CITY OF EL PASO DE ROBLES

“The Pass of the Oaks”

July 15, 2010

Peer Review of Paso Robles Groundwater Basin Studies
Executive Summary

In the 8 years since publication of the “Paso Robles Groundwater Basin Study” (Fugro), two updates have been prepared (2009 – Todd and 2010 – Fugro); perplexingly, their basin status findings differ. Consequently, the City of Paso Robles commissioned a peer review of the updates to examine the differences, as well as indentify steps to enhance future groundwater analysis.

Key report conclusions:

- The 2002 Groundwater Study (Fugro) concluded that perennial yield of the Paso Robles Basin is 94,000 acre feet per year (AFY), and Atascadero’s sub-basin yield is 16,500 AFY.

- The 2002 baseline study, as well as the 2009 Todd and 2010 Furgo updates estimated total demand:

	2002 Fugro	2009 Todd	2010 Fugro
Groundwater Basin	82,600 AFY	88,154 AFY	92-97,000 AFY
Atascadero Sub-Basin	11,100 AFY	15,545 AFY	15-16,000 AFY

- The 2009 and 2010 updates also estimated groundwater storage:

  Todd found *declines* in basin and sub-basin storage between 2000 and 2006

  Fugro found *increases* in basin and sub-basin storage between 1998 and 2009

Consulting Hydrologist Gus Yates, PG, CHg, was engaged to conduct a peer review of the Todd & Fugro updates. In evaluating the assumptions and methods employed, he:

- Questions the hydrologic distinction of the Atascadero Sub-basin.
- Questions stream recharge estimation method.
- Argues that (a) the presumption that recharge occurs only after the plant root zone is fully saturated, and (b) using a single, averaged rainfall value over the entire basin (Fugro, 2002) is not sound.
- Suggests that calibrating water balance based upon limited well level records is not entirely accurate.
- Suggests increased modeling and data collection to improve accuracy of future evaluations.

Summary:

There is general agreement that groundwater pumping is nearing perennial yield, and that efforts to supplement supplies (including the Nacimiento Water Project, State Water Project, conservation, and recycling) will help maintain balance. However, just a 10% increase in basin-wide pumping could negate those benefits.

The best course of action is to:

- MONITOR - Establish the 40+ recommended monitoring wells across the Paso Robles Groundwater Basin and Atascadero Sub basin[1]. Use the improved well monitoring system to regularly analyze changes in water levels (as an indicator of basin conditions).
- MODEL – Update and enhance the model to cross-check and integrate water level data, water balance calculations, rainfall, recharge, in and out flows for more reliable yield and storage estimates.
- SUPPLEMENT – Secure supplemental water (Nacimiento Water Project, State Water Project, recycled water, etc.) in lieu of groundwater to meet demands.
- MANAGE – Achieve cooperative groundwater management.

[1] See SLO County analysis of well measurement program dated 2008 by Cleath & Associates.

MEMORANDUM

Gus Yates, PG, CHg, Consulting Hydrologist
1809 California Street, Berkeley CA 94703 • Tel/Fax 510-849-4412 • gusyates@earthlink.net

Date: June 29, 2010
To: Christopher Alakel, City of Paso Robles
From: Gus Yates, consulting hydrologist
Cc:
Subject: Peer Review of Paso Robles Groundwater Studies

I have completed a review of five major studies of the Paso Robles groundwater basin completed since 2002, as well as several key reports cited in those studies.[1]. My review focused on discrepancies and sources of uncertainty in the previous studies. In some cases, discrepancies arose from differences in assumptions and methods, and in other cases from a cumulative evolution in conceptual understanding of the basin. In addition, I occasionally thought that alternative data or methods would have improved the accuracy or consistency of previous studies.

This memorandum documents the results of my review. It describes in detail discrepancies, uncertainties, weaknesses and possible improvements, grouped by major topic areas. It concludes with recommendations for future data collection and analysis activities that would be of greatest value in reducing uncertainty and supporting management of water resources.

Discrepancies Stemming from Geographic Scale of Analysis

Different scales of analysis have led to conflicting conclusions in previous studies. Local groundwater conditions can deviate substantially from average conditions for the basin as a whole. For example, a recent study concluded that "the basin should be considered to be essentially in balance by a small margin" (Fugro 2010). But hydrographs of some wells exhibit unmistakable long-term declines, such as the one for well 26S/13E-30B2 in the Estrella subarea shown in **Figure 1**. This discrepancy can be attributed to a difference in scale of analysis.

Previous studies consistently divided the basin into two parts for quantitative analysis, separating the Atascadero subbasin from the main Paso Robles basin. Subareas of the main basin were identified early on for qualitative discussion purposes, but complete water balances have not been calculated on a subarea basis.

Figure 2 shows the subareas of the Paso Robles basin originally delineated by Fugro and Cleath (2002). Among the main basin subareas, the Estrella subarea has groundwater

[1] See 'References Cited" section at the end of the memo for a list of reports that were reviewed.

conditions that most clearly differ from basin-wide average conditions. A pumping trough—or depression in the groundwater surface—has steadily developed over the past 20 years. **Figure 3** shows contours of cumulative water level decline in the Estrella subarea during 1997-2009, which is in addition to the decline during 1981-1997 previously documented by Fugro and Cleath (2002).

Ironically, the hydrologic separation of the Atascadero subbasin from the main basin was overemphasized in previous studies. The difference in water level between a warm water spring and a well on opposite sides of the Rinconada Fault were cited as evidence that the fault is a barrier to flow, at least in the Paso Robles Formation (Fugro and Cleath, 2002, p. 19). Aside from the questionable assumption that a thermal spring is representative of ambient groundwater conditions, hydrographs of a larger set of wells on either side of the fault reveal substantial variation in water level with well depth and very little difference between the two sides of the fault (monitoring wells 26S/12E-33 Q1, 33Q4, 27S/12E-4K2, 9N2 and 9N3). Furthermore, the river alluvium is much more permeable than the Paso Robles Formation (800 times more permeable in the calibrated groundwater model), and it reportedly is unaffected by the fault. Because of this permeability contrast, the fault probably has little effect on groundwater to flow between the Atascadero and main basin areas in any case. Finally, any shift in groundwater balance in the Atascadero subbasin would be absorbed by a change in river-aquifer exchange and be conveyed across the fault as surface flow.

The advantage of dividing the basin into subareas for analysis is that local problems can be identified and more effectively managed. However, local water balances are more complex because they include additional terms representing groundwater flows between subareas. Nevertheless, understanding the dependence of yield in one subarea on recharge in another subarea is very useful for planning and management purposes.

The greatest drawback to subarea analysis is that it can undermine political support for management measures that encompass the entire basin. Water users in subareas with few local groundwater problems may be disinclined to help pay for regional solutions. In reality, the subareas are all hydrologically connected, and solutions with the lowest overall cost may involve the entire basin. It should be emphasized that all users have an interest in maintaining the integrity of the whole basin.

Rainfall Recharge

Infiltration of rainfall is the largest source of recharge to the groundwater basin, so uncertainty in the estimate of this flow has a major impact on uncertainty in the overall water balance. Two previous studies estimated rainfall recharge using a method that produces infrequent, large pulses of recharge (Fugro and others, 2002; Fugro, 2010). For example, rainfall recharge in only two years (1998 and 2005) contributed 43% of total basin recharge for the 12-year analysis period (1998-2009) (Fugro [2010] Tables 3 and 4). Therefore, errors in this flow heavily influence errors in the overall water balance and in basin yield.

The rainfall recharge estimates in those studies relied entirely on linear regressions of rainfall penetration studies by Blaney (1933). However, Blaney's estimates of rainfall recharge in areas of natural vegetation were supported by measurements at only two sites in a single year (grass-weed sites A and G in the Ventura basin in 1932). Extrapolations to other year types, root depths and soil conditions were based on modeling and assumptions.

Blaney's approach to rainfall recharge is commonly referred to as a "bathtub model". It assumes that deep percolation beneath the root zone (i.e. groundwater recharge) does not commence until the available water capacity of the root zone is fully saturated. I have used this approach many times in my own studies. In some cases, I have had other information to help corroborate the recharge estimates, such as groundwater hydrographs, stream baseflow data, or joint calibration of a groundwater model with the soil moisture budget model. My general experience has been that the bathtub approach can produce reasonable long-term average recharge rates but that simulated recharge is commonly too sporadic. This appeared to be the case for the Paso Robles basin, also. In order to calibrate the groundwater model, the original time series of annual recharge values estimated using Blaney's method was redistributed more uniformly over the calibration period (Fugro and others [2005] pp. 29-30).

The sporadic time series of annual rainfall recharge produced by the Blaney method may also be inconsistent with measured groundwater levels. The Blaney method predicts rainfall recharge only in exceptionally wet years. In contrast, hydrographs generally show little response to wet years. If rainfall recharge truly occurs as large infrequent pulses, it should be noticeable in the hydrographs. An example of the discrepancy arising from the Blaney recharge method is that Fugro (2010) estimated an increase of 391,174 acre-feet (AF) in groundwater storage from 1997 to 2006 using the Blaney method, whereas Todd Engineers (2007) estimated a decrease of 29,767 AF using a water level approach. Some of the discrepancy could arise from uncertainty in water levels, which is discussed more fully in the section on "Uncertainty in Water Levels", below.

Blaney's 1933 study and the regression equations developed from that study by Fugro and Cleath (2002) are not as solid a basis for estimating recharge as previous reports implied. For example, the threshold of 11.5 inches of cumulative seasonal rainfall to initiate deep percolation beneath typical, shallow-rooted crops (for example, truck crops) in Figure 5 of Fugro (2010) is too high. The regression equations all trace back to Blaney (1933), which had internal inconsistencies. Blaney's 16 sites included only two sites with irrigated annual crops (beans) and four additional sites with relatively shallow-rooted evergreen tree crops (oranges and lemons). In all of those sites, rainfall penetrated beyond the root zone in the one year that soil moisture was monitored. Blaney did not measure how much water percolated beyond the root zone. Using numerous assumptions, Blaney then **simulated** the soil moisture balance for various crops over a period of five years. The simulated results are the basis for Fugro's regression equations, and they appear to underestimate deep percolation, particularly for annual cropland that is bare in winter. The errors are as follows:

- The initial soil moisture deficits at the start of the rainy season are reasonable for truck crops (2.5 inches, corresponding to a root depth of 30 inches, available water capacity of 0.16, and 50% moisture depletion), but they are too high for vineyards and deciduous trees (10 inches). Vine roots extend to a depth of 6 feet. Assuming a typical loamy soil with an available water capacity of 0.15 in/in, total soil moisture storage capacity between field capacity and wilting point would be 10.8 inches for vines. For natural vegetation, it is reasonable to assume soil moisture is nearly fully depleted, but not for irrigated crops. Irrigated truck crop soils rarely if ever fall below 50% of moisture capacity (or yield would be adversely affected). Drought-stressed vineyards might end up at less than 50% of moisture capacity, but probably not close to zero. Assumptions regarding initial soil moisture are important because they strongly influence simulated rainfall recharge.

- The estimates of bare soil evaporation are too high. Blaney assumed evaporation equaled one-half inch following each winter storm, for a seasonal total of 5.8 inches on a site that received 17.54 inches of rain (Blaney's Table 17). Applying the more modern approach presented in FAO Bulletin 56 (pages 144-146) using daily rainfall and ETo data from the Atascadero CIMIS station for May 2009 through April 2010 obtained an estimated annual soil evaporation of only 2.8 inches, even after scaling rainfall up by a factor of 1.16 to equal the same annual total as in Blaney's study.

- It is unclear how Blaney obtained such low estimates of deep percolation for truck crops shown in Table 57 of his report, which are the basis for the regression equations in Fugro and Cleath (2002) and Fugro (2010). Assuming an initial soil moisture deficit of 2.5 inches (see above), Blaney's assumption of zero runoff, and an estimate of 2.8 inches of bare-soil evaporation in winter suggests that deep percolation should have been initiated when seasonal rainfall reached 5.3 inches, not 11.5 inches. Even using Blaney's estimate of 5.8 inches of bare-soil evaporation should have resulted in a threshold for deep percolation of 8.3 inches of seasonal rainfall.

- An evaluation of vineyard deep percolation is particularly relevant to the Paso Robles basin because it is now the dominant crop. For vineyards, a reasonable estimate of initial soil moisture deficit might be 8 inches for vines managed under regulated deficit irrigation (80% depletion of available water). Combining this with the FAO estimate of 2.8 inches of bare soil evaporation and assuming zero runoff obtains a threshold for deep percolation of approximately 10.8 inches of seasonal rainfall, not the 13.6 inches indicated by the regression equation on Figure 5 of Fugro (2010) (deciduous tree category).

The assumed distribution of rainfall across the basin is another source of uncertainty in previous studies. Fugro and Cleath (2002, p. 99) used a single, averaged value of rainfall for the entire basin each year. Todd (2007, Figure 2) prepared an isohyetal map showing that average annual rainfall varies from 10 in/yr to 16 in/yr. This amount of variation would significantly affect average annual deep percolation, which is approximately proportional to rainfall once the seasonal soil moisture deficit has been refilled.

The authors of previous studies were aware of the limitations of the methods they applied. For example, Fugro and Cleath (2002, pp. 124-127) emphasized that “any estimates of effective rainfall for a study of this sort are extremely gross”. Given the importance of rainfall recharge in the basin water balance, improvement of the recharge estimation method is warranted.

A more systematic multi-year simulation of daily soil moisture budgets for various combinations of vegetation, soil and annual rainfall would be useful for refining the rainfall recharge estimates. The soil-moisture-budget model could be jointly calibrated with the groundwater flow model, because errors in simulated water levels can sometimes be traced to systematic errors in estimated recharge.

Vineyard Irrigation

Vineyard irrigation accounted for 76% of agricultural pumping and 51% of total pumping in 2006 (Todd 2007). Therefore, errors in this budget item strongly influence the accuracy of the overall water balance and basin yield estimates.

The vineyard irrigation estimates rely on letter reports of two experts: Mark Battany (2004) and Frank Honeycutt (2004). Battany estimated a +/- 50% uncertainty in estimated average vineyard irrigation (“somewhere around 1.25 ft/yr, plus or minus 50%”). Applied to a basin-wide vineyard irrigation estimate of 60,000 AFY, this corresponds to an uncertainty of +/- 30,000 AFY.

Honeycutt presented three estimates of basin-wide irrigation pumping (including Battany's estimate) representing a range of +/-10,000 AFY (17%) around an average of approximately 60,000 AFY. This estimate assumed a “maximum reasonable future irrigated acreage” of 45,000 acres planted 100% to vineyard.

Todd (2007) tabulated actual 2006 irrigated acreage (40,836 ac, 84% vineyard). In spite of less acreage and a different crop mix, Todd's estimate of total irrigation pumping exactly equaled Honeycutt’s long-term estimate of 60,000 AFY (Table 5). This presumably was achieved by adjusting the water duties for the other crops, because Todd kept Honeycutt’s 1.25-1.5 ft/yr duty for vineyard (Table 3). This appears to indicate some uncertainty in crop coefficients, irrigation efficiency, or both.

Honeycutt's estimate of irrigation pumping incorporated an assumption that crop water demand in Shandon (the eastern part of the basin) is 20% to 50% greater than in Paso Robles and applied that higher irrigation demand to 30% of the basin-wide cropland. This geographic difference is overstated. Spatial modeling of reference ET (ETo) by the California Irrigation Management Information System indicates that ETo in Shandon is only 5% greater than in Paso Robles (http://wwwcimis.water.ca.gov/cimis/cimiSatSpatialCimis.jsp). Assuming the true difference is 5% not 50%, the original basin-wide irrigation estimate could be as much as 13.5% too high (45% ET error x 30% of basin area). For a base value of 60,000 AFY, this equals an error of 8,100 AFY.

Vineyard water use depends on a number of factors, including vine spacing, vine pruning (as it affects the percent canopy cover at midday), grape variety, and the degree of planned soil moisture depletion during the growing season (regulated deficit irrigation). Most growers now calculate irrigation demand in gallons per vine per week rather than inches per acre per month. Additional data from a variety of vineyards could substantially narrow the range of uncertainty in agricultural irrigation demand.

Crop Water Demand and Irrigation Efficiency

There appear to be discrepancies within Fugro and Cleath (2002) regarding irrigation efficiency and gross versus net pumping. Irrigation efficiencies were assumed to increase from 63% in 1980 to 70-75% in 1997 (see Table 58). Also, excess applied water to manage soil salinity was estimated to equal 2-16% of base irrigation demand for various crops (Table 56). But the water budget (Table 72) shows irrigation deep percolation equaling only 2-4% of gross irrigation pumping, equivalent to 96-98% efficiency. An earlier discussion indicates that "irrigation losses" are in the range of 18-38% (Table 42). Table 42 also indicates "irrigation return flows" equal to 2.1-4.5% of gross pumping, but the text describing the table states that deep percolation below the root zone is 2-17%. The discussion of irrigation efficiency (p. 129) states that the irrigation efficiency is calculated over an entire growing season. Normally, the seasonal efficiency accounts for irrigation return flow (deep percolation in this case) that is re-pumped for irrigation use the same season. This approach is inconsistent with the estimates of gross pumping based on total applied water with no adjustments for return flow component. It is also inconsistent with a layered model where pumping derives from deep layers while irrigation return flow accrues to the top layer. The most recent study (Fugro, 2010) assumed an average efficiency of 2.2 % (p. 6, section 3.1.4). Some of the apparent discrepancy among these numbers could be the result of unclear documentation. They were presented in various places in the 2002 report in discussions of disparate topics.

There is also an inconsistency between the discussion of salt leaching requirements (Fugro 2002, pages 54-55 and 127-128) and the Blaney (1933) estimates of rainfall recharge. If Blaney is correct and significant recharge occurs only once every 3-4 years, rainfall percolation would not be frequent enough to provide adequate leaching. Fugro (2002) Table 13 shows that grapes are relatively sensitive to salt and have the highest leaching requirement among crops commonly grown in the region. Soil salinity typically increases substantially during the course of a single irrigation season. It is unlikely that vines could wait 4 years between salt-flushing events. Thus, the estimated frequency of rainfall recharge influences irrigation efficiency as constrained by the need for salt management.

The most unambiguous approach to calculating applied water and deep percolation would be to use a per-irrigation efficiency to convert consumptive use to gross irrigation pumping. If the efficiency did not appear sufficient to achieve an adequate leaching ratio (on an annual basis, in conjunction with deep percolation of winter rainfall), then a lower efficiency could be assumed.

Several other apparent discrepancies or conceptual inconsistencies related to agricultural water use were identified during my review of previous studies. These included:

- Todd (2009, Table 12) subtracted irrigation return flow to obtain net agricultural pumping in a water balance calculation, but did not subtract WWTP and septic percolation to get net municipal and rural residential pumping. This seems inconsistent.

- There appears to be a discrepancy between the estimated water balance and observed water-level trends in Fugro and Cleath (2002). The water balance calculations (Table 71) indicated that annual groundwater pumping decreased during 1981-1997 because much of the cropland shifted to vineyard, which has a smaller water duty than pasture and other crops. The regression slope for annual pumping during 1981-1997 was -498 AFY per year for Estrella subarea pumping and -3,470 AFY per year for the entire basin. In spite of the decrease in pumping, groundwater levels declined during that period, in some cases at an increasing rate.

- The historical trend in agricultural water use is considerably different from the future irrigation trend assumed in the most recent study (Fugro, 2010). As noted above, estimated irrigation water use in the Estrella subarea and the basin as a whole decreased substantially and steadily during 1981-1997, reaching a basin-wide level of about 50,000 AFY in 1997 (Fugro and Cleath [2002] Table 71). In contrast, Fugro (2010) assumed irrigation pumping in 2010 was 63,077 AFY (26% higher than in 1997) and that it would remain constant during 2010-2025. The basis for this assumed change in pumping amount and trend was not explained in the report.

- Two estimates of future water demand used quite different assumptions regarding future rural residential pumping. Todd (2009, Table 14) estimated that rural groundwater pumping in 2025 would be 44% greater than in 2006 (16,504 AFY versus 11,485 AFY). Fugro (2010, Table 13) assumed rural residential pumping would remain constant at the 2009 level (11,817 AFY). In addition to this range of uncertainty in the number of rural residences, there is uncertainty in the amount each residence uses. Fugro (2010) tested water use factors ranging from 1.0 to 1.7 AFY per residence. In both instances, the assumptions appeared to come from planning agencies, not the report authors. For example, Todd (2009) explored the maximum "buildout" water use for rural residential development based on a San Luis Obispo County inventory of potentially developable rural residential parcels. The resulting estimate of potential water use is probably high because some of that development would likely require permits that local agencies would be reluctant to issue given the continuing water-level declines in the Estrella and Shandon subareas.

WATER LEVELS ARE A MAJOR SOURCE OF UNCERTAINTY

Trends in measured water levels are critical to evaluating the sustainability of pumping. Regardless of what water balances and groundwater models might show, chronically declining water levels at multiple wells are a certain indication of excessive pumping. However, water level hydrographs in the Paso Robles basin can be difficult to interpret because in many cases they do not respond clearly and consistently to changes in recharge or pumping. Theoretically, both factors should strongly influence water levels, but empirically the relations are weak. This somewhat counterintuitive condition probably results from layering within the basin, which slows and attenuates recharge pulses as they percolate down to the aquifers tapped by water supply wells. Layering also creates confined aquifer conditions, in which water levels fluctuate widely in response to individual pumping cycles, which can result in large and apparently random fluctuations in quarterly or semiannual water level data.

The hydrographs in **Figure 4** illustrate the connection—or lack thereof—between water levels and pumping or recharge. If groundwater levels responded strongly to recharge, they should trend noticeably upward during wet periods and downward during droughts. A cumulative departure analysis of annual rainfall at Paso Robles indicates that the 1984-1992 period was dry, as indicated by the downward trend in the red line in **Figure 5**. The 1993-1998 period was wet (upward trend), and the 1999-2009 period consisted of mostly below-average rainfall years except for wet years in 2005 and 2006. The groundwater hydrographs show little or no response to these trends in rainfall. The declining trend evident in all of the hydrographs commenced in the mid-1990s in most cases, when climatic conditions were still wet. An exception is the temporary increase in water levels in 2005-2006 at wells 16P2 and 29N1. These wells apparently responded to above average recharge from nearby creeks.

The hydrographs also do not correlate with the expected effects of seasonal pumping. Spring water levels are indicated on the hydrographs by pink dots. Given that the vast majority of groundwater pumping in the area is for irrigation, the spring water levels should be higher than the fall water levels every year, but in many wells and years this is not the case. Although the hydrographs do not respond entirely as expected to recharge and pumping, the ubiquitous long-term declining trend can only be the result of an imbalance between the two.

Another potential source of error in interpreting hydrographs is mixing data for shallow wells tapping younger alluvium with data for deeper wells tapping the Paso Robles Formation. **Figure 6** shows hydrographs for two wells located less than 2,000 feet apart along the Estrella River in the Estrella subarea. The well with steady, high water levels

(5F1) probably draws from the alluvium, while the well with large, long-term declines (5D2) is deeper and draws from the Paso Robles Formation.

These examples support a conclusion that interpretation of water level trends is best done by examining a large number of hydrographs, identifying general trends common to most of them, and looking for hydrogeologic or other physical circumstances to explain wells that deviate from the norm. Also, comparing water levels between two particular dates—by hydrographs or contours—can lead to conclusions that are not representative of long-term trends. Trend analysis that includes all years is more robust.

Streamflow and Stream-Aquifer Interaction

Several methods were used in previous studies to estimate groundwater recharge from stream percolation, including groundwater modeling and calculations based on gauged streamflows and measured groundwater levels. One method suffered from conceptual limitations, and other aspects of the analyses are not sufficiently well documented to enable a systematic comparison of results.

Fugro and Cleath (2002) calculated stream recharge based on vacant alluvial storage capacity, with no limitation related to streambed infiltration capacity. This approach probably overestimates recharge from high, brief flow events, when infiltration capacity may limit the percolation rate. Conversely, the method probably underestimates recharge from sustained flows after vacant storage capacity in the alluvium has already been refilled. Under those circumstances, the stream can keep the alluvial aquifer continuously full as water percolates from the alluvium into the underlying Paso Robles Formation. Furthermore, it appeared that vacant storage capacity may have been estimated in some cases from deep wells completed in the Paso Robles Formation, but deep water levels are poorly correlated with recharge, pumping and shallow water levels. Therefore, they are not reliable indicators of available storage at the water table.

Fugro and Cleath (2002) included no discussion of groundwater discharge into streams, and it’s not listed in Table 71 or 72. Groundwater discharge into streams is a substantial part of the water budget. Subsequent groundwater modeling indicated that this flow was approximately 29,000 AFY, or 42% as large as seepage from streams (ZoneBudget output for 1981-1997).

The MODFLOW model (Fugro and others, 2005) overcame some of the limitations of the earlier study. Stream percolation is governed by available storage capacity in shallow aquifers near the stream as well as by the stage, permeability and wetted area of the streambed. The model also simulates groundwater discharge into streams where groundwater levels are higher than the stream surface. In all these respects, the MODFLOW approach is conceptually correct. Documentation of the MODFLOW results in the report was somewhat complicated, however, so it was difficult to compare them with the prior study. Table 3 of the modeling report shows 46,000 AFY of percolation from streams. However, this includes WW percolation and excludes percolation from streams other than Salinas River (per e-mail from Nels Ruud 4/27/10). Therefore, the total is not directly comparable to Table 41 of Fugro and Cleath (2002), which listed 41,800 AFY of seepage from streams.

When the MODFLOW model was reactivated for the present review, the ZoneBudget results showed total percolation from all streams of 68,400 AFY. This estimate is 26,600 AFY (64%) larger than the 2002 estimate. A possible explanation for the discrepancy is that the vacant-storage-capacity method used in 2002 omits ongoing percolation from the alluvium to the Paso Robles Formation when the alluvium is "full".

The MODFLOW model requires estimates of streamflow at model boundaries, not at gage locations. The method for extrapolating flow from the gauge locations to the model boundaries is not documented, either for streams with downstream gauges (Salinas and Estrella Rivers) or for ungauged streams (all others)(Fugro and others [2005] pp. 15-16). This is not a trivial exercise, given that flow depletions along ungauged streams and upstream of gages are unknown. The method used by the modeling team to estimate these inflows is unclear (P. Sorensen, pers. comm. 4/29/10).

Finally, the 6-month stress periods used in the model are too long to accurately represent stream-aquifer interaction. Stream recharge is quite nonlinear, especially for flashy flows in broad sandy channels with variable flow width. If average streamflow over the 6-month period is entered into the model it will grossly overestimate stream recharge (which is a large percentage of small steady flows and a smaller percentage for flashy high flows). This issue is not discussed in the model documentation.

Subsurface Inflow

Groundwater inflow from areas adjacent to the modeled area were supposedly estimated using the Darcy equation, but no data were available for the three factors in that equation: hydraulic gradient, flow depth and hydraulic conductivity. The hydraulic gradient was assumed to equal the topographic slope of the overlying ground surface (Fugro and Cleath [2002] p. 94). In reality, there is no physical mechanism requiring that the two gradients be similar. No well data were used to estimate saturated thickness, and the hydraulic conductivity was similarly assumed (Fugro and Cleath [2002] Table 34).

Furthermore, groundwater inflow was assumed to vary substantially from year to year, which is improbable. This variability was justified by reference to a tunnel seepage study in Santa Barbara County that documented pulses of tunnel inflow following rain storm events (Fugro and Cleath [2002] p. 95). This conceptual model of groundwater flow pulses rapidly following rainfall events contradicts the Blaney (1933) data used to estimate rainfall recharge for the groundwater model. Blaney's studies indicated that deep percolation beneath the root zone occurred only in wet years (Fugro and Cleath [2002], pp. 96-99). If the Blaney concept is correct, there would be surges in groundwater inflow across the model boundaries during wet years followed by a recession during subsequent normal and dry years. Table 35 of Fugro and Cleath (2002) does not closely follow this pattern.

The estimated annual variation in subsurface inflow seems too high. The estimates of annual subsurface inflow to the basin during 1981-1997 vary by more than a factor of two (Fugro and Cleath [2002] Table 35). This is implausible, because 1) it implies that groundwater gradients across basin boundaries fluctuate by a factor of more than two, and 2) it implies that large pulses of rainfall recharge cause large fluctuations in water levels adjacent to the basin, which is not a pattern observed in monitoring wells within the basin.

The estimates of annual variability in inflow are presented as fact in Figure 3 of Fugro (2010), which shows a regression of annual subsurface inflow versus rainfall for 1981-1997. It implies that subsurface inflow was actually measured, when in fact the inflow data are entirely synthetic, as described above. Apparently, the regression equation shown on the figure reflects nothing more than the assumptions underlying the inflow estimates. After deriving an estimate of average gradient and flow across the basin boundary, annual variations in this flow were then estimated by assuming that inflow varies as a percentage of annual rainfall (Fugro and Cleath [2002] p. 95 and Table 35). This assumption contradicts the Blaney approach used for rainfall recharge, which estimates recharge as a highly nonlinear function of annual rainfall (i.e. very threshold-dependent).

A better approach to estimating boundary inflows would be to delineate external upland areas likely to contribute inflow to the basin (bounded by faults, flow divides beneath ridges, or distance from other discharge boundaries such as upland creeks). The same procedures used to estimate rainfall recharge within the basin should be applied to the external areas and assumed to become inflow to the basin. Finally, inflow is probably fairly constant from year to year due to the attenuating effects of flow through the relatively impermeable geologic materials present in the external upland areas.

During model calibration, subsurface inflows were substantially increased along selected boundary segments "where insufficient inflow was available to simulate the measured groundwater elevations" (Fugro and others [2005] p. 18). Adding water to a groundwater model without a plausible physical source—especially by means of a general head boundary capable of supplying unlimited quantities of water—is always suspect. That approach to fixing a calibration problem is typically non-unique. Errors in recharge, pumping or hydraulic conductivity might also overcome the problem, and in some cases the water level data themselves might not be representative of ambient groundwater conditions. In this case, lower hydraulic conductivity might have elevated groundwater levels in the problem areas as much as increased boundary inflow.

Recharge to the South Gabilan area was further boosted by increasing stream recharge. The stream channel density in the model for the South Gabilan area was more than two times greater than in the North Gabilan area, in spite of similar terrain, rainfall and geology. As a result, stream recharge in the South Gabilan area was 1.9 times greater. The extra boundary inflow (2,800 AFY) and extra stream recharge (3,000 AFY) contributed to the 10,400 AFY of outflow to the Estrella area, averaged over the 1981-1997 calibration period. This flow comprised nearly half of the total inflow to the Estrella area and therefore substantially influenced model calibration in that area. It is not clear whether a smaller storativity value in the Estrella area could have achieved an equally acceptable simulation of long-term water level declines.

Groundwater Storage

Two of the previous studies mention the total volume of groundwater in storage in the basin (Fugro and Cleath [2002] p. 143; Fugro [2010] p. 14). In my opinion, this number is of little practical value and can be misleading for lay audiences. It would be physically impossible to pump a basin dry (some saturated thickness is required to convey groundwater to wells), and a host of adverse effects would intervene long before that endpoint were reached (for example: pumping costs, dry wells, elimination of baseflow in rivers, subsidence, mortality of riparian vegetation). A more useful storage volume for management purposes is the volume defined by minimum and maximum desirable water level surfaces. This range of water levels is much smaller than the total basin thickness; perhaps 100 feet in some areas and much less near sensitive habitats. The volume of storage between the upper and lower water level surfaces constrains the calculations of perennial yield because it defines the volume of water that can be borrowed from storage during droughts. Groundwater management should be based on this operable storage range and not on total basin storage.

There is some discrepancy among previous studies regarding storativity values. Fugro and Cleath (2002, Table 68) assumed a range of specific yields (0.08-0.11) for the basin areas (0.08 for Estrella).The groundwater model (Fugro and others [2005] Figs. 33-36) used 0.17 for alluvium (layer 1). Most of layer 2 (where the water table is located for most of the Estrella area) has a specific yield of only 0.01. Specific yield in layer 3 closely matches the values in the 2002 report, and that is the layer in which the water table occurs throughout the largest part of the basin. The low specific yield value for layer 2 creates a discrepancy between simulated storage changes in the Estrella subarea and storage changes estimated independently of the model (for example, Todd [2007], Table 1).

There appears to be an error in one or more entries in Table 9 of Fugro and others (2005), which shows the simulated average annual change in storage by subarea during the calibration period. For example, the value for the San Juan subarea is four times greater than for the Estrella subarea, when Estrella experienced much larger water level declines. Also, the Shandon subarea should not have a large increase in storage, because water levels did not rise (see Figure 34 of Fugro and Cleath (2002) for contours of 1997 minus 1980 water levels).

Similarly, storage and water level information seem inconsistent in Todd (2007). Referring to the hydrograph for well 26S/15E-18J001 (Todd Figure 11) as representative of groundwater conditions in the Shandon area, the text asserts that “water levels appear to have decreased beginning in 2003, suggesting increased local pumping in the area" (page 9, bottom of 2nd paragraph). However, a declining trend is inconsistent with the increase in storage listed for the Shandon subarea in Table 1 (page 10).

Basin Yield

Three estimates of perennial yield have been presented in previous studies, all of them remarkably similar. Fugro and Cleath (2002) used the practical rate of withdrawal method in which annual change in storage is plotted against annual groundwater pumping. The expected relationship is that storage change would be negative in years with high pumping and positive in years with low pumping. The method was applied twice: once with storage changes calculated using the inventory method (total inflows minus total outflows) and once with changes calculated using the specific yield method (water levels). Linear regression of the scatterplot data resulted in a line, and the perennial yield was the amount of pumping corresponding to the point where the line crossed the x axis (zero storage change). The two estimates of perennial yield were 93,500 ac-ft/yr and 94,600 ac-ft/yr, respectively (Fugro and Cleath, 2002).

The similarity of the two estimates is not an indication of high accuracy, however. The two scatterplots without the trend lines are reproduced in **Figure 7**. There is a large amount of scatter in the data, especially when storage changes are estimated using the specific yield method (lower plot). Individual years plot in quite different locations in the two plots, relative to the other data points. Examples are highlighted in color. This suggests that the two methods do not strongly confirm one another and that the similarity in x-axis intercepts is merely a coincidence. The low precision of the slopes is also indicated by the low r-squared values (0.256 and 0.039 for the two plots, respectively). Finally, the very shallow slope of the regression line for the lower plot turns out not to be significantly different from zero at even a 60% confidence level. Thus, the perennial yield estimate based on the specific yield method is meaningless.

The third estimate of perennial yield was obtained using the groundwater model. All types of pumping throughout the basin were adjusted by a uniform percentage until the average annual storage change over the calibration period was zero. This occurred at an average annual basin-wide pumping rate of 97,700 ac-ft/yr, or 2.4% less than the estimated historical pumping (Fugro and others, 2005).

The two valid estimates of yield differ by 4,200 ac-ft/yr, or slightly more than 4%. Both methods were based on basin-wide averages and could include localized storage depletion. A broader range of estimates could undoubtedly be obtained with different data and assumptions, particularly if the geographic distribution of pumping were rearranged. This is because perennial yield is influenced by the location of pumping relative to head-dependent boundaries such as creeks and rivers.

There may be a discrepancy between these estimates of yield and an independent comparison of pumping and water levels. Todd (2009, Table 12) completed a detailed inventory of pumping in the basin, which totaled 88,154 AFY. This total is well below the prior range of yield estimates (93,500 – 97,700 AFY), yet water levels continue to decline in the Estrella and Shandon areas. While these declines may be local, they would have to be more than offset by increases in other areas to be consistent with the basin yield estimates.

RECOMMENDATIONS

- Collect vineyard irrigation data from a large sample of growers to improve estimates of salt leaching needs, irrigation pumping and irrigation efficiency.

- Monitor groundwater levels at selected locations on a frequent basis and at multiple depths. This information could substantially improve our understanding of basin storage, relationships between pumping, recharge and water levels, and rates of flow between the alluvium and Paso Robles Formation. The data would also reveal the amount of error in quarterly and semiannual water level data sets caused by short-term drawdown in response to pumping cycles in a confined aquifer. In practice, this program may require installation of additional monitoring well clusters and deployment of data loggers at selected wells to measure water levels frequently.

- Update the groundwater model to facilitate further analysis of water balance and water management issues. It provides the best available tool for analysis because it enforces consistency between water balances and water levels and because it provides a means of testing alternatives. Specific improvements include:

    - Simulate rainfall recharge using a daily model of soil moisture balance. Test the sensitivity of simulated recharge to key input parameters. Apply the recharge model to zones representing various combinations of soil type, rainfall, slope, land use, crop type and irrigation status. Continuous simulation of a multi-year period eliminates errors associated with estimating soil moisture status at the beginning of each rainy season. Compare the results with the Blaney method.

    - Estimate groundwater inflow around the perimeter of the model by applying the rainfall recharge model to adjacent upland areas that plausibly contribute inflow to the basin. Assume the inflow is relatively constant from year to year.

    - Use the model to define physically realistic upper and lower water level surfaces defining a range of operable storage for basin management purposes.

    - Calculate and interpret subarea water budgets using the MODFLOW ZoneBudget post-processor.

- Use the model to investigate yield issues on a subarea basis, including possible changes in the locations and depth of well production.

REFERENCES CITED

Battany, Mark. August 19, 2004. Estimate of annual vineyard water consumption. Unpublished memorandum. University of California Cooperative Extension, San Luis Obispo, CA.

Blaney, H.F. 1933. Rainfall penetration. Chapter 6 in Ventura County Investigation. Bulletin No. 46. California Division of Water Resources, Sacramento, CA.

Fugro West, Inc. March 2010. Paso Robles groundwater basin, water balance review and update. Prepared for San Luis Obispo County Public Works Department, City of Atascadero, Atascadero Mutual Water Company, Templeton Community Services District, and City of Paso Robles.

Fugro West, Inc. and Cleath & Associates. August 2002. Paso Robles groundwater basin study, final report. Prepared for San Luis Obispo County Public Works Department, San Luis Obispo, CA.

Fugro West, Inc., ETIC Engineering, Inc. and Cleath & Associates. February 2005. Paso Robles groundwater basin study, phase II: numerical model development, calibration and application. Prepared for San Luis Obispo County Public Works Department, San Luis Obispo, CA.

Honeycutt, F. September 20, 2004. Agricultural water use. Memorandum to Paso Robles Groundwater Basin Technical Review Committee. San Luis Obispo County Public Works Department, San Luis Obispo, CA.

Todd Engineers, Inc. December 2007. Update for the Paso Robles groundwater basin. Prepared for Paso Robles Groundwater Basin Committee.

__________________. May 2009. Evaluation of Paso Robles groundwater basin pumping, water year 2006. Prepared for City of Paso Robles and San Luis Obispo County Public Works Department.

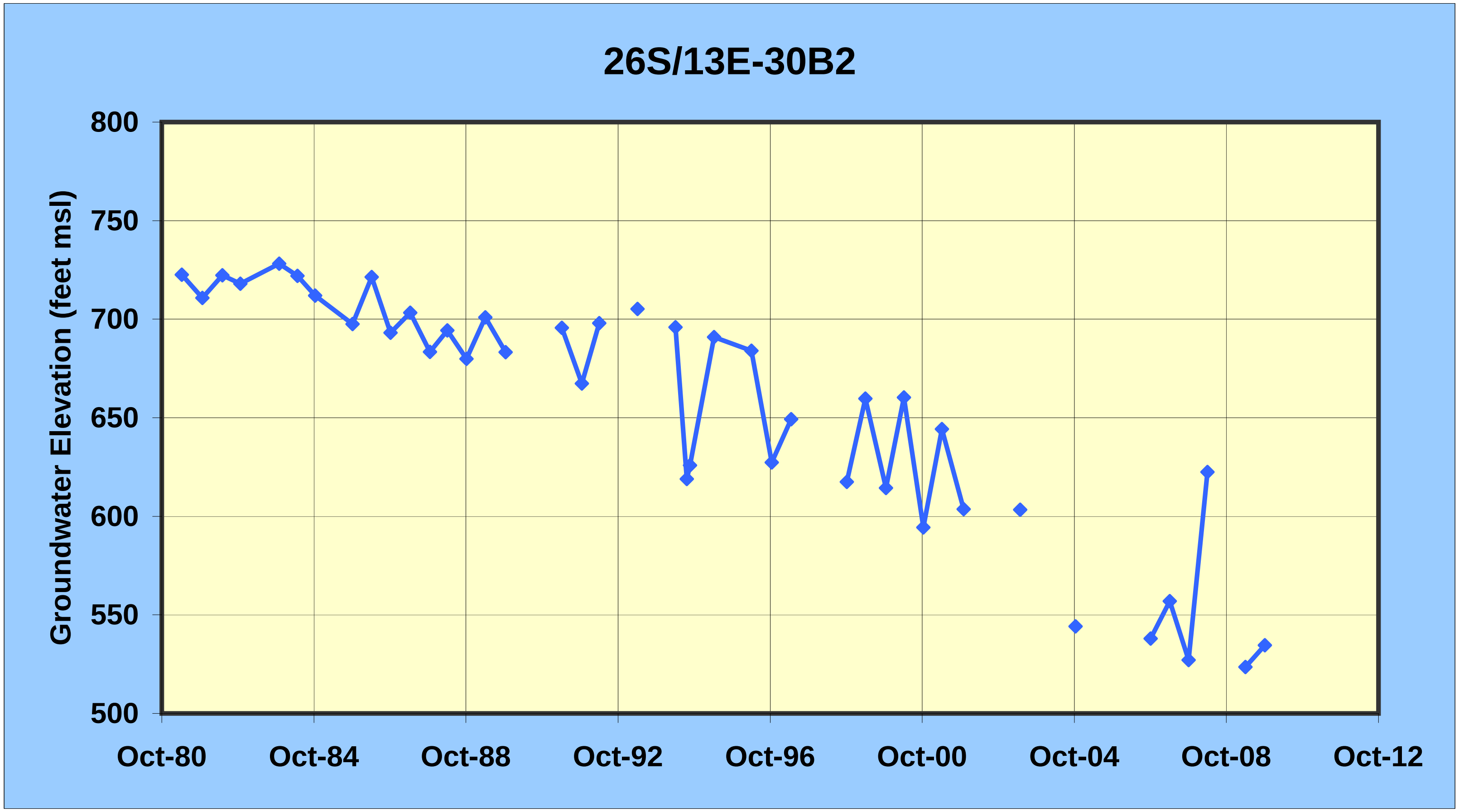


Figure 1. Hydrograph of Water Levels at Well 26S/13E-30B2 in the Estrella Subarea

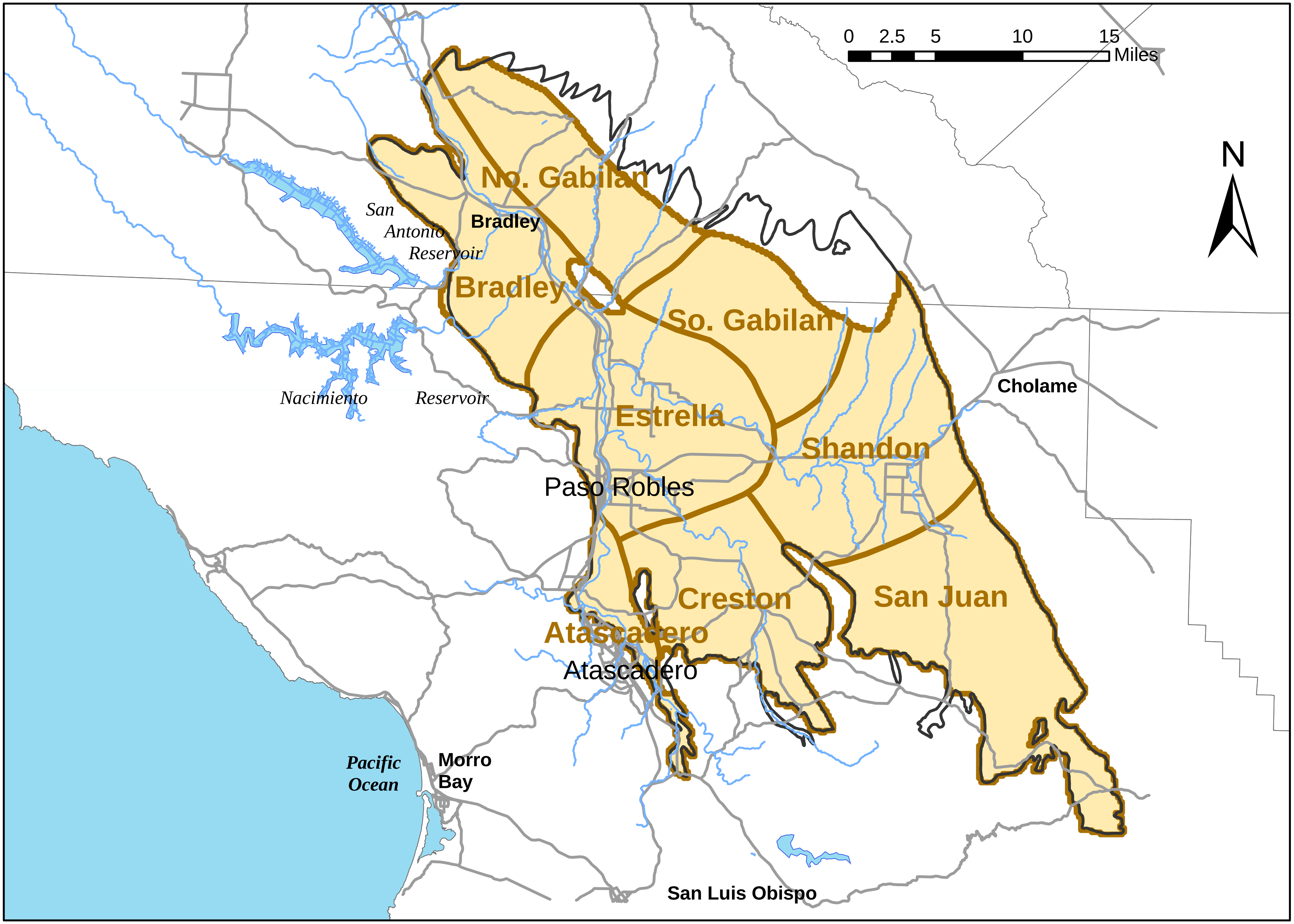


Figure 2. Paso Robles Groundwater Basin and Subarea Boundaries

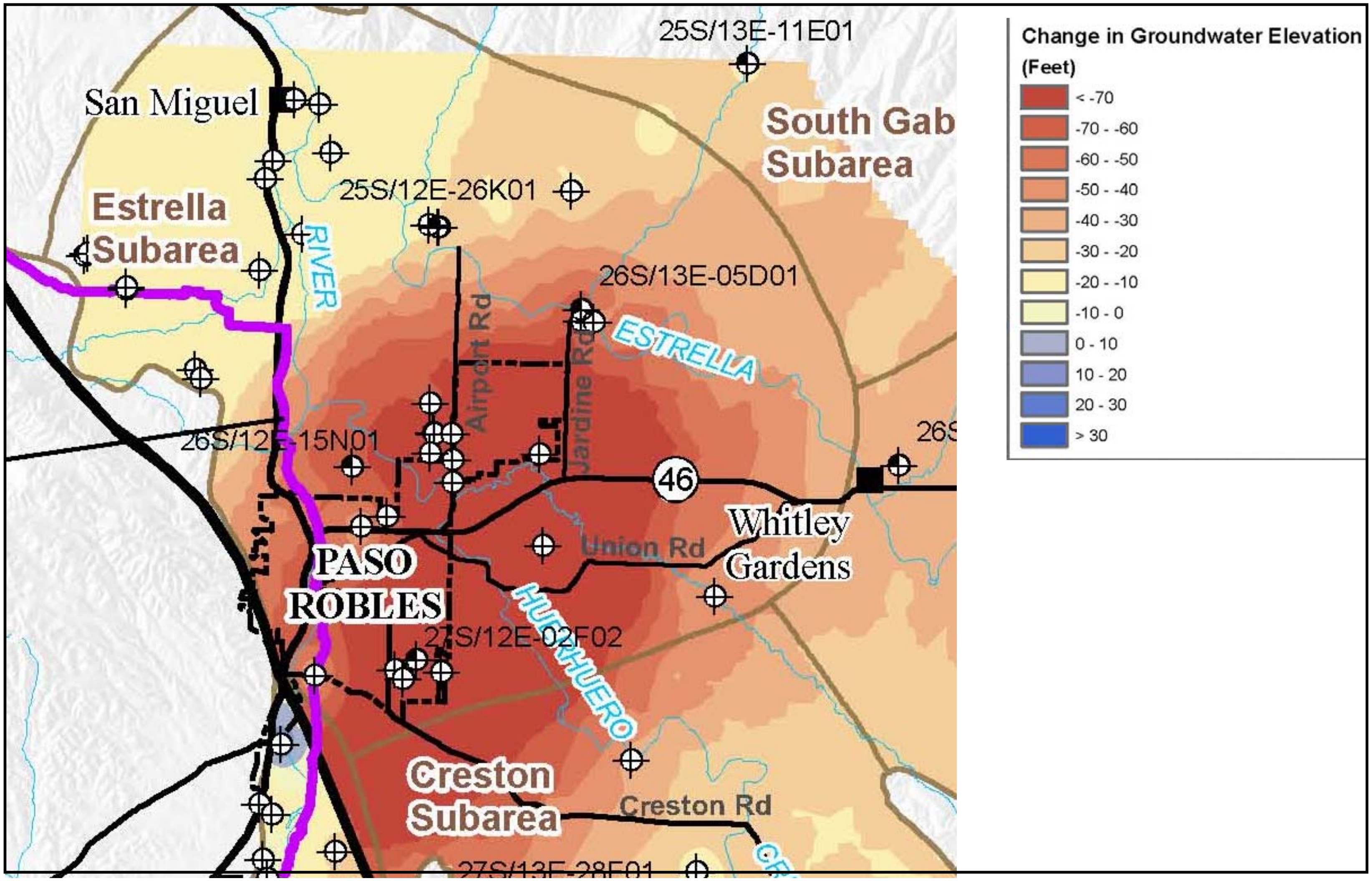


Figure 3. Map of Change in Groundwater Levels in the Estrella Subarea, 1997-2009

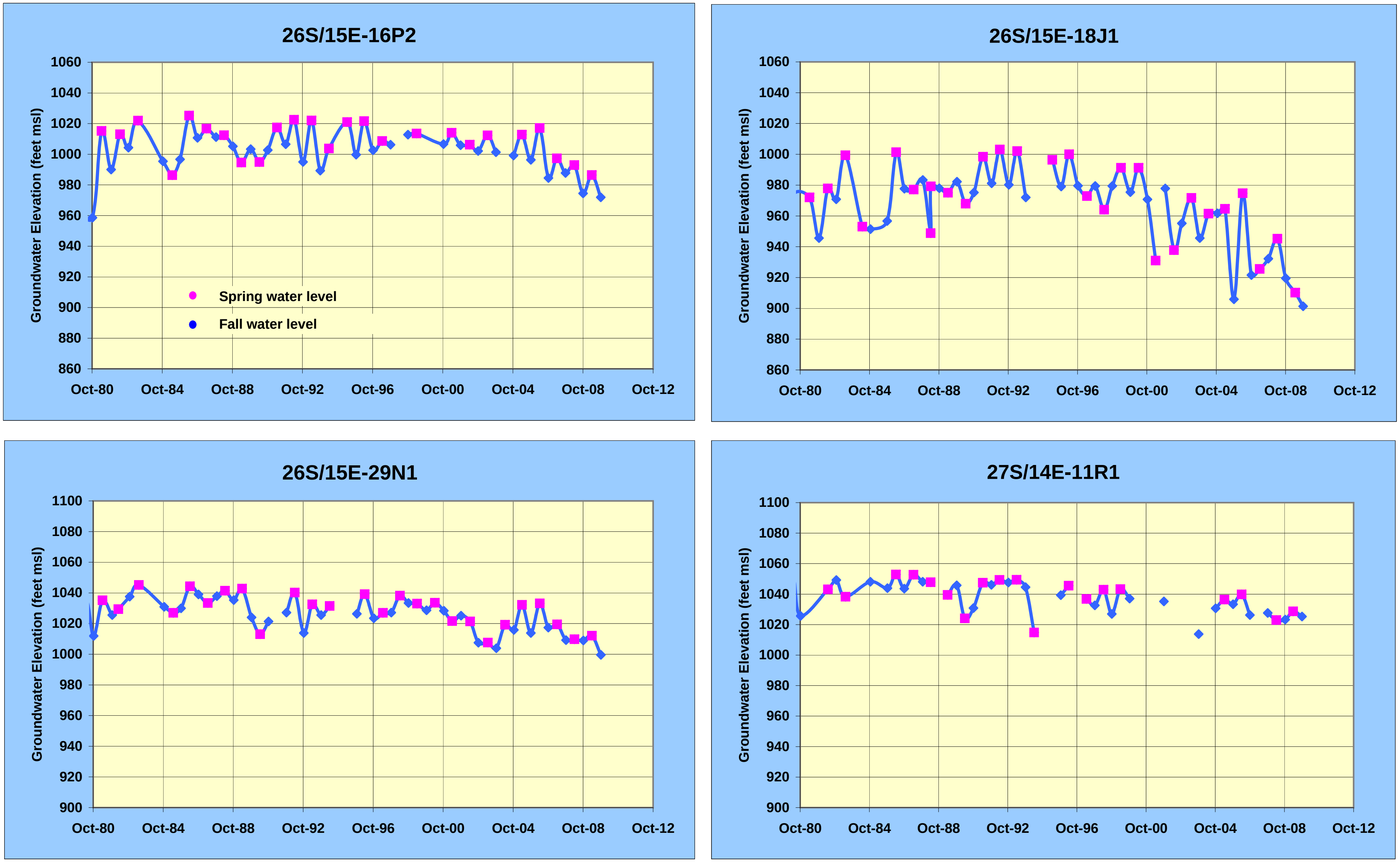


Figure 4. Hydrographs of Selected Wells in the Shandon Subarea

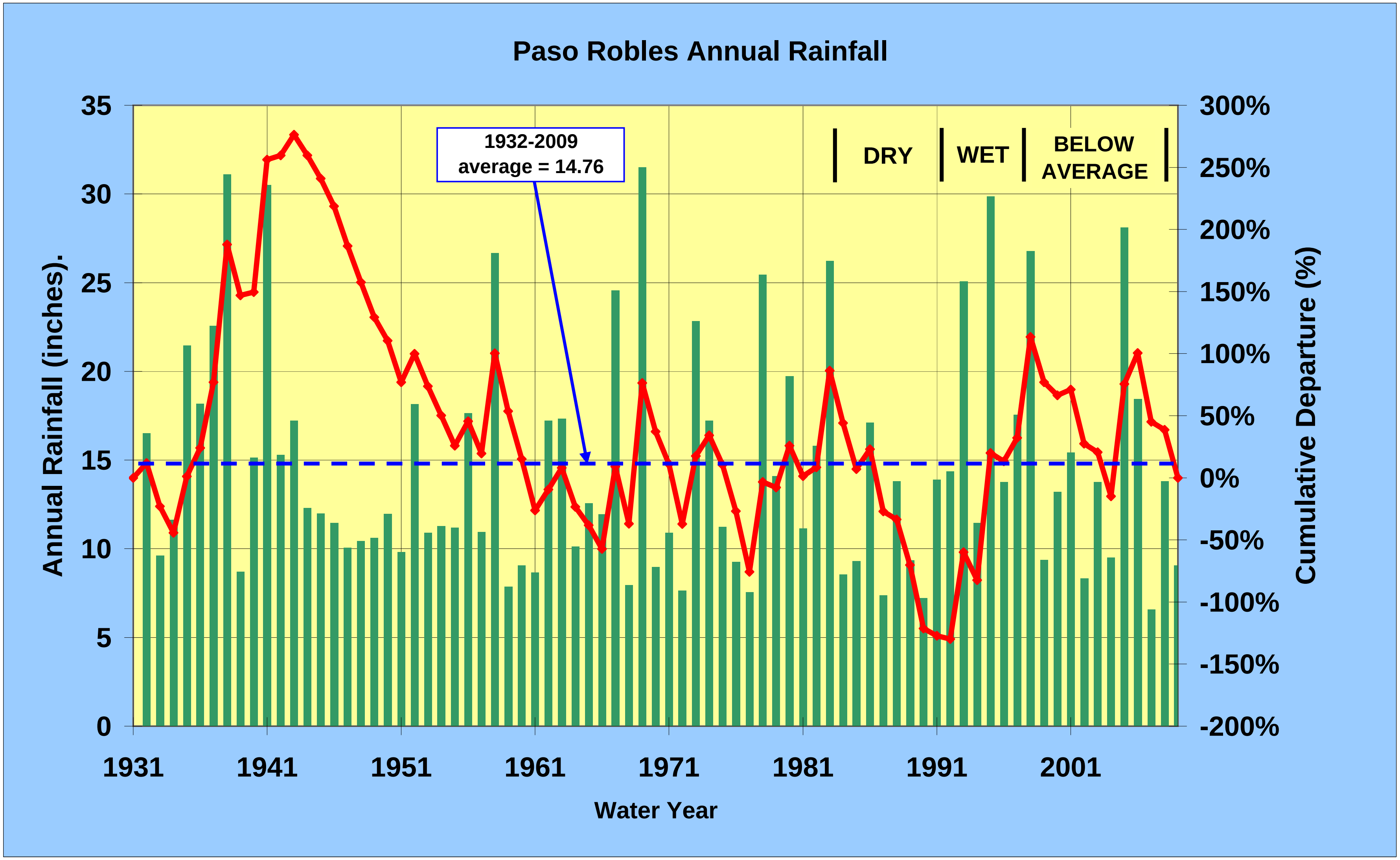
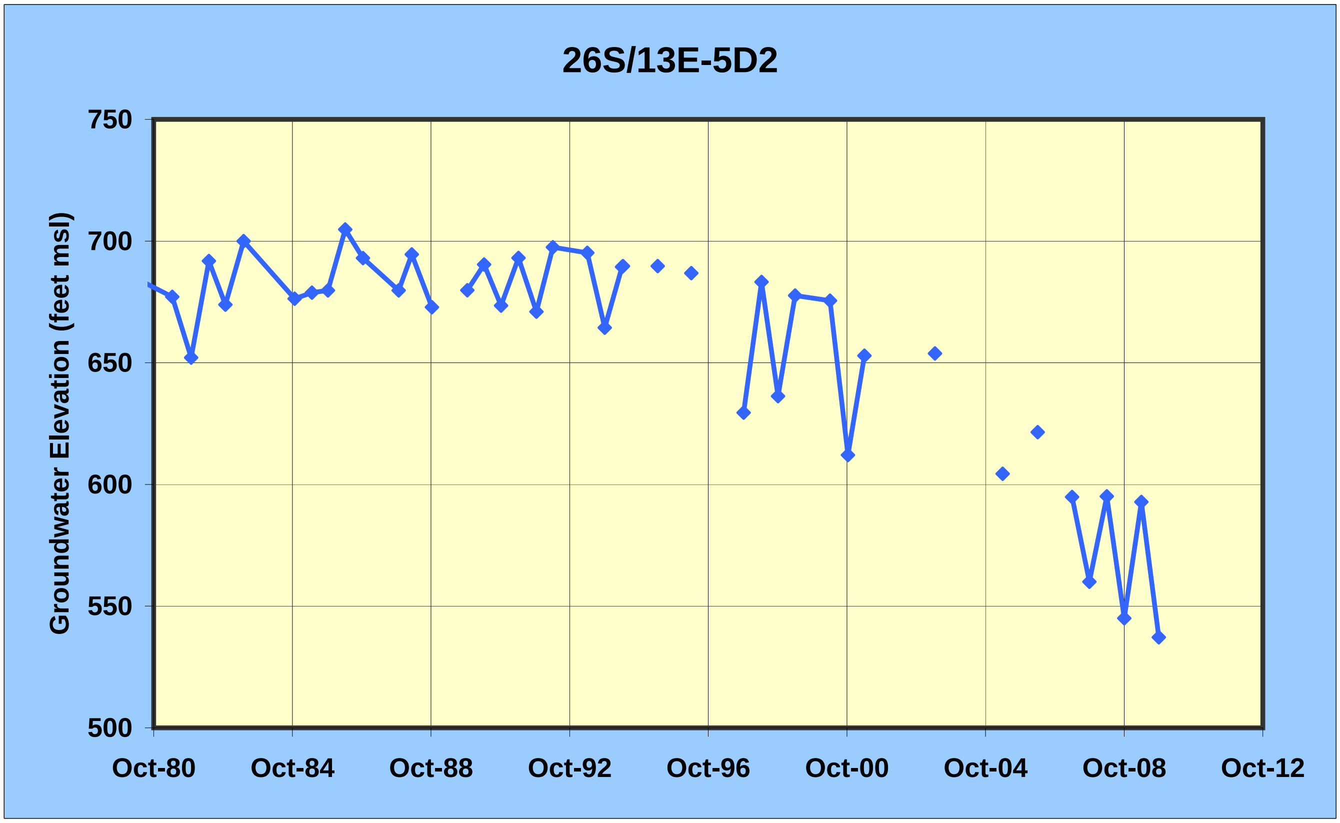


Figure 5. Annual Rainfall and Cumulative Departure of Annual Rainfall at Paso Robles, 1932-2009



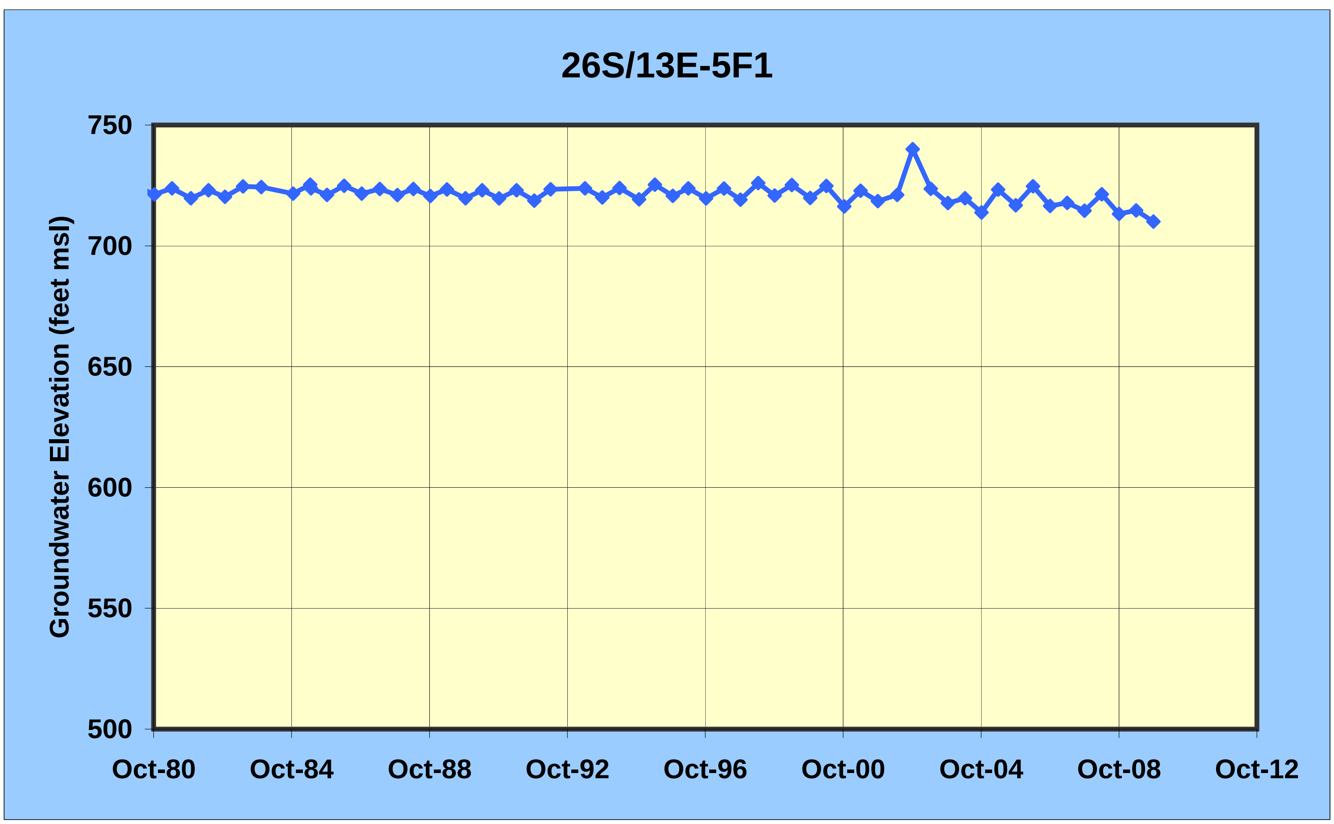
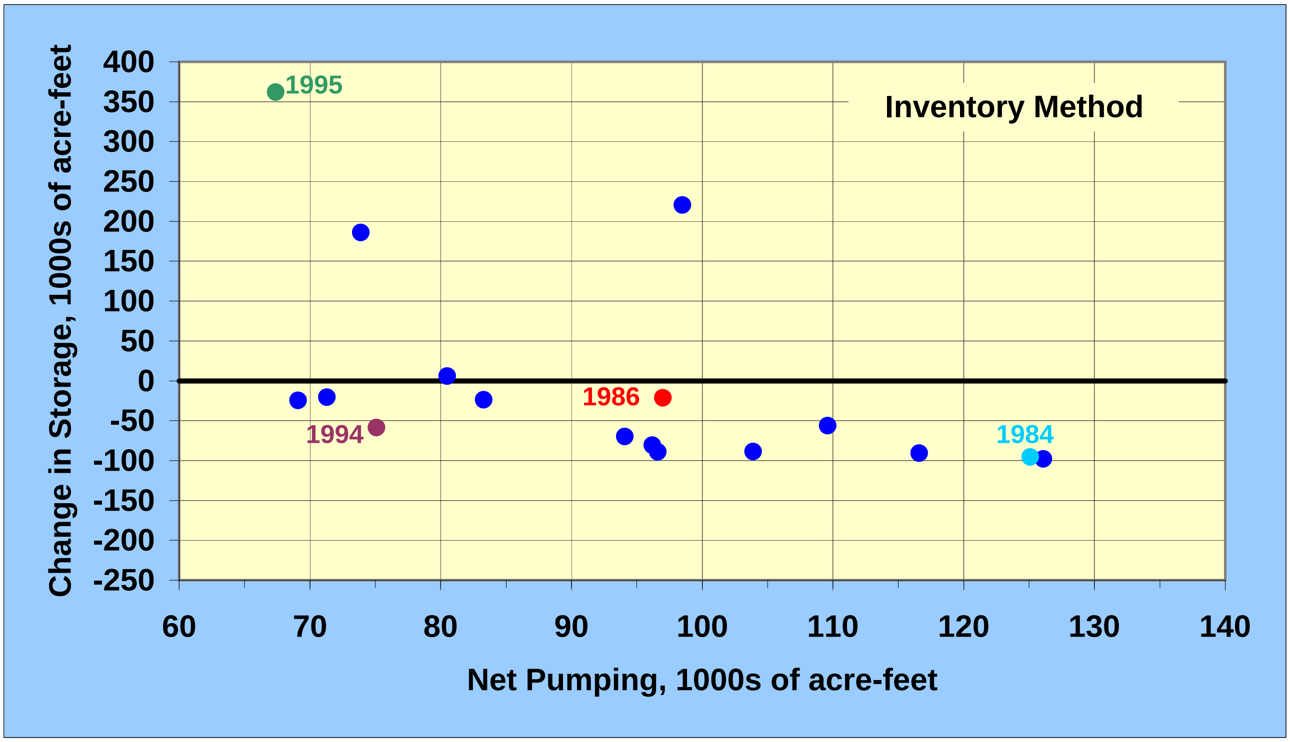


Figure 6. Hydrographs of Two Nearby Wells in the Estrella Subarea



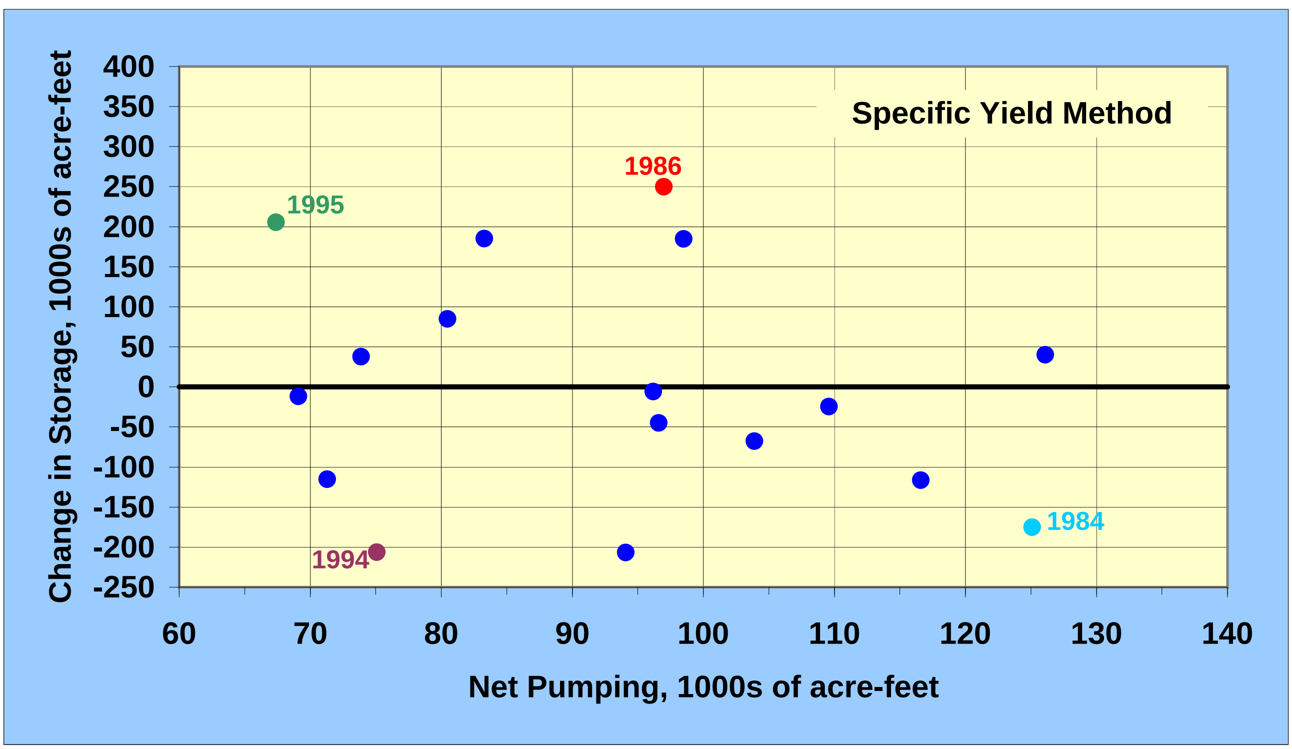


Figure 7. Relation of Annual Basin-Wide Change in Storage to Annual Groundwater Pumping, 1981-1997

Comments

TODD ENGINEERS

GROUNDWATER · WATER RESOURCES · HYDROGEOLOGY · ENVIRONMENTAL ENGINEERING

MEMORANDUM

Date: July 30, 2010

To: Christopher Alakel

From: Iris Priestaf, PhD, President

Re: Observations on Gus Yates, Peer Review of Paso Robles Groundwater Studies, June 29, 2010

I appreciate the opportunity to comment on Gus Yates' peer review. Yates' review has been thoughtful, has involved significant in-depth analysis, and has yielded useful findings and recommendations. While some findings may be subjective or not definitive, the peer review is useful in spotlighting critical uncertainties and pointing the way to improved water management. Our focus here is on application of Yates' memo to ongoing and future management.

1. Yates indicates that the hydrologic separation of the Atascadero subbasin is overstated.

The City has a unique position in straddling the Atascadero-Estrella boundary, with wells in each subarea. The degree of hydrologic separation of the Atascadero subbasin has been a long-standing issue, marked by determined advocacy by some parties for separation. Yates' opinion is an important reminder that the hydrogeologic evidence is insufficient and that future decisions (for example, regarding groundwater development, Nacimiento storage, and wastewater disposal) should not assume separation. If the Paso Robles basin is adjudicated in the future, this will be a primary issue.

Also important is Yates' emphasis on the need for all stakeholders to recognize a shared interest in maintaining groundwater supply throughout the basin. This unity of the basin needs to be recognized in County planning, including the Resource Capacity Study (which initially was focused on a limited area of concern) and Master Water Plan. It should also be reinforced during development of the Groundwater Management Plan (GMP), which by necessity is addressing the basin on a subarea basis. The City's active participation in management of the Atascadero and Estrella subareas can be an important unifying factor.

2. Yates indicates that the available water level data is a major source of uncertainty. He warns against use of groundwater level change maps to assess the overall state of the basin in terms of perennial yield and recommends analysis of numerous hydrographs.

I agree that groundwater level data should be considered with everyone's recognition of the limitations of the data and monitoring network. This is important because the City, County, and stakeholders are developing a GMP and planning on annual "state of the basin" reports. Such documents typically include change maps and key hydrographs that are selected to represent an area. While Yates has identified legitimate problems with groundwater level change maps, they are useful to show where declines are occurring. However, given the uneven distribution of monitoring wells (particularly in marginal recharge areas of the basin) and uncertain reliability of some deep monitoring wells as indicators of storage, they do not currently give us the whole picture. Hydrographs from selected wells also do not give the whole picture.

In the short term, the GMP and annual reports should be explicit about the data shortcomings and in the long term, <u>the monitoring network needs to be improved</u>. Consideration should be given to increasing the frequency of monitoring from semi-annual to quarterly, at least for the purposes of investigation. Yates mentioned the possibility of dedicated new monitoring well clusters; if given three choices, where would he put them? In regional terms and focusing on the groundwater level decline, it would be useful to bracket the area of decline with a well cluster in eastern Estrella near the Estrella River, central-western Estrella near the Salinas River, and near the Atascadero-Estrella boundary. An updated and improved numerical groundwater flow model would be useful in defining optimal locations for well cluster sites.

3. Yates indicates that stakeholders should focus on operable storage instead of total storage.

In the Paso Basin, total storage is not relevant to basin management. Operable storage is the groundwater storage located between minimum and maximum desirable water levels. Yates provides good reinforcement for the current GMP discussion of Basin Management Objectives (BMOs), which is focused on establishing those desirable water levels for each subarea.

4. Yates points out significant uncertainties in important water balance elements, including agricultural water consumption, rainfall recharge, subsurface inflow, and stream-aquifer interaction.

To varying degree, these have been the subject of discussion and in fact, vineyard water consumption is being investigated now by the University of California Cooperative Extension. (Yates' queries about vine spacing, canopy cover, deficit irrigation and salt leaching should be forwarded to UC.) While recognizing the benefits of focused studies and updates, I am concerned about a piecemeal approach to the water balance in the Paso Robles basin. Accordingly, I concur with Yates' recommendation to update the numerical groundwater model, including the water balance that is an integral part of the model. I have discussed the Paso Robles Basin numerical model with Dan Craig, Senior Hydrolgeologist/Modeler with Todd Engineers, who is an original MODFLOW modeler with more than 20 years experience. We recommend that the City, County and other stakeholders plan for update of the model within three years. This would make appropriate use of the UC Extension findings in the context of the entire water balance. The numerical model update should involve re-evaluation of rainfall recharge and subsurface inflow using soil-moisture balances, reconsideration and more robust simulation of stream-groundwater interactions, and a rigorous water-level trend analysis. The numerical model should be shifted to a monthly time step to better simulate the known dynamic conditions and to provide improved predictions of groundwater levels, in and outflow rates, and storage.

5. To support the model and water balance update, Yates provides recommendations for improving specific water balance estimates, including soil moisture balances to investigate rainfall recharge and subsurface inflow.

Soil moisture balances are a practical methodology to provide an independent check on these two inflows. Given the apparent importance of subsurface inflow from the South Gabilan to the Estrella subarea, application of a soil moisture balance to the South Gabilan tributary uplands and valley areas would be especially revealing. Increased understanding of the sources of Estrella subarea inflow has practical application in terms of monitoring (where should we expand the monitoring system) water balance (what is the sustainable yield), and management (where and how should we protect recharge areas).

6. Yates recommends application of the model to explore alternatives for the location and depth of well production.

This is a practical recommendation that could allow the City and other stakeholders to make better use of available groundwater resources.

I concur with Yates that improvements should be made to the groundwater monitoring program, elements of the water budget, and groundwater flow model. Improvement of the groundwater monitoring program is an important part of the ongoing GMP and should account for the recommendations provided by Yates in addition to those in the County's Data Enhancement Plan, and the Cleath & Associates' 2003 memorandum. A focused program improvement would address rainfall and stream flow in addition to groundwater; identify locations, methods, frequency of monitoring of both existing wells and potential new monitoring wells; describe data compilation, organization, and reporting; and discuss data evaluation methods (hydrographs, trend evaluations, storage calculation methodologies) to achieve monitoring program objectives.

The water balance/numerical model should be improved and updated within the next three years. It should have improved soil-moisture, recharge, and subsurface inflow rates, and it should be updated with current groundwater level data and well pumping rates. This will allow both an improved estimate of basin-wide sustainable yield, and refined assessments of local-scale flow and storage conditions around pumping centers and other critical areas.

FUGRO WEST, INC.

660 Clarion Court, Suite A
San Luis Obispo, California 93401
Tel: (805) 542-0797
Fax: (805) 542-9311

August 11, 2010

City of El Paso de Robles
1000 Spring Street
Paso Robles, California 93446

Attention: Mr. Christopher Alakel
Water Resources Manager

Comments on Peer Review of Paso Robles Groundwater Basin Studies

Dear Mr. Alakel:

Thank you very much for providing Fugro the opportunity to review the comments of Gus Yates relative to water supply, water balance, and groundwater management objectives for the Paso Robles Groundwater Basin. Mr. Yates makes many excellent points regarding how the accuracy of and uncertainty associated with estimates of components of recharge to the basin might be improved as well as how estimates of groundwater use and annual changes in the amounts of groundwater in the basin could be better determined. These are many of the same comments we have suggested over the past few years in support of an effort to update the Basin model.

Although it has not occurred to any significant degree in the past with regard to the Paso Robles Groundwater Basin, peer reviews are common in water supply studies. It is important to recognize that in virtually all peer reviews, certain aspects of the work under review can be criticized and made to appear flawed, should the reviewer be so inclined. Groundwater and hydrogeology studies involve many parameter estimates and assumptions because it is not physically and/or financially possible to measure all the components and variables needed in water balance and groundwater modeling studies. Thus, the peer reviewer can always say that a given assumption or parameter estimate is flawed and that another assumption or methodology should be used, even though there is no immediate means of measuring if the alternative would yield a better result. It is not difficult to find a hydrogeologist that will proffer an opinion that disagrees on the approach or methodologies used for a given component of a groundwater study due largely to the inability to directly measure that component. Alternative methodologies or results provided by the peer reviewer can usually be equally criticized by another peer reviewer.

It is important to recognize that the hydrogeologic understanding of a groundwater basin (including perennial yield) tends to evolve over time as more studies are completed and more data collected. Confidence in water balance estimates and groundwater models generally improves with additional data collection and data analysis; however, it is important to understand that there will always be some amount of uncertainty in water balance and groundwater modeling results

In light of the above, decision makers should recognize that while hydrogeologic consultants may strongly disagree with each other on certain components of the work/results, the best approach is to evaluate recommendations made in the past by Fugro and other consultants in the Basin in conjunction with some of the recommendations made by Mr. Yates to decide on how best to allocate the available financial resources to improve the hydrogeologic understanding of Paso Robles Groundwater Basin.

Again, we appreciate the opportunity to review the comments of Mr. Yates on our past work and the work of others and look forward to continuing our technical relationship with all stakeholders in the basin as future studies are conducted.

Sincerely,
FUGRO WEST, INC.

Paul A. Sorensen, PG, CHg
Principal Hydrogeologist

Christopher Alakel

From: Timothy Cleath [timothycleath@sbcglobal.net]

Sent: Tuesday, August 10, 2010 5:03 PM

To: Christopher Alakel

Cc: Paul Sorensen

Subject: Comments on Yates Peer Review of Paso Basin Updates

Mr. Alekal:

Mr. Sorensen of Fugro shared with me Gus Yates' peer review of the Paso Robles Groundwater Basin Updates. Cleath-Harris Geologists (formerly Cleath & Associates) participated in the earlier groundwater basin studies. There are some review comments that relate to the earlier work and the groundwater flow characterization based on the initial study.

Mr. Yates' statement that "Ironically, the hydrologic separation of the Atascadero subbasin from the main basin was overemphasized in previous studies." is an opinion that I do not share. There are geologic structural features that control the groundwater flow within the basin sediments underlying the alluvium. For further reference, the Dibblee geologic map and the DWR 1981 study "Water Quality in the Paso Robles Basin" show that there are folds as well as faults that have deformed the pre-Holocene sedimentary beds. As a result, groundwater flow into the main basin from the Atascadero sub-basin is restricted to the alluvial deposits where the Salinas River alluvium passes over the Rinconada fault. This restriction greatly impacts groundwater flow from the higher rainfall/runoff area recharge west of the Salinas River and it's importance should be recognized.

Improvements in groundwater monitoring are recommended by Gus Yates as well as every purveyor and active consultant. It has been recognized in every management study workshop and by County Public Works.   CHG has been working for the County recently on ways to incorporate more good data monitoring wells into the program that they have been doing for more than 40 years.

Cleath-Harris Geologists recognizes that this model can be a valuable tool and increasingly improved as it is modified for future work. Future efforts to utilize the groundwater model locally or regionally will do well to modify the model appropriately. Many of Mr. Yates' recommendations could be incorporated into those efforts.

Sincerely,
CLEATH-HARRIS GEOLOGISTS, INC.

Timothy S. Cleath, CHg #81
President