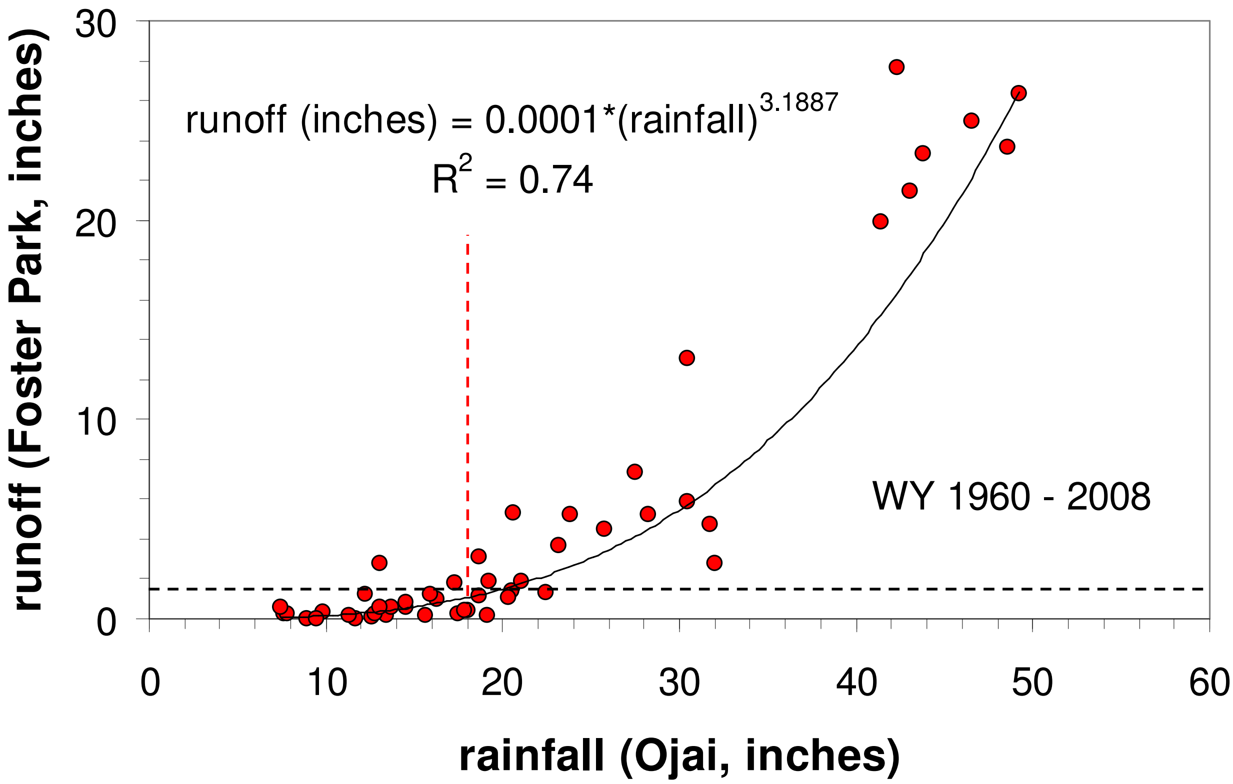


During the June SBCK sampling John and I were talking about the relationship between rainfall and runoff (we'd just had a bit of rain and could see no effects on the river at Foster Park, nor anywhere else). I mentioned I had drawn up some interesting graphs on the subject intended for a talk scheduled before the Ventura Watershed Group, a talk subsequently canceled. And I promised to send them to him.

However, since the Ventura's runoff/rainfall relationship plays a direct role on the presence or absence of algae on the river and it's tributaries, I've decided to do a slightly more organized and formal exploration, going into greater detail instead of simply mailing off a couple of graphs. You can blame John. My first graph is shown above. It simply plots annual runoff (by annual I mean water-year; October 1 through the following September 30) at Foster Park (USGS gauging station records) against annual Ojai rainfall (Ventura County rainfall records) for every year from 1960 through 2008.

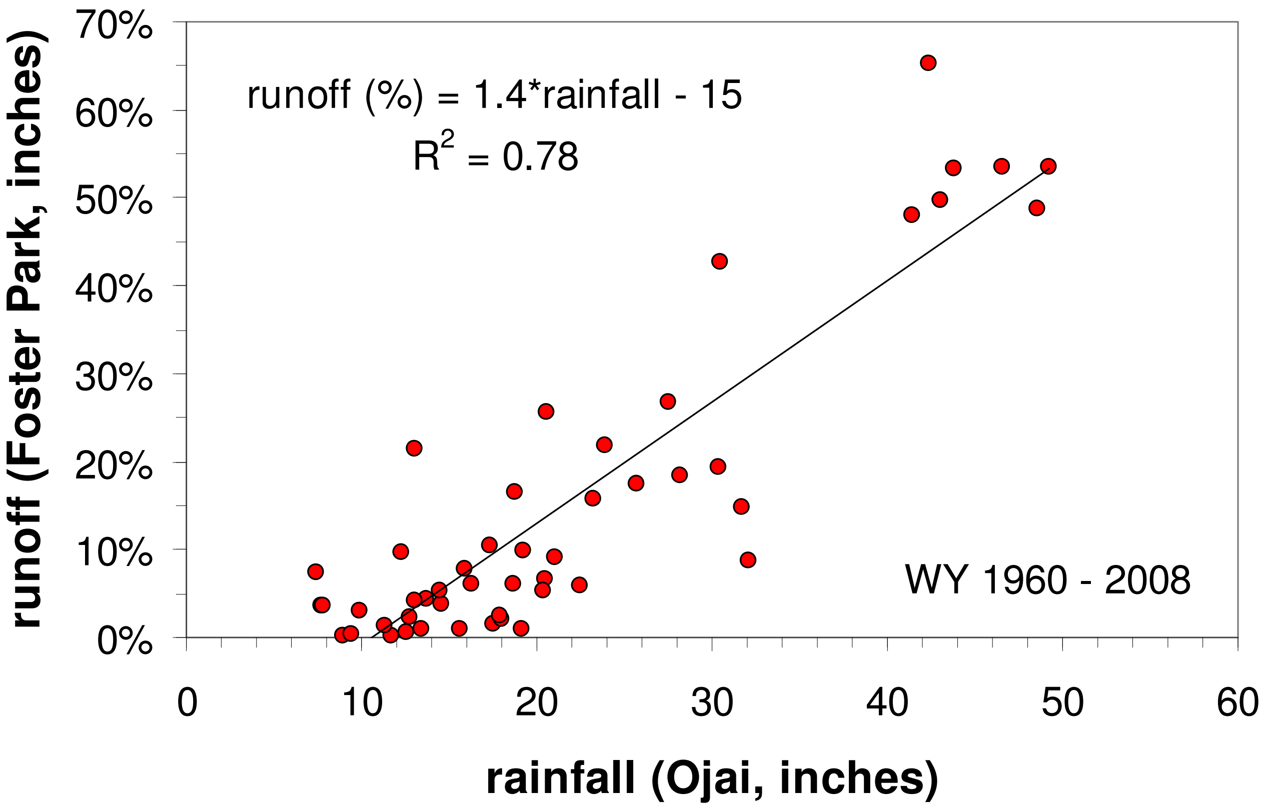
(These are readily available records. The only trick is the unit used for runoff. Flow is typically measured in cubic feet per second (cfs), not in inches of water per year, but if you know the average daily flow during a year in cfs, multiplying it by the number of seconds in a year and then dividing by the number of square feet in the watershed above the gauging station, you can convert cfs to feet of runoff per year; multiplying by 12 turns it into inches – an inch meaning that amount of water spread over the entire watershed, i.e., just like we measure rain. And how big is the watershed above Foster Park? It's 188 square miles, or, at least, that's what the USGS says. I'll let you figure out on your own just how many square feet that happens to be if you're still curious.)

One way to think about the graph is that Ojai rainfall represents the number of inches that fall upon the watershed in a given year (I'm using Ojai, about halfway up the catchment as a proxy for what happens *on average* in the watershed), and some fraction of that total runs off down the Ventura River: so many inches in, so many 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. Both the annual rainfall and runoff records are highly *skewed*, i.e., the mean being different than the median (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).

Not all years with the same rainfall are created equal. Twenty inches of rainfall in one year may not be the same as 20 inches in another. Size of the individual storms matters (one big 20 inch storm has quite a different affect on the watershed than 20 one-inch rainfalls) as does the spacing between storms (6 storms in one month being different that one storm a month for 6 months). Most of the Ventura catchment, especially in the upland and mountain areas, is covered by a thin but porous upper soil layer. Come the beginning of the rainy season this soil layer sits there like a dry sponge and all the first rains usually manage to do is to gradually fill that sponge; only when it's filled can these areas begin to contribute runoff to creeks and the river. It takes a real big storm (or lots of smaller storms occurring in close succession) to saturate these soils and then some, generating the big runoff and floods we see in years like 2005. In other years, like 2009, the storms are not big enough, or come too far apart (allowing soils to dry out, increasing their water-holding capacity, between storms) to contribute *any* runoff.

Further down the catchment it's another story. Developed areas, areas with lots of impervious surfaces (roofs, pavements, etc), contribute big fractions of even small storms to runoff, and contribute it very quickly. But developed areas make up a small fraction of the Ventura watershed so what happens in the undeveloped majority of the basin controls the overall response of the river. At least as far as water *quantity* is concerned; the *quality* of runoff being another story. Visiting the river during a storm you can visually distinguish between these two kinds of contributions: upslope undeveloped runoff is heavily sediment laden and light brown in color (words said about the Mississippi in flood would also apply to the Ventura – too thick to drink, too thin to plow); urban impervious runoff is light on sediment and blackish in color. Keep in mind that things usually look different at Main Street than they do at Foster Park. Lots more urban runoff at Main Street, so much



so that big storms often produce a double peak in flow: urban runoff crests and diminishes before the real flood peak – from upstream mountain areas – gets there. (I'm simplifying of course. There is another category of developed area, agricultural lands – and we could probably include residential subdivisions with extensive landscaping in this group – that have a response midway between the developed/undeveloped extremes I've described. But let's not complicate a good story.)

We can revise the first graph by plotting, not runoff in inches on the vertical axis, but runoff as the percent of annual rainfall that occurred in each water-year. I've shown this above. This plot gives a new equation, one that explains roughly the same amount of variation in the data but allows us to draw an interesting conclusion. The equation is

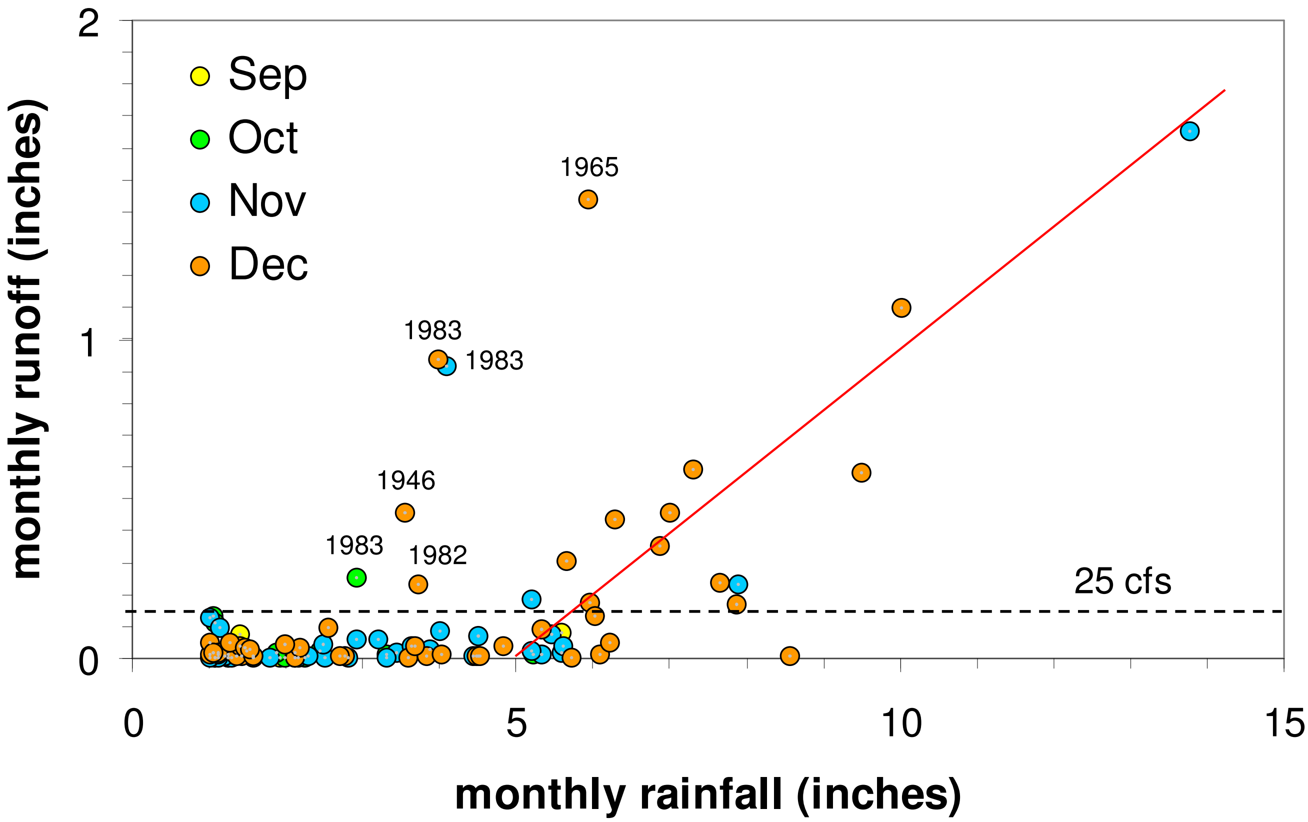
Runoff (as a percent of annual rainfall) = 1.4 * (annual rainfall in inches) – 15

and it indicates that we can expect almost no runoff unless rainfall exceeds 10 inches a year, and nothing serious until we exceed 20 inches – something that happens in only one year out of every three. Our current year is a good example. Total 2009 Ojai rainfall was 12.9 inches. Plugging this value into the equation tells us to expect about 3 % of that 12.9 inches to show up at Foster Park, i.e., 0.4 inches, equivalent to an average daily flow of 5.5 cfs. Estimating expected flow at Foster Park during the coming months of July, August and September, the true value will probably be a little higher, closer to 7.6 cfs. But not a hell of a lot of runoff in any case.

(I've ignored, and will ignore until later, the fact that flow at Foster Park is diminished by water extractions occurring upstream: at the Robles Diversion (transferring runoff to Lake Casitas) and by municipal water-supply wells above the gauge. The resulting underestimate of total annual runoff does not seriously affect the conclusions of this analysis.)

A similar methodology can be used to answer a more important question: How much rain is needed to cause a reasonable size flood – one which begins to flush rooted aquatic plants and fine sediment downstream? A river-cleaning flood, after all, is the event that dramatically changes river ecology, substituting an open water, gravelly bottom, environment friendly to steelhead propagation – and lots of algae – for a muddy bottom dominated by aquatic plants. And what the hell might “reasonable” mean in the first place?

Let’s back up and start off with a slightly different, but related, question: how much rainfall does it take before the entire watershed begins to contribute runoff to flood flow? Later we can take a stab at what kind of flow it might take to remove aquatic plants and fine sediment, and at what point do brush, trees and rocks start to go. The most accurate way to go about this would be to take it storm by storm: tabulating total rainfall, total flood flow and peak river flow, all the while looking at antecedent conditions – i.e., previous rainfall that might have, so to speak, primed the pump. Unfortunately, I lack the time, patience and data to follow this path so I’ve taken a short-cut.



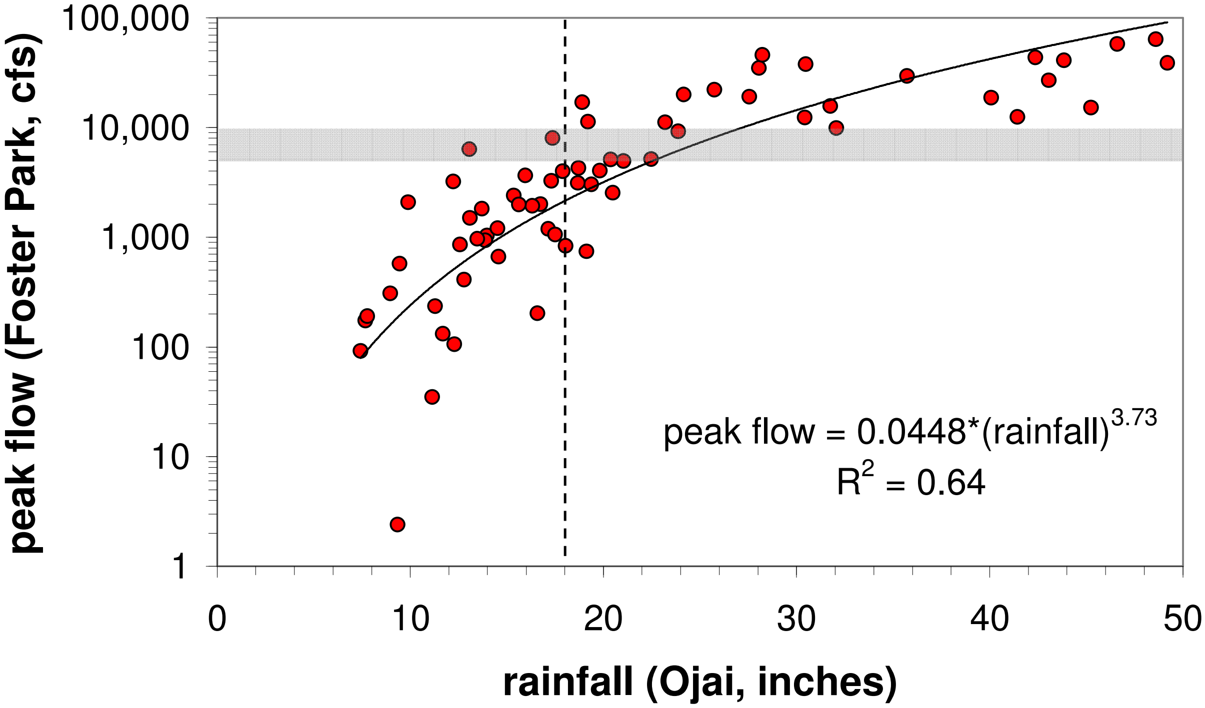
In the graph above monthly runoff (in inches at Foster Park) is plotted against monthly rainfall for the months of September through December from the Ojai rainfall record (which begins in October 1940) for months with more than 1 inch of rainfall. I’m using only months at the beginning of the rainy-season 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 those dry soils saturated, it’s another story, and a story that usually occurs 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 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 the entire watershed *had* to be contributing to flow. Note its intersection with the rainfall axis occurs at ~5 inches, i.e., 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.

I've labeled with the year those points that didn't fit this nice picture – months that produced pretty good flood flows with a lot less than 5 inches of rainfall. They form exceptions that prove the rule: in all cases these months were preceded by large amounts of rainfall. 1983, of course, was *the* big wet year: 2 inches of rain in August and September, 3 inches in October, 4 inches in November, and another 4 in December (not to mention 21 more inches over the next three months). December 1965 was preceded by 14 inches in November, December 1946 by 8 inches, and December 1982 by almost 6 inches. So for "real" runoff to occur in any one year we now have two yardsticks: at least 20 inches of total rainfall, with 5 inches of that rain occurring within a relatively short period of time – roughly a month. Keep them in mind while we await the effect of this winter's rainfall on the many fire-scared slopes that now dot our region.

The question of how big a storm is big enough to sweep the watershed of aquatic plants and fine sediment is a more difficult one. We know that a flood like that of 2005 (January flow peaked at 41,000 cfs, with a wall of water over 15 feet deep at Foster Park) is a real "clock-cleaner," sweeping out trees and brush, not to mention sediment, cobbles, rocks and the occasional boulder; re-setting the clock of ecological succession on the river back to zero. But where the lower boundary might be is harder to determine. In a way, it's partially dependent what went before: the longer the river goes without a substantial flood the harder it becomes to disturb the status quo. As dry year (i.e., low rainfall year) succeeds dry year, vegetation grows and roots get stronger and go deeper. 2003 and 2004 gave us a hint of what it might take. In 2003, a flood flow of 5,100 cfs removed lots of aquatic plants and sediment, but not all. The river became open enough to foster a significant algal bloom, but aquatic plants, their root systems along the river's edge never completely eradicated, had re-established dominance on the lower river by mid-summer – in marked contrast with 2005 when nary a plant was seen the entire year. In 2004, a larger flood of 6,300 cfs did far less removal, and the subsequently much smaller algal bloom was dead and gone by June.

Unfortunately, the other years of Channelkeeper monitoring on the river have been either feast or famine. Years like 2002 (peak flow of 191 cfs), 2007 (92 cfs) and 2009 (estimated at 240 cfs) produced nothing that could even be considered a "flood"; other years, 2001 (19,100 cfs), 2005 (41,000 cfs) and 2008 (17,700, estimated) were at the other extreme. Only 2006, with a peak flow of 9,250 cfs, fell in-between, but in 2006 there was little vegetation or sediment available for removal due to the dramatic flood of the year before (but what little there was, was removed). However it seems safe to say that wherever this boundary may lie it's probably between 5 and 10 thousand cfs. A flood of that magnitude would at least prepare the scene for a significant algal bloom later in the year – at least in sunlight-exposed reaches. (However, while a necessary precondition, a flood of this magnitude may not, in and of itself, guarantee a significant bloom – a topic I'll consider later.)

In Figure 1 I've plotted annual peak streamflow at Foster Park against annual rainfall (upper panel) and annual runoff (lower panel). I've shown the 5-10 thousand cfs "significant" flood flow discussed above



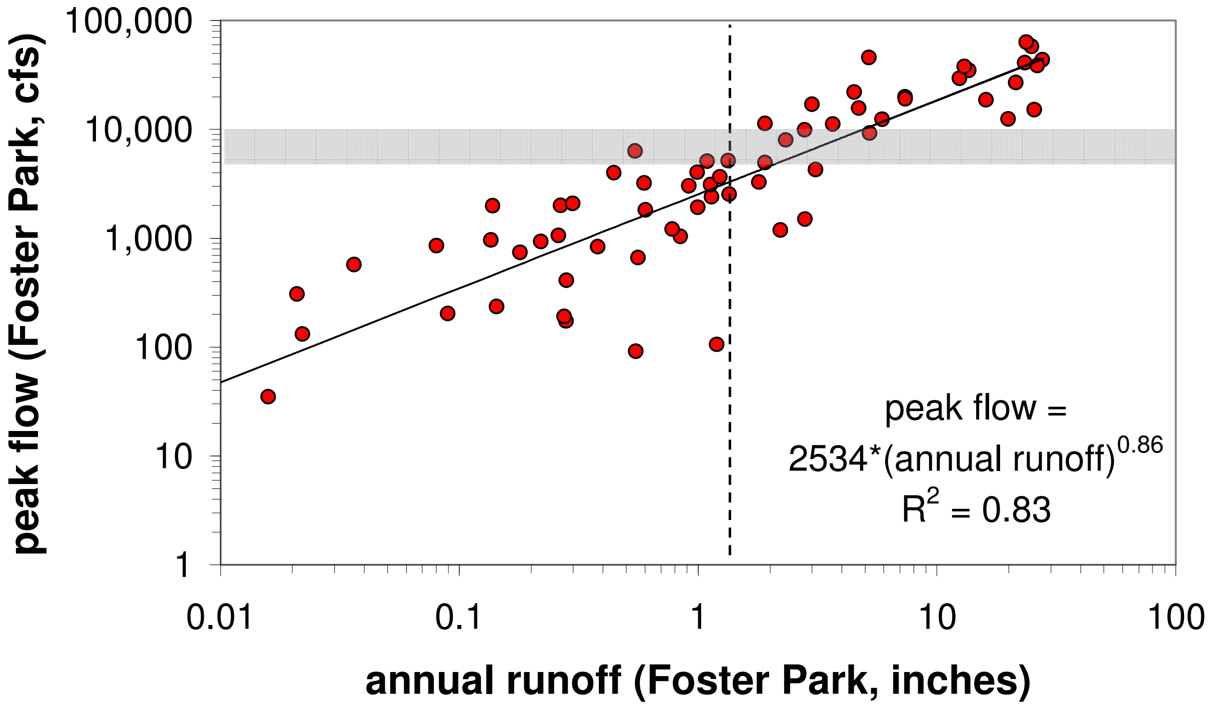


Figure 1. (upper) A semi-log plot of annual peak flood flow (at Foster Park) against annual rainfall (at Ojai). The horizontal band represents the range of the minimum flood necessary to sweep the river of a sufficient quantity of aquatic vegetation and fine sediment to foster a significant algal bloom during the subsequent dry-season (5-10 thousand cfs). (lower) A log-log plot of annual peak flood flow against annual runoff (at Foster Park). The dashed lines represent median annual rainfall and median annual runoff, respectively.

as a horizontal band, and the respective median values for runoff and rainfall as dashed horizontal lines. The relationship between flood flow and annual runoff is noticeably better, as might be expected, but both are pretty good: annual rainfall alone explains about 64 % of the variation in peak annual floods, and total annual runoff can explain 83 %. It turns out that 23 inches of rainfall, or 4 inches of annual runoff, practically guarantee we will have a sufficient flood, one with a peak flow above 10,000 cfs. And how often might that happen? About 30 % of the time; not quite one year out of every three.

And one of those real clock-cleaners? If we define them as a year producing a flood flow of greater than 25,000 cfs, there have been 11 since 1933, about 1 every 7 years. And not always in a year with extravagant rainfall; chance – in when a big storm occurs and its actual size – plays a big role.

Figure 2 is a closer look at Ventura runoff and rainfall since 2001 – the water-year Channelkeeper's monitoring program began. In the lower panel the years are arranged in chronological order but in the upper, in order of increasing annual rainfall. The dashed lines show the respective medians as determined by the full data records. Five out of the nine Channelkeeper years had above median rainfall (>18 inches); four out of the nine above median runoff (>1.5 inches, >18.5 cfs); and one (2005) was a real clock-cleaner. It's all pretty much as expected, statistically speaking. In Figures 3 through 6 I've tried to show with photos what these differences in annual flow and runoff have meant on the river, how the appearance and ecological performance are dramatically modified year by year.

Arranging the years in order of increasing rainfall (Figure 2, upper panel) points out a number of intriguing discrepancies: 2007 had lower rainfall than 2002 (7.4 vs. 7.8 inches) but twice the runoff (0.55 vs. 0.28 inches); 2008 had slightly more runoff than 2006 (5.27 vs. 5.23 inches) but with noticeably less rainfall (20.6 vs. 23.9). And one striking non-discrepancy: 2004 and 2009 had almost the same rainfall and are looking to have the same amount of runoff. I believe a good part of the explanation for these differences and similarities lies in groundwater recharge and subsequent water-table contributions to the river during the following dry-season – or if, the amount of groundwater replenishment is high enough, dry-seasons.

To explain I'm afraid I'll have to introduce another graph – but, I promise, a final one. The upper panel of Figure 7 shows Ojai rainfall and Foster Park runoff from water-year 1941 (the beginning of the Ojai precipitation record). The data show wet periods (e.g., the early 1940s, from 1978 to the mid-1980s, and the 1990s) and dry periods (the 1950s and 1960s), but there are no obvious trends in either rainfall or runoff (i.e., no obvious evidence of a changing pattern – think climate change – in Ventura County). The bottom panel again shows Ojai rainfall, but in place of runoff I've substituted something I'm calling *loss*: loss being the difference between rainfall and runoff. In other words, the annual amount of missing water – rainfall that didn't make it to Foster Park. We can write the following equation to account for this missing fraction:

loss = abstractions from the river + evapotranspiration + changes in groundwater storage

or if we include runoff and rainfall in the equation

annual Foster Park runoff = annual Ojai rainfall - abstractions from the river - evapotranspiration - changes in groundwater storage

Call it a water budget; it's just like a regular budget if we consider rainfall as "income," river flow and abstractions (think the Casitas Diversion and water supply pumping from below the river at Foster Park) as "expenses," and changes in groundwater storage (positive for recharge in big winters,

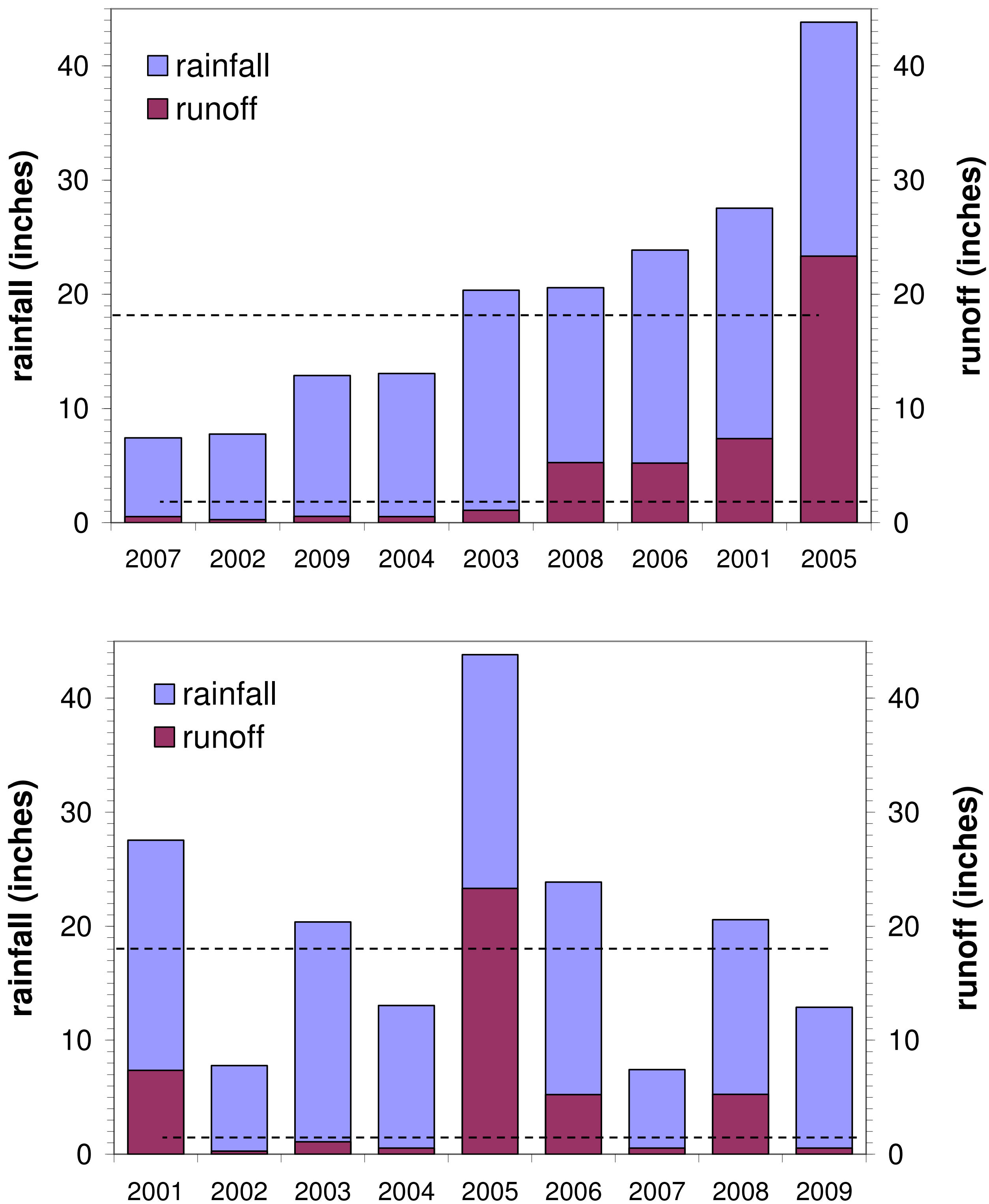


Figure 2. (upper) Rainfall (Ojai) and runoff (Foster Park) during the years of Channelkeeper monitoring – arranged in order of increasing annual rainfall. (lower) The same, but in chronological order. Dashed lines show the median rainfall (18 inches) and runoff (1.5 inches) (as determined from all the years of record). July, August and September 2009 flow at Foster Park has been estimated as a fixed percentage of flows recorded in 2008 (40 %).

Figure 3. Looking upstream from the Shell Road Bridge (annual rainfall/annual runoff, in inches, shown in bold face for each year): left to right, top: July 2001 (algae following a wet winter; **7.4/27.6**), Aug. 2002 (aquatic plants in a dry year; **0.3/7.8**), March 2003 (open environment following a large storm; **1.1/20.4**); bottom: Oct. 2003 (aquatic plants succeeding algae by year's end), Sept. 2004 (aquatic plant dominance at the end of another dry year; **0.6/13.1**), May 2005 (a *real* big year clears the riverbed and algae return; **23.3/43.8**). The photos document extreme changes caused by wet-winter/dry-winter rainfall differences on the lower Ventura River: large storms = algal dominance; the absence of large storms = dominance by aquatic plants. 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.

negative when the water-table drops in dry years) as the sum total of what you've managed to save or borrow over the course of the year.

Diversions to Lake Casitas vary each year, governed by water availability and rules that limit the amount diverted; rules governing allowable turbidity of diverted water, dates of allowable diversion, minimum flows to be left in the Ventura, etc. More water is diverted in wetter years than in dry, but the fraction of flow diverted in dry years is greater, simply because there is much less available runoff. Diversions are least important in real big years when total runoff is extremely high due to limited capacity of the diversion channel (~500 cfs) and a probable lower need for extra water at Casitas.

Along with surface diversions for water supply at Foster Park, wells here, and further up the river, indirectly reduce natural flow by intercepting up-welling groundwaters. Although annual variations in the quantity of water removed are probably small, pumping operations in dry years, as with diversions at Robles, have more severe consequences. Not having data to evaluate these abstractions year-by-year presents a problem but not a severe one, because diversions represent but a small fraction of the biggest term in the loss equation. (But if someone could provide annual diversion and pumping volumes, or tell me how to obtain these data, I'd be happy to revisit this analysis to include these factors.)

Evapotranspiration represents the transfer of water from land to atmosphere: evapo- (evaporation of water from water surfaces, e.g., ponds, puddles, creeks, etc., plus transpiration (the loss of up-taken moisture by plants). If water were unlimited – as in a continually watered lawn or agricultural field for example – the total loss via evapotranspiration during the growing season in the Ventura basin would probably exceed 3 feet, i.e., more than twice the typical annual rainfall in Ojai. (Corrected evaporation pan measurements at Lake Casitas and Matilija Dam show average annual losses of 55 and 63 inches of water, respectively.) But water is not unlimited; on the contrary, it's seriously limited in our Mediterranean climate where soil moisture is usually reduced to near-zero early in the dry-season.

I don't have a clue as to what the actual basin-wide annual evapotranspiration loss might be, and to make matters worse it too, like the other factors we've discussed, varies annually. In dry years potential evapotranspiration (the amount of evapotranspiration that would occur if water was not limiting) is usually at its maximum, but since less water and soil moisture are available actual evapotranspiration is usually at a minimum. Wet years, with greater water availability and increased vegetative growth, have greater evapotranspiration losses. And, naturally, dry-season weather conditions also play an important and variable role (air temperature, humidity, amount of cloud cover and coastal overcast, etc.).

However, ignorance is no barrier to the bold and while I have no knowledge of actual values, estimates of the *average* amount of water abstracted from the Ventura are readily available which, in turn, allow us to calculate *average* annual evaporation. Let's go back to our earlier equation and rearrange it in this fashion

evapotranspiration = loss - abstractions - changes in groundwater storage

If we know the annual loss (rainfall – runoff) and the average annual abstraction we can get around the difficult term – annual changes in groundwater storage – by simply tabulating amounts for a period when the groundwater level was the same at the end as it was at the beginning, i.e., from one real big rainy season to another. We're helped by the fact that the most important groundwater reservoir in the Ventura basin is small and easily filled (the upper Ventura River basin; the other basins, the lower Ventura River basin, and the upper Ojai and Ojai Valley basins are peripheral and exert much less

Figure 4. Continuing with an upstream view from the Main Street Bridge (annual rainfall/annual runoff again in bold face): left to right, top: June 2005 (algal takeoff after the big winter; **23.3/43.8**), Oct. 2006 (aquatic plant dominance in the fall of a moderately wet year; **5.2/23.9**); middle: Sept. 2007 (aquatic plant dominance throughout a dry year; **0.6/7.4**), May 2008 (algae following a wet winter; **5.3/20.6**); bottom: Nov. 2008 (aquatic plants dominating by fall), June 2009 (aquatic plant dominance throughout another dry year; **0.6/12.6**). A clock-cleaning winter = algal dominance throughout the dry-season; a moderately wet winter with large storms = algal dominance in the beginning, but aquatic plants by the end of the season; the absence of large storms = dominance by aquatic plants.

Figure 5. Looking upstream from the bridge below Foster Park: left to right, top: Sept. 2002, May 2003; middle: Sept. 2003, Sept. 2004; bottom: May 2005, Oct. 2006. Winter rainfall and storm intensity influence dry-season flows at Foster Park, and cause a shift between the relative densities of aquatic plants (watercress) and algae, but not to the extent seen on the lower river. In this open reach, with high sunlight exposure, algae are always present, but not to the same extent in every year. This variation in annual density and extent indicates that factors other than sunlight availability and aquatic plant competition play a role. (The change in perspective in the lower photos is due to river re-alignment from its west to east bank by County flood repairs in the spring of 2005).

Figure 6. Bringing the Foster Park story up to the present, again looking upstream from the bridge: left to right, top: June. 2007, Nov. 2007; middle: May 2008, Sept. 2008; bottom: March 2009, June. 2009. I suspect that appreciable groundwater recharge in years with adequate rainfall, and the subsequent augmentation of dry-season flows by higher nitrate groundwater inflows, are the major causal factor between big and not-so-big algal blooms at this location. Reduced habitat availability, lower stream velocities (i.e., lower nutrient fluxes) and increased predation in low rainfall years may also play a role.

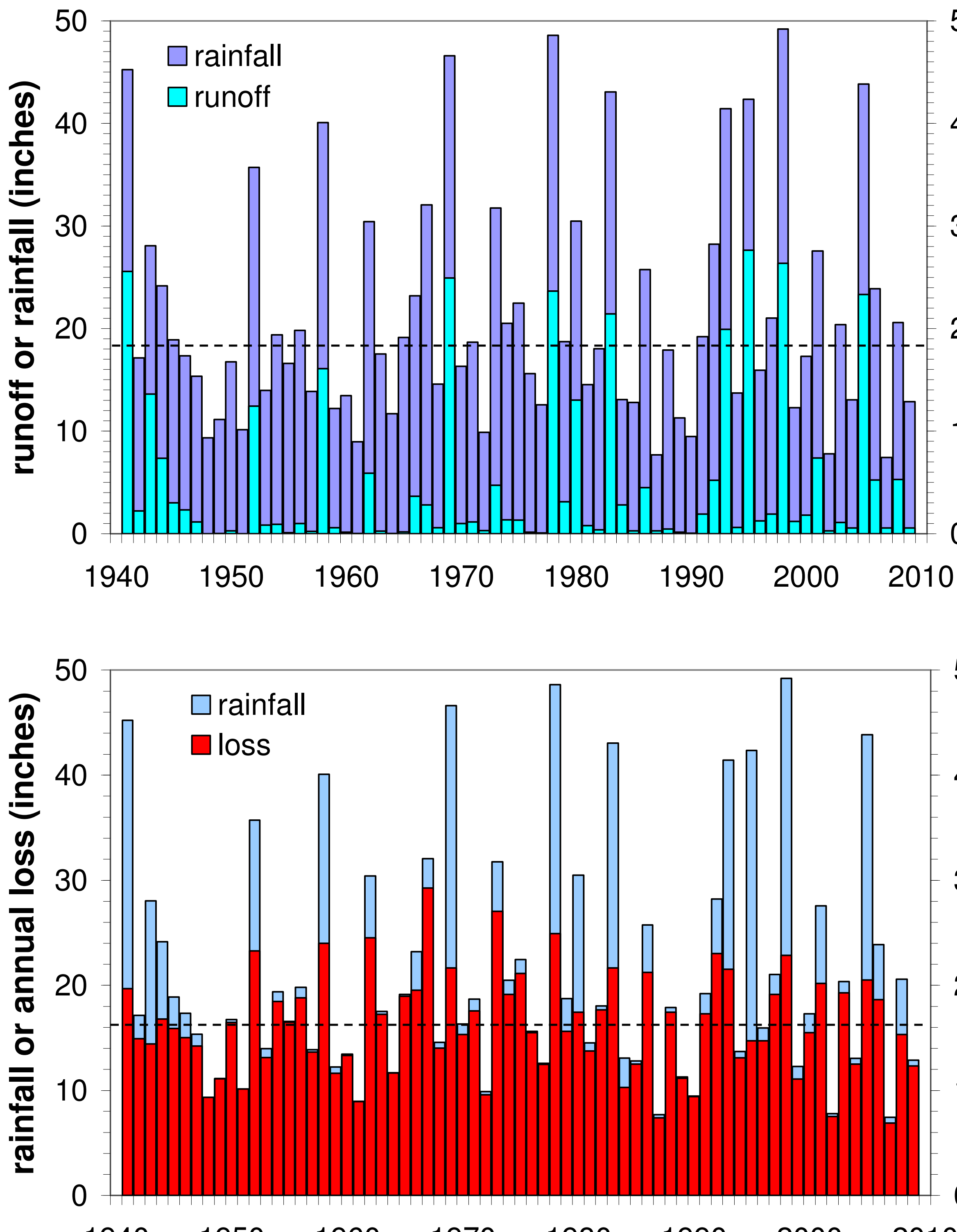
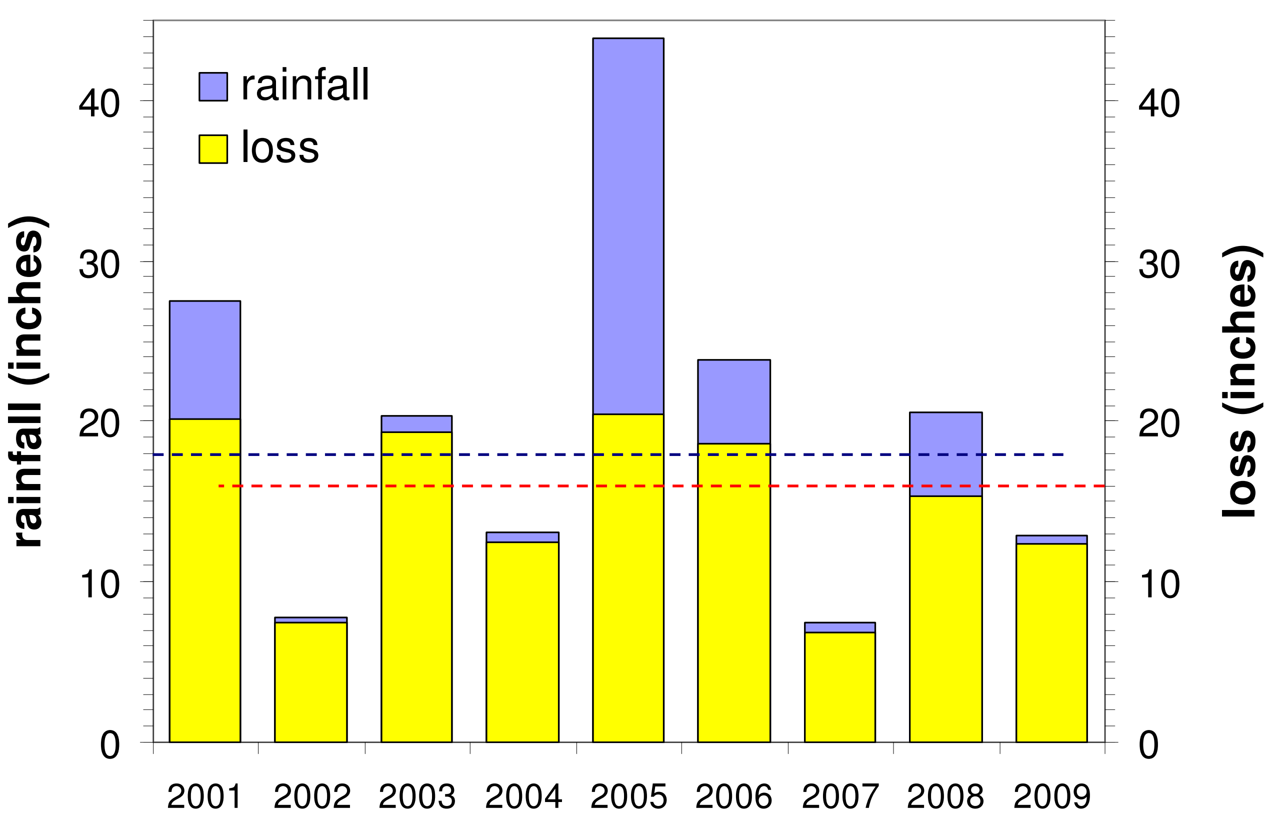


Figure 7. (upper) Annual (water-year) rainfall (Ojai) and runoff (Foster Park) since 1941; the dashed line represents median rainfall for the period.. (lower) Rainfall and annual loss (the difference between Ojai rainfall and Foster Park runoff) for the same years. The dashed line at 16 inches represents average annual evapotranspiration and abstraction. Years with losses above the line were years of substantial groundwater recharge; years with losses appreciably below the line were years of no recharge. Smaller groundwater basins like the upper Ventura were probably recharged in years falling near the line.

influence on the overall watershed water-balance for lots of reasons that I wouldn't go into, but the primary ones have to do subsurface geology and appreciable hydraulic head that cause significant upwelling in a river reach that extends from Foster Park to above the San Antonio confluence). The volume of the upper Ventura groundwater basin, which extends from Matilija Dam to Foster Park and includes Lake Casitas, has been variously estimated at around 14,000 to 19,000 acre-feet (an acre-ft, or AF, being the amount of water that would cover an acre to a depth of one foot; an acre being 43,560 square feet – think of a plot of land roughly 200 ft. by 200 ft.). Converting acre-ft. to inches of water distributed over the entire Ventura watershed gives us 1.4 to 1.9 inches. In other words, it doesn't take much excess rain to completely top-off the upper Ventura basin. Conversely, a couple of dry years would probably be enough to drastically limit groundwater inflows on the river: rapidly filled = rapidly drained.

Similarly, annual average abstractions via the Robles diversion (12,500 AF), by the City of Ventura at Foster Park (2,500 surface water + 3,900 groundwater) and other major groundwater users (~2,500) are around 21,000 AF – or roughly 2.1 inches (these values culled from the relatively recent 2001 Entrix report and earlier reports going back to 1971). Subtracting this 2.1 inch average annual abstraction from each year's annual loss since Casitas Dam was completed (1959), and then summing up the average remaining annual loss for various time periods between big years gives us the following values: 1978-83, *16.4 inches*; 1978-95; *14.4 in.*,1978-05; *14.1 in.*, 1983-98, 14.0 in.; 1983-05, *13.7 in.*; 1998-05, *14.1 in.*; and even the recent Channelkeeper years 2001-05, yield *13.9 in.* So 14 inches of annual evapotranspiration in the Ventura watershed seems a reasonably robust average estimate and I've accordingly shown a "16 inch line" (14 inches of average annual evapotranspiration plus 2 inches of average annual abstraction) on the lower panel of Figure 7 and a new figure, showing the more recent years in greater detail, below (yeah, I lied about Figure 7 being the last one).



(Using water-year accounting, as I have done, works well with rainfall, runoff and basin abstractions, but is not strictly accurate when applied to groundwater storage; groundwater levels in the upper Ventura basin are likely to have been at their maximum, and thus roughly equal in big years, at the end of the rainy season not the end of the water year. However, given the number of years being averaged, and probable errors in the various estimates being used, I deemed a more accurate tabulation an unnecessary and complicating refinement.)

The point of this exercise – and the 16 inch line – is that significant groundwater recharge occurred in years showing losses above the line, while almost no recharge occurred in years falling appreciably below. Years in the general vicinity of the line probably had substantial recharge in smaller groundwater basins like the upper Ventura, but larger basins, e.g., the upper Ojai, may not have been appreciably changed. Looking at the Channelkeeper years in the previous graph, 2001, 2003, 2005, 2006 and 2008 were years of recharge on the upper Ventura; 2002, 2004, 2007 and 2009 were not. They were years of continual groundwater depletion.

Recharge means more than increased dry-season flows, it also means increased groundwater nitrate concentrations as rainfall percolating downward to the water-table carries with it not only nitrogen deposited as wet and dry deposition during that particular year (think nitrogen in particulate matter floating down from above and landing on plant surfaces and soil, and other nitrogen scrubbed from the atmosphere by falling rain) – not to mention other, more direct, sources of nitrogen – but in all preceding years in which recharge didn't occur. Nitrogen, and other pollutants, not transported to streams, river or groundwater basins remains on surfaces and in the soil awaiting a storm big enough to do that job, e.g., recharge in 2008 carried with it all the nitrogen deposited in undeveloped areas of the watershed since the last substantial rainstorm of 2006 not just that of 2008.

Figure 8 (the last; absolutely; my word on it) shows this correlation between recharge – represented by increased dry-season flows at Foster Park (these flows consist predominately of upwelling groundwater, higher flows indicating greater groundwater availability hence appreciable recharge during the preceding rainy season) and average nitrate concentrations during the dry months (May through September). Even more important than either dry-season flows or nitrate concentrations is the product of the two (*flow* multiplied by *concentration*) which yields the nitrate flux, the amount of nitrate available to fuel algal blooms at this location. It's no accident that we see much less algae this summer than we saw in 2008 . . . there is only about 1/10th the available nitrogen. The Figure 8 caption explains some of the details.

It turns out we can blame it all on the weather.

I find that comforting.

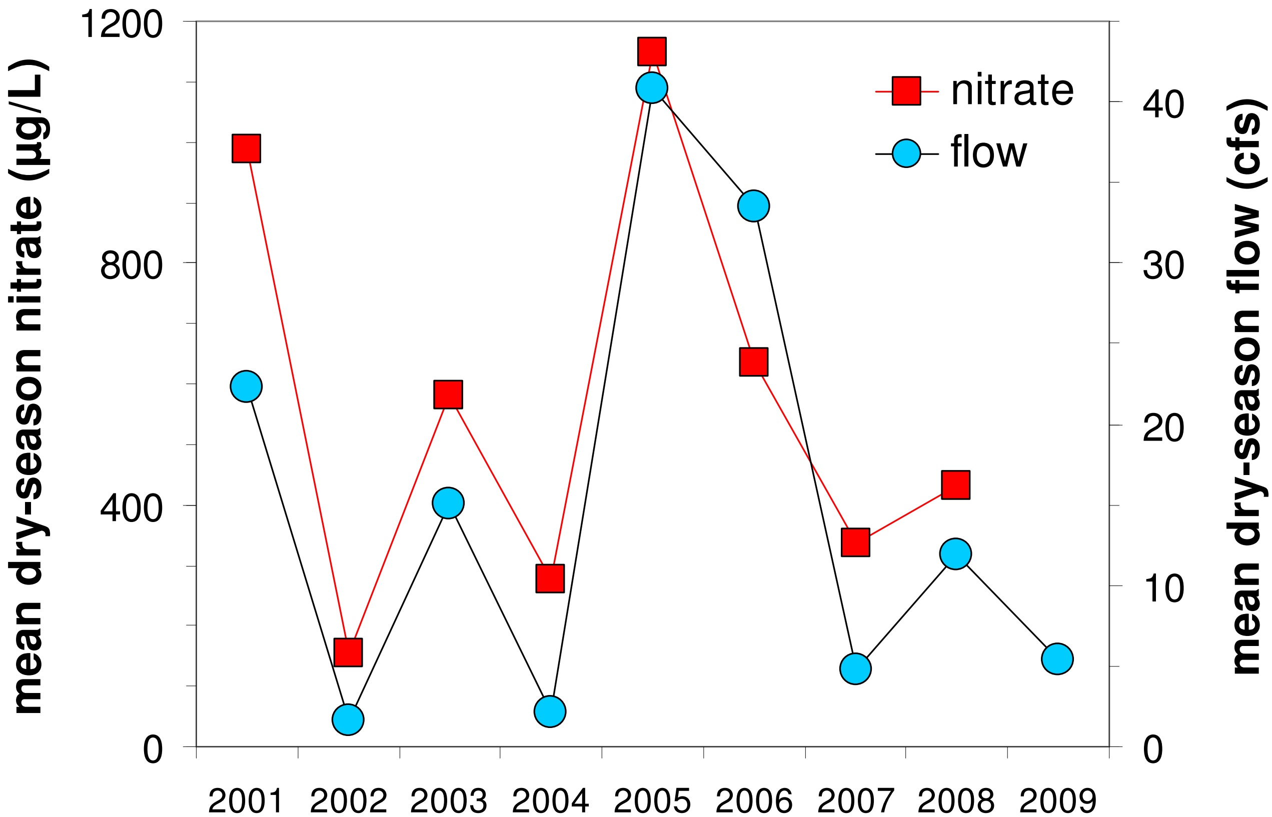


Figure 8. Mean dry-season (May through September) nitrate concentrations (in µg/L) and mean dry-season average daily flow (in cfs) at Foster Park for 2001 through 2009. Dry-season flows at Foster Park generally originate from upwelling groundwater in the reach extending from above the San Antonio confluence to this location (the river at Santa Ana Blvd. typically being dry and San Antonio Creek a minor contributor) and higher flows indicate substantial rainy season recharge to the upper Ventura groundwater basin. Higher flows (i.e., greater recharge) correlates well with higher nitrate concentrations. More importantly, the *flux* or *amount* of available nitrate is the product of flow and concentration. Of the 8 years shown, 2008 exemplifies the median flux. Big algae years (i.e., 2001, 2003, 2005 and 2006, years of appreciable recharge and high nitrate concentrations) had anywhere from 1.3 to 6.7 times the median flux of nitrate. Conversely, low algae years (2002, 2004, 2007, and now 2009, years of little or no recharge and reduced nitrate concentrations) had from 3 to 24 % of the median nitrate flux. It's too early to determine what the average dry-season nitrate concentration at Foster Park will be in 2009, but that nitrate in May was 330 µg/L compared with 1,540 in May of 2008 and 430 in May of 2007 is a good indication that it will conform to the pattern shown.