## Cycles of Change: Part III The Ventura River – a look at rainfall and the river

Annual rainfall is not a constant; the same amount of rain doesn't fall every year, year after year. In the Ventura River watershed it does anything but. Even the average annual rainfall, roughly 20 inches (roughly, because rainfall varies over the basin and local records in some areas are sparse and incomplete), has little meaning; inter-annual variations are so extreme that the word "average" applied to this river becomes simply a mathematical concept. More than 90 % of the rainfall occurs between November and April, in 10 to 15, mostly small, storms. Simply put, in spite of all the green around us, we live in what would be a desert without that winter rain. And if the rain doesn't come we notice it quickly.

Since river flow depends on rainfall, its variations are also extreme: mean annual flows vary from 5 to 3400 cubic feet per second (cfs); in other words, a "wet" year can have almost 700 times more flow than a "dry" year. The river is hydrologically "flashy" and responds within hours to storms and changes in rainfall. Average daily and peak-15-minute flows during a storm on February 12, 1992 were 12,400 and 43,800 cfs, respectively – compared with the 0.1-5 cfs we usually see at Foster Park. A majority of the annual runoff usually occurs over 3 to 7 days, produced by a single large storm.

Here we talk about rainfall and discuss the various climate cycles that may be the cause of this extreme variation. We look at how rain – or the lack of rain – affects the river, and discuss a surprising increase in conductivity recorded over the past four years. In short, we discuss reasons for the cycle of changes shown in Parts I and II.



There are a number of ways of showing rainfall variability. A simple bar chart of annual rainfall (top) is one. Another is to graph the *cumulative* departure of annual rainfall from the *mean* (bottom) – in other words, showing long-term trends using the year-to-year pattern of how annual rainfall varies from the average (the average rainfall of 15 inches, the red line in the top figure, is subtracted from each year's rainfall; the graph represents the running total). This graph also shows "big years," rainy seasons when Los Angles (we use LA because a longer data-record is available) rainfall exceeded 22 inches (the grey line in the top figure). Most of these big years occurred during strong El Niños, cyclical events that heavily influence our rainfall record

Something else is also at work: a 30-to-50 year pattern of alternately greaterthan-average and less-than-average rainfall caused by a cycle called the "*Pacific Decadal Oscillation*" (PDO), a long-period climate fluctuation that varies the location of warm and cold waters in the 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, south – giving us wetter winters.



## The rainfall pattern at Santa Barbara,

100 miles further up the coast, is roughly the same. The long-term average of 18 inches a year is indicated by the red line, while the black marks a 27 inch "big year." The year here is a water-year, e.g., the 2004 water-year extends from October 2003 to September 2004. There were 17 "big events" in the 137-year Santa Barbara record, an average of one every eight years. Of course, this is subjective: were "big vears" defined as rainfall over 40 inches, there would have been only four - one every 35 years. Big years are also unevenly spaced: less during the cold PDO phase, more during the warm. The '90s were unusual in that we had three closely spaced big events, something that hadn't happened since the turn of the last century.

However, not all big years were El Nino years (1969 and 2005 are good examples); some really wet winters are caused by a much shorter cycle of 30 to 60 days called the "Madden-Julian Oscillation." Simplifying the process greatly, atmospheric high pressure off of the Pacific Northwest moves *west*, allowing low pressure to develop off-shore of Oregon and Washington, which in turn sweeps heavy moisture from Indonesia into our area. It's sometimes called a "pineapple express," since this plume of moisture passes over the Hawaiian Islands en route.



Annual flow on the Ventura River is also highly variable. Median annual flow at Foster Park is 21 cfs, i.e., half the years on upper chart had average flows of less than this, the other half were greater. The distribution is skewed – "above the median" years tend to be really big. Years shown as dark bars were strong El Niño episodes. The 1940s, 1950s and 1990s were relatively "wet" decades, the others a lot drier.

A cumulative departure from the mean curve (bottom) can also be plotted for annual (water-year) flow: a running record of the cumulative *flow* excess or deficiency - how much each water year's flow (measured in inches of runoff at Foster Park) varied from the 4.8 inch overall average. Unsurprisingly, the plot shows the same pattern as rainfall: rising and falling trends heavily influenced by big years. Big years, here, represent Ojai rainfall above 31.5 inches. Big years mean a lot but not everything: in the late '60s it took two big years to reverse a 10year declining trend. As an aside, average Foster Park runoff is 4.8 inches, while average Ojai rainfall is 21 inches, indicating that roughly only 20 % of the rain ends up flowing in creeks and rivers. As for the rest, much is transpired by plants and trees, or it evaporates, while some part remains in the soil and replenishes the water table.



Conductivity is a measure of water's ability to carry an electrical current. It's an indication of the amount of total dissolved solids in water, and it typically varies from creek to creek and region to region, depending upon the geologic strata that source waters traverse and the time required for passage which is why we see different conductivities at Foster Park and on the Matilija (top), or at various locations on San Antonio Creek (bottom). Generally, the longer water is in contact with soil and rock, the higher its conductivity - rainwater has very low conductivity; water draining from soil higher values; and groundwater, which spends years or even decades in contact with geologic strata, the highest of all. The biggest cause of a change in conductivity on the Ventura is rain, and the figures show the drastic drop in values measured during the storms of May 3 and January 8.

Conductivity in the Ventura is usually above 1,000  $\mu$ S/cm because of high, and readily dissolved, mineral content in the loosely consolidated marine sediments that form Southern California's coastal mountains. However, the most intriguing thing about the Ventura data is a general trend towards increasing conductivity with time (shown by the solid line drawn on the graph). It's really quite astounding: roughly a 23 percent increase since the Spring of 2001, an increase of about 7 % or nearly 80  $\mu$ S/cm per year.



The long-term trend of increasing conductivity is caused by a number of factors: (1) increasingly depleted groundwater inflows, (2) enhanced uptake by growing riparian vegetation, and (3) a relative increase in evaporation as dry-season river flows diminish the further we get from the last big El Niño year. Evidence of these trends are shown in the figures. The top panel displays the average monthly dry-season flow at Foster Park for the big El Niño year of 1998 and every year since. Since we get no summer rain, river flow is a indicator of consumptive use and groundwater input, and indirectly, the height of the watertable. This is particularly true at this location; upstream of the sampling site a bedrock dike and concrete weir below the riverbed force groundwater to the surface, ensuring flow even though the river above this point is usually dry.

In 1999, flows remained high, despite low rainfall (9 inches vs. an average annual rainfall of 14.3 inches in Ventura). This high flow was a carryover from heavy El Niño rainfall in 1998 (37 inches) and an almost total loss of riparian vegetation from flood scouring of the river bottom. Although total summer flows increased in 2000, there was much less flow than we might have expected from above average rainfall (19 inches) - the ratio of flow to rainfall continued to decrease. Only another aboveaverage year, with 17 inches of rain in 2001, caused a relative flow increase; since then, it's been all downhill flows in 2004 are as low as they were in 2002, a year with little rain (~7 inches). Average flows for this 3-month season are shown in the lower figure, along with "indexed" flow: the average July to September flow divided by the previous winter's rainfall (cfs/ft), i.e., flows roughly corrected for annual rainfall differences. The general trend is decreasing summer flows as the years since the last big event go by.



**It's a case of the "rich get richer, and the poor get poorer."** Low rainfall means less groundwater recharge and lower summer flow; and no winter storm big enough to flush out riverine vegetation. In turn, plants and trees continue to grow, consuming more water; and lower, shallower and slower flows increase relative evaporation. A lower water-table means relatively older groundwater and higher conductivities. On the other hand, a "big year" replenishes the water-table, increasing summer flow and, by sweeping clean the river channel and much of the floodplain, reduces consumptive loss to vegetation; and evaporative losses are proportionally lower in deeper, faster moving river flow.

On top, "indexed" June through September flows (average flow for the four months divided by the previous winter's rainfall) are shown in the same cumulative departure format used earlier: a running record of how much summer flows in successive years, corrected for rainfall differences, varied from the mean. Water-year Oxnard rainfall is also shown; rainfall over 22 inches defines a "big year" (LA, Oxnard and Ojai rainfall records are variously used depending on which offered the closest and most complete record for the time period shown). Wet periods – trends of rising cumulative departure – usually show "momentum" – flows continue to be relatively high beyond the final big year (after 1943 and 1998); and it usually takes more than a single wet year to reverse a declining trend (e.g., from 1945 to 1972).



If big years are rare and the usual state of the Ventura River is one of trickling, plant-choked flows along a wooded riverbed, our final questions concern the transition from one state to another and what we can expect in the future. The departure from the mean of indexed summer flows are again plotted here, but for individual years and not as a cumulative sum. The average indexed summer flow (June through September) at Foster Park is 4 cfs per 12 inches of rain; positive years had flows per foot of rain higher than this, negative years lower flows. The black lines give a rough indication of the transition from "big year" to more typical conditions: while this is far from rocket science, it seems to take about 4 years; varying from 2 to 6 years depending on whether we're in a dry or wet cycle. Some dry-cycle big years had no impact. The red line is an approximation of the typical state of the summer river (ignoring big years and transitions): average flows around 1.5 to 2 cfs. To put this into context, flows slightly less than we saw in 2004 (2.6 cfs). Unfortunately for the river, we appear to have entered a new cold phase in 2000. In spite of this winter's extravagant rainfall, we can expect lower flows in coming years. We might also expect more wildfires, increased summer fog and intended drought conditions. And you thought gas prices and global warming were all you had to worry about.