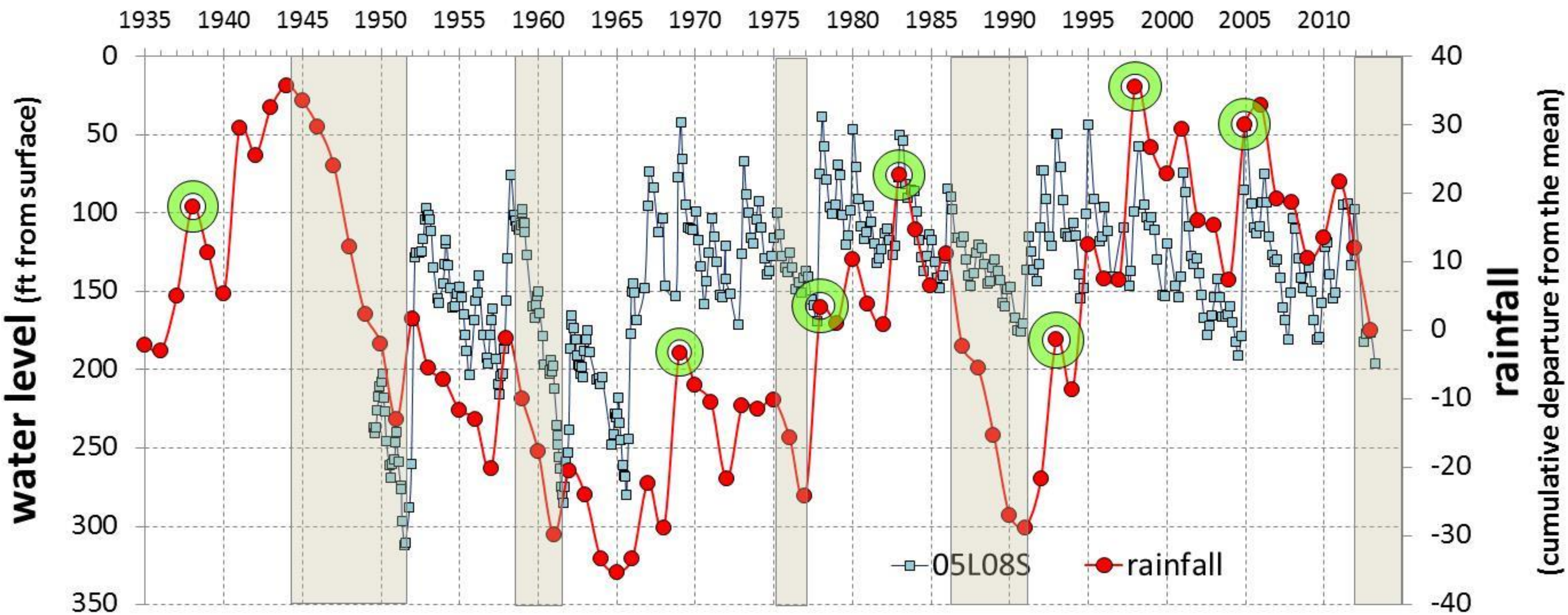


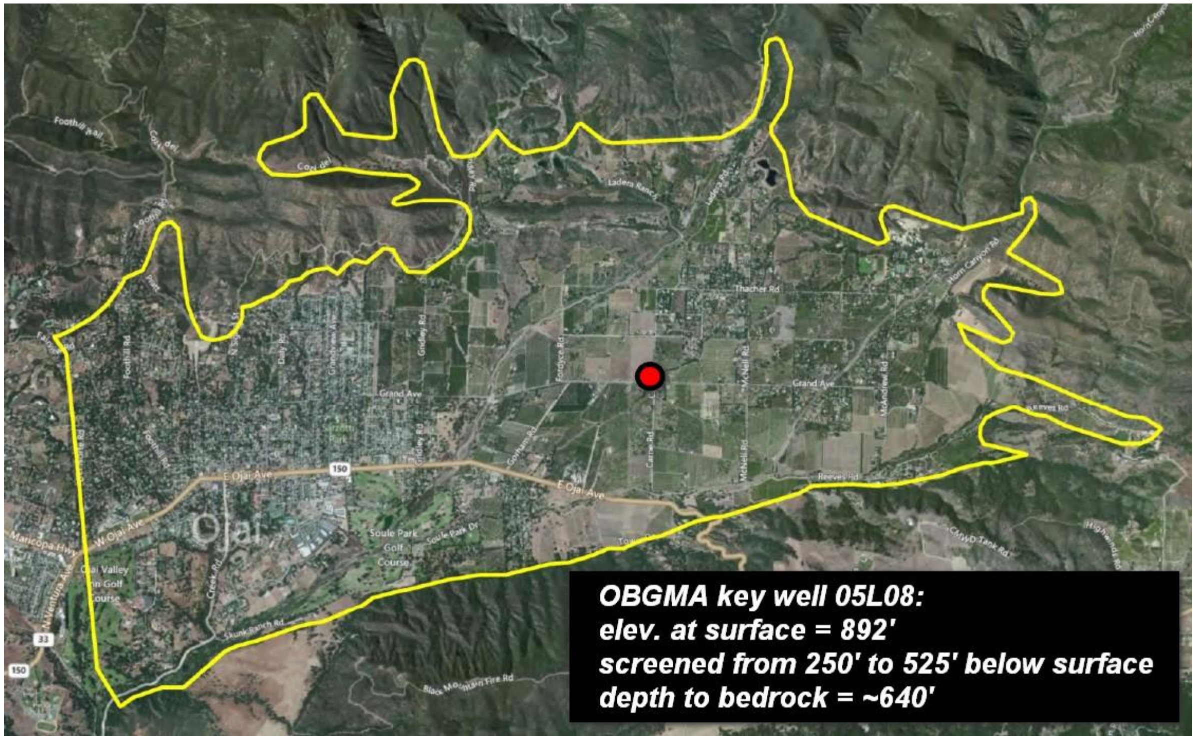
Rainfall and the Ojai Watertable

Well 05L08 is the Ojai Basin Groundwater Management Agency's (OBGMA) "key" well on the eastside of Ojai Valley (more on where and why later). The water-depth record for this well goes back to 1949 and is shown in the graph (blue squares showing depth-to-water as measured from the surface on the left axis).

The red circles indicate changes in annual (water-yr.) rainfall (recorded at the Ojai Fire Station) as its cumulative departure from the mean. Simply put, this is a running total of how much the year-after-year rainfall is falling behind, or running ahead, of the expected mean or average (the Ojai average being 21 inches a year). If Ojai received its average rainfall every year there would be no cumulative departure from the mean and we would see only a horizontal line of red circles across the graph. In years of below-average rainfall the cumulative departure *decreases* and the red circles head to the bottom of the graph; conversely, in years of above-average rainfall the circles climb and the cumulative departure turns positive. This type of plot allows us to easily identify cycles of below and above average rainfall.

Droughts are multi-year periods of severe rainfall deficiency and our major droughts since 1935 are blocked out on the graph with grey rectangles (1943-51, 59-62, 76-77, 87-91 and our present drought). These are the major events that affected either large sections of California or the entire state. Since droughts show up as multi-year declines in cumulative departure we can also identify other episodes of local importance, e.g. 2002-04 and 2007-09.

Similarly, abrupt *increases* in cumulative departure signify very wet years; these are marked on the graph with green circles. The big flood years (which were also high rainfall and big groundwater recharge years) in Southern California were 1998, 1938 and 1969, but 2005, 1983, 1995 and 1978 were not far behind. Overall, a cumulative departure graph provides a good picture of how rainfall in any area varies. In Ojai most years are below average (the cumulative departure decreases from one year to the next), wet years (an increase in cumulative departure) are much rarer, and average years (where the cumulative departure stays the same—the circles are side-by-side) almost never happen.

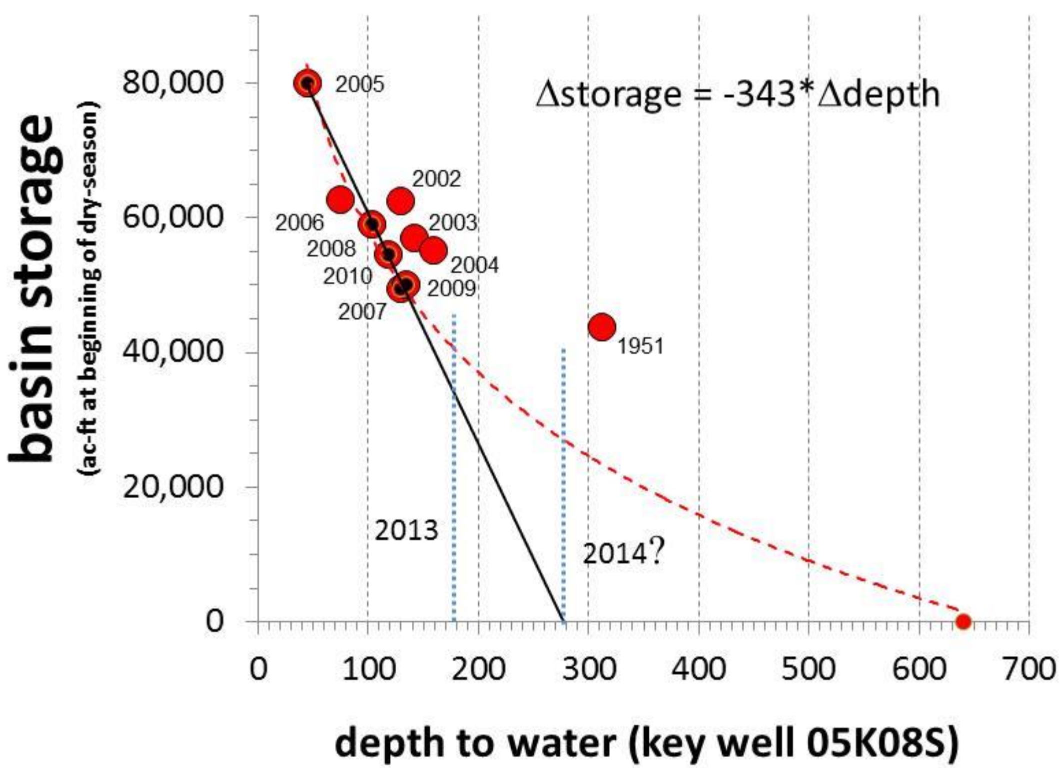


The location of the well used to indicate depth to the watertable in the graph is shown in the aerial view on the left (copied from the Ventura County Water Protection District's 2012 groundwater report). The extent of the Ojai aquifer is outlined in yellow. It's considered a "key well" because of its central location; its depth, extending down to nearly the lowest point in the aquifer; its long screened length which allows it to draw water from nearly half its depth; and its long measurement record, extending back to 1949. That year is significant, coming near the end of one of the longest and most severe California droughts, and may well account for the well being drilled as deep as it was. Note that the greatest depth to water (312 ft.) was recorded in September 1951. Conditions have never been as dry since.

You can see from my initial graph that fluctuations in the watertable follow changes in cumulative rainfall—the saw-tooth-like patterns of up and down match each other closely—since rainfall (and rainfall runoff) is, by far, the principal source of groundwater. Appreciable recharge, the addition of new water to the aquifer bringing groundwater closer to the surface and decreasing the depth to the watertable, occurs only in big years, years of above-average winter rainfall (the cumulative rainfall increasing by 10 to 25 inches in those years, indicating 31 to 46 inches of total rainfall). Only small amounts of recharge occur in normal or below normal rainfall winters and well 05L08 may reflect greater amounts of recharge than others in the basin because of its location adjacent to McNell Creek.

When the aquifer is full (which occurs in years like 1995 and 2005) the depth to the watertable for this well is about 50 ft. and, as mentioned earlier, it has gone as low as 312 ft. during a previous drought. This large fluctuation of depth-to-groundwater in response to changes in rainfall is another characteristic leading to it's designation as a key well.

In any given year the watertable is at its maximum soon after the end of the rainy season; from that point the level drops as water is removed throughout the dry-season. On average, some 5,000 acre-ft. are withdrawn by wells and another 2,500 acre-ft. seeps into streams (an acre-ft. equals an acre—roughly 200 ft. by 200 ft. —covered by 1 foot of water; it's about a third of a million gallons). [With the exception of the Ventura River below the waste-water treatment plant and some other rare situations, groundwater is the source of all dry-season streamflow in the Ventura watershed.] However, as we've seen, the average almost never occurs. In wet-years much more groundwater flows into streams and a lower amount is withdrawn by wells (less water being needed for lawns, gardens and agricultural irrigation). In dry-years the opposite occurs. More water is used for irrigation and, as the watertable drops, very much less seepage flows into streams. Put a couple of dry-years back-to-back and almost no water will be seen flowing in creeks and the river during the dry-season. For groundwater to flow into a stream the bottom of its channel must be at or below the watertable. The moment the watertable falls below the channel, water seeps from the streambed down to the aquifer and not the other way around. A look at the depth-to-water graph for well 05L08 shows why McNell Creek has been totally dry for years.



Another reason why 05L08 is a key well is that, until recently, it's been used as a rough model to estimate the status of water storage in the Ojai groundwater basin. Intrigued by some data in the OBGMA 2010 annual report, I've plotted it on the graph to the left. The report states that a 13 ft. change in watertable elevation represents a 4,600 acre-ft. change in storage. In other words, they were using these data in a simple linear model.

However, the data don't exactly line up, and I used only certain points– the ones with black dots– to draw the suggested linear relationship. [The data are inconsistent, e.g. its seems unreasonable that storage in 2002 should have been the same as in 2006, but the fault could be mine since the report did not make clear exactly what water depth measurements were used to estimate storage for a given year; I simply assumed it had to be the maximum end-of-rainy-season elevation.]

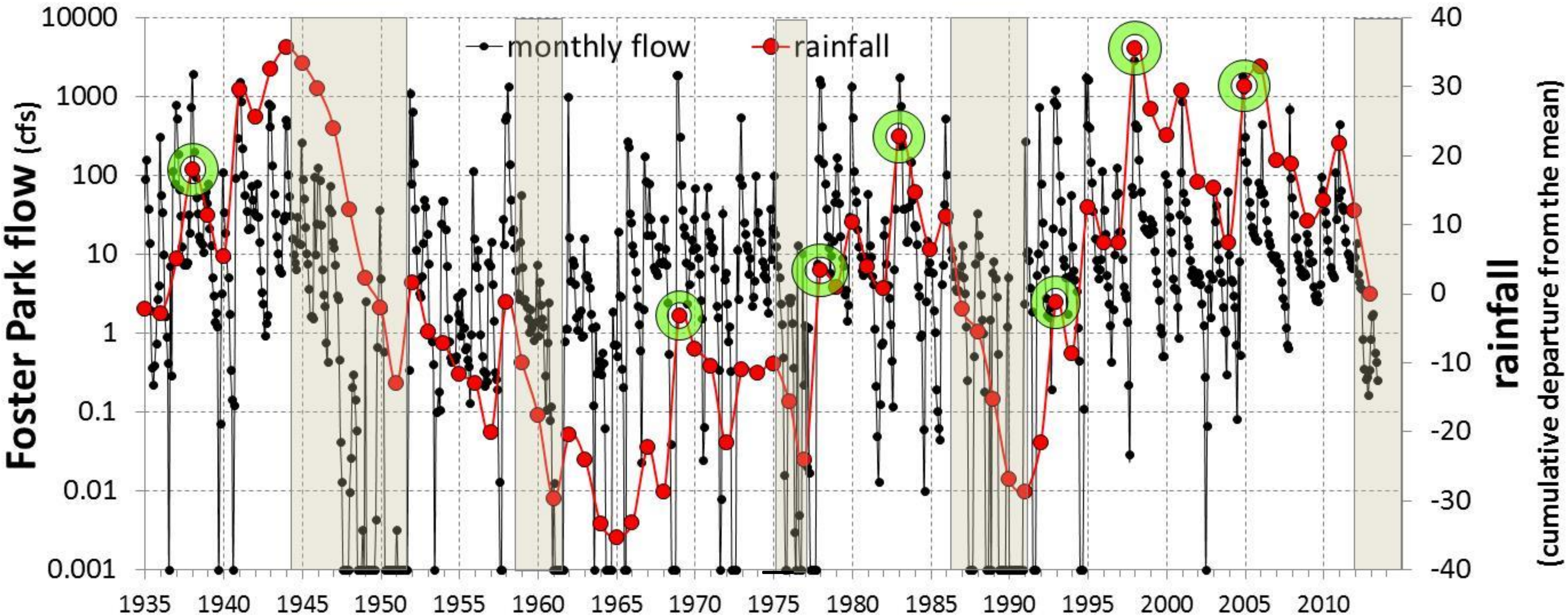
My linear equation (the solid black line) yields a storage change of about 4,500 acre-ft. for every 13 ft. change in watertable elevation, which is close enough to the statement in the report for this discussion.   Of course, the relationship between depth-to-water and the amount of water stored in the aquifer cannot be linear. The aquifer is not a box nor a cylinder, nor anything else with straight sides. It is more like a bowl—a distorted, sloping, uneven kind of bowl, but a bowl nevertheless—where the top inch holds a lot more liquid than the inch on the bottom. We know there must be two fixed points: 2005 when the aquifer was filled to the brim, and the depth to the absolute bottom of the aquifer when the bowl would be totally empty.   I've marked my estimate of this latter point with a small red dot at the bottom of the graph. Using these two anchor points, and the other "black-dot" data, I've plotted the logarithmic relationship shown as a dashed red line on the graph.

The red line is a better model for what will be taking place in the aquifer should our present drought continue. I don't mean to imply that the use of a linear model by OBGMA is inappropriate. It isn't. Note that a straight line is a pretty good representation of the upper end of the logarithmic curve. I'm simply saying that at some point—such as may occur during a severe drought—it will become invalid. A good example might be 1951. The report states "*The basin storage low was estimated at 43,741 acre-feet in 1951*." Irrespective of whatever 1951 depth measurement may have been used there is no way that estimate can be correct. Using my rough logarithmic model, storage near the end of the 1951 dry-season had to be nearer 23,000 acre-ft., in other words, the groundwater basin was not more than half full, is was almost three-quarters empty.   No straight-line model could be extended to account for whatever storage there actually was in 1951.

The first dotted-blue line on the graph represents the depth-to-water measured in mid-March 2013 (176 ft.); the second is a worse-case scenario of where we might be by the end of this year's dry-season—should we have another winter like the last (down to 276 ft., my estimate is based on what happened between 1950 and 1951 and our increased present-day withdrawal rate). The last depth measurement for 05L08 was 196.2, taken on June 19th. By now the water level is down another 20-30 ft. The last time a depth this low was recorded was back in 1965. So our previous "bad" drought, the 1987-1991 event, the defining drought for those of us old enough to remember, may not be a good example for what might be coming our way. Should the present situation continue we will probably be looking at something much worse.

A more recent groundwater model was constructed for the Ojai Basin by Daniel B. Stephens & Associates in 2011. They used it to predict the response to a 5-year drought by applying current water withdrawals to the 1985-1989 (water-years) recharge (the driest 5-year period in the data they used to develop the model). Looking at its effect on streamflow they made this statement: "*Groundwater discharge rates to stream channels observed at the end of the 5-year simulated drought . . . declined to 65% of the smallest simulated discharge during the model calibration period.*" The calibration period referred to was from 1970 to 2009. In other words, we can count of almost every stream being dry for much of the year.

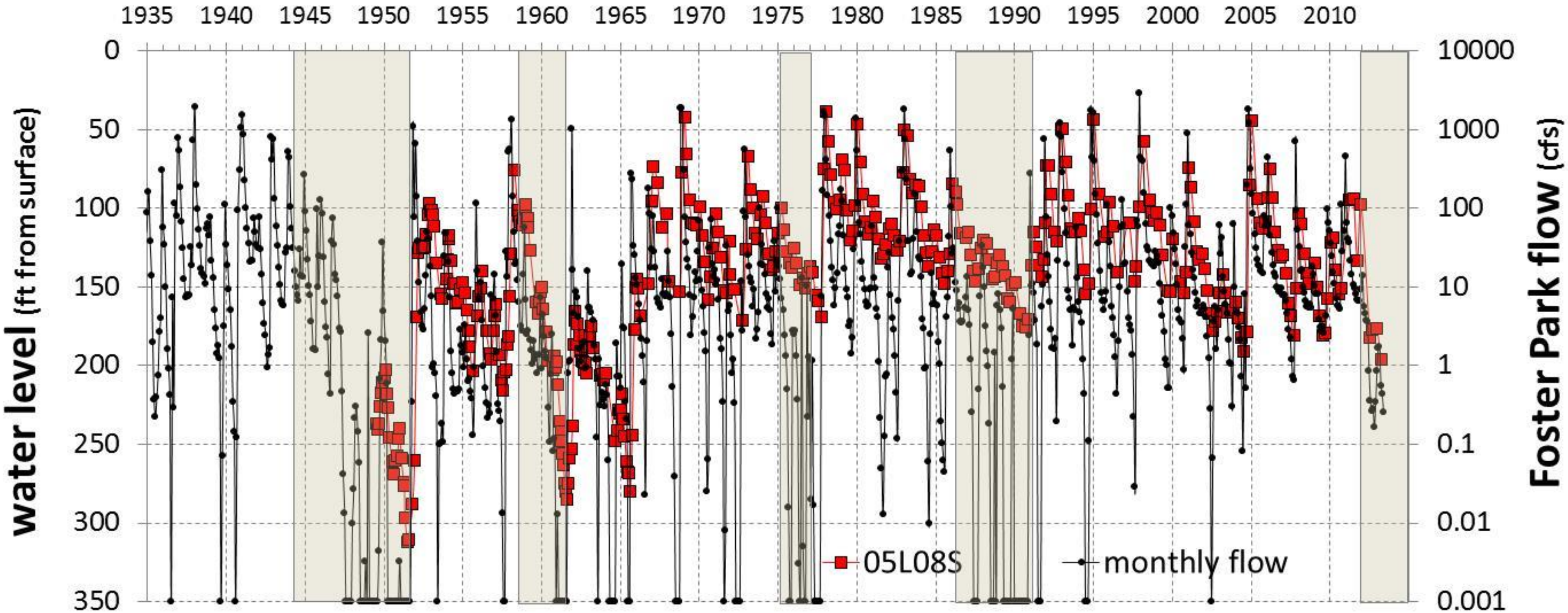
They also predicted the drawdown in well 05L08 at the end of this simulated drought at 227 ft. This is pretty much the level we are currently at the end of January 2014. Unfortunately, we are only at year 2½ of this developing drought.   Praying for rain is probably not a bad idea.



I'm done, having said all I wanted to say. But in looking at the 05L08 data I did prepare some additional graphs. I've added them here for those who might be interested.

In this graph I've substituted average monthly Foster Park flow (measured at the USGS gauging station) for the well data. Since river flow is dependent on rainfall, both patterns are similar—as they were when cumulative departure from mean rainfall was plotted along with depth-to-water well data. Notice the a huge difference between wet and dry years (the flow scale is logarithmic—meaning big differences are visually minimized).

Big wet-years (the "green-donut" years) have at least one month where average flow exceeds 1,000 cfs. In dry-years the peak monthly flow never gets above 100 cfs. And near the end of drought periods it's very much closer to 1 cfs (last year, 2013, being a good example). The lower flow numbers on the graph are little better than guesses. No gauging station can measure flows this low; any monthly flow near or below 0.1 cfs means the river was, for all intents and purposes, dry. [0.1 cfs is 40 gallons per minute; not bad for a well, but little more than a trickle for a river like the Ventura, and 0.01 cfs is pretty close to what a faucet in my duplex puts out.] Again, 2012-13 is a good example: even though the river at Foster Park was dry the gauging station recorded flow (the IR measurement beam was bouncing off a puddle). Still, note that in the last half of each major drought the river at this location went dry.



Finally, this is a graph of depth-to-water for well 05L08 and average monthly Foster Park flow. It should come as no surprise that the patterns match each other very closely. Both, the level of groundwater in the aquifer and the amount of flow in the river, being dependent on rainfall. The important point to consider, however, is that the depth-to-water scale is arithmetic while the scale for monthly average flow is logarithmic: when the groundwater level drops by tens of feet, river flow decreases by orders-of-magnitude. As an example of what I mean, between May 2001 and October 2002, a period without meaningful rainfall, the water level in 05L08 fell 90 feet. At the same time average monthly Foster Park flow went from 46 cfs to 0.1 cfs. —a 460-fold decrease. The river essentially went dry.