Long-term and Seasonal Trends of Well 01S08E08J01M in the San Joaquin Valley Basin.

Abstract

The invention of the deep-well turbine pump in the 1920's facilitated the extraction of large volumes of groundwater in the San Joaquin Valley but has led to declining water levels and subsidence (Narasimhan 1996). The purpose of this paper is to model the long-term and seasonal water level trends in a selected well, assess the role of surface water contribution, and forecast future levels based on these factors. Multivariate linear regression revealed that levels have declined an average of 0.92 feet per year and a one million acre-foot increase Water Year Index (WY Index) raised water level 0.72 feet over the 1955 to 1998 record period. If the overall trend continues, the linear model predicts that well level will have declined from 32 to –80 feet (above mean sea level) by 2050 (current EWS is about –20 feet). This report is preliminary and future studies should involve multiple wells, but it does highlight the need of effective groundwater monitoring and management in a state with no state-wide groundwater policy.

I. Introduction

Groundwater is of vital importance for irrigation and domestic water supplies, supplying 36% of the developed water in California in normal years and 60% in dry years (Department of Water Resources 1979). Intensive extraction in the San Joaquin Valley has been manifest in land subsidence and increased exploitation costs, urging assessment of trends in the estimated groundwater level surface (EWS) and the role of surface water contributions. I tested the following hypotheses:

$H_{O(1)}$: The is no discernable yearly trend in EWS.
$H_{A(1)}$: There is a discernable yearly trend in EWS.
$H_{O(2)}$: WY Index does not contribute to changes in EWS.
$H_{A(2)}$: WY Index does contribute to changes in EWS.
$H_{O(3)}$: There is no significant seasonal variation in EWS.
$H_{A(3)}$: There is significant seasonal variation in EWS.

II. Data & Methods

I obtained EWS, precipitation, snow pack, and WY Index data from the California Data Exchange Center for 1955 to 1998. One well from San Joaquin County with the longest period of record, 400 measurements, was selected. Attempts were made to analyze several wells at once, but inconsistencies in data recording made it difficult. I assumed the selected well was representative based on visual analysis of other well patterns. Initially, I attempted to incorporate rainfall data from Stockton and Fresno into the analysis, but found that *WY Index*, a measure of net river flow through the San Joaquin Valley Basin, best characterized direct precipitation and Central Valley Project (CVP) deliveries. We can assume that precipitation and CVP deliveries would significantly augment groundwater extraction in meeting the evapotranspirative needs of crops, the likely use for this water. Descriptive statistics for *WY Index* and *EWS* can be found in **Figure 1**.

The dependent response in the models was monthly mean *EWS* (above mean sea level), including several time lags ranging from one to 24 months. Initial regressors in the model included: total monthly rainfall at Stockton and Fresno, mountain snow depth measurements, WY Index, year, and month. *Year* incorporated the long-term trend into the model and can be seen in **Figure 3**. *Month* addressed seasonal variation, a source of serial correlation, and was incorporated into the model by transforming each month into a portion of an annual cosine and sine wave to account for the cyclical nature seen in **Figure 4**. I tried to incorporate several transformations up and down the ladder of powers but the identity was found to fit best.

III. Analysis and Results

First, I developed a linear multivariate regression model using stepwise regression to distill out the important and statistically significant regressors, yielding the equation found in **Equation 1**. This equation found several regressors significant and details are found in **Figure 2**. You will note that the 10-month lag of EWS fit the best. The coefficient of *Year* is –0.92 (95% Confidence Limits = -0.9888 to -0.8469), meaning that *EWS* has declined on average 0.92 feet per year throughout the period of record. Additionally, the *WY Index* coefficient was 0.73 (95% Confidence Limits = 0.2364 to 1.2197), meaning that a million acre-foot increase in *WY Index* was correlated to a one-foot rise in *EWS*. The coefficients of *Sinterm* and *Costerm* allow us to calculate seasonal groundwater fluctuations as the amplitude of the wave and equal to 4.6 feet per year (95% Confidence Limits = 3.0 to 5.9). The adjusted r-squared value of this whole model is 0.64 (Probability > F = < 0.0001) .

$$EWS(lag10) = 1792.8 - 0.918Year - 3.321Costerm + 2.946Sinterm + 0.728WYIndex$$

Equation 1: Linear Multivariate Regression Model of Groundwater Level Change. *EWS(lag10)* is a ten-month lag of the estimated water level surface in the well. *WY Index* is an estimation of the water year based on flow in the San Joaquin River Valley. *Costerm* and *Sinterm* are estimates of seasonal variability in water level.

Second, I used an autoregressive (AR) model with *WY Index* as shown in **Equation 2.** This model calculates the autoregressive coefficients *Phi* and *Mu*, and calculated 1.195 coefficient of *WY Index* (Standard Error = 0.214). This model suggests a larger contribution by *WY Index* to *EWS*. Details can be seen in **Figure 2**.

$$Mu + a * WYIndex + Phi \begin{Bmatrix} EWSi - 10 - Mu, & if\ EWSi - 1 != ? \\ ARModeli - 10 - Mu, & otherwise \end{Bmatrix}$$

Equation 2: Autoregressive Model . Mu and Phi are the autoregressive coefficients. The coefficient of the water year index (WYIndex) is "a".

Third, I used the equations from both models to forecast *EWS* to year 2050. To accomplish this I needed to generate data for *Year*, *Costerm*, *Sinterm*, and *WY Index*. *Year*, *Costerm*, and *Sinterm* are simply functions of time which is known. To predict *WY Index*, I used Monte Carlo methods to simulate future years based on the previous period of record from 1905 to 1998 in this case. The forecasted graphs of the linear model and the AR model are shown in **Figure 5**. The linear model decays linearly out to 2050, ending at about –82 feet. The AR model by design tamps down to the mean of observed EWS measurements of about –22 feet.

IV. Key Findings and Discussion

- $H_{O(1)}$ was rejected and $H_{A(1)}$ accepted as a reasonable theory based on findings of a statistically significant change in groundwater level of –0.92 feet per year.
- $H_{O(2)}$ was rejected and $H_{A(2)}$ accepted based on findings of a statistically significant contribution of *WY Index* to *EWS* of 0.73 feet per million acre-feet per year (1.2 feet per million acre-feet in the case of the AR model).
- $H_{O(3)}$ was rejected and $H_{A(3)}$ accepted based on findings of a statistically significant average seasonal variation of 4.6 feet in a given year.
- The linear regression model predicts continued declines in groundwater level to 2050 to –82 feet at current extraction rates and *WY Index* patterns.

Although variations in the WY Index, year, and season play a significant role in these models, visual examination revealed these regressors alone were not able to account for all of the variation in the response. Intuitively, rates of withdrawl vary in response to factors absent here. Nonetheless, the State of California has designated many groundwater basins in the San Joaquin Valley as critically overdrafted, meriting studies into the long-term trends of water level change and strategies to efficiently manage groundwater (Department of Water Resources 1998).

V. Appendix

Descriptive Statistics

	WY Index (millions of acre-feet)	**EWS** (feet above mean sea level)
75% Quartile	4.13	-15.7
Median	3.21	-23.35
25% Quartile	2.3	-30.98
Upper 95% Mean	3.43	-20.48
Mean	3.35	-21.72
Lower 95% Mean	3.27	-22.96
Standard Error	0.04	0.63
N	1128	408

WY Index is based upon river flow measurements in the San Joaquin Valley Basin.

Figure 1: Descriptive statistics for WY Index and EWS.

Model Results

Multivariate Linear Regression Model

	Estimate	**Std Error**	**t ratio**	**Prob>|t|**	**95% Confidence Interval** **Lower**	**Upper**
Intercept	1792.8	71.53	25.06	<.0001		
Year	-0.918	0.036	-25.42	<.0001	-0.9888	-0.8469
WYIndex	0.728	0.25	2.91	0.0038	0.2364	1.2197
Costerm	-3.321	0.522	-6.36	<.0001	-4.3474	-2.2945
Sinterm	2.946	0.545	5.4	<.0001	1.8742	4.0177
Adjusted R-squared	0.643					
Model Probability > F	<.0001					

Autoregressive Model

	Estimate	**SE**	**DF**	**t ratio**	**Prob>|t|**
Mu	48.69	50.959	403	0.955474	0.3399
Phi	1.047	0.0336	403	31.16071	0.0000
a (WYIndex coefficient)	1.195	0.214	403	5.584112	0.0000

Figure 2: Details of the Linear Multivariate Regression Model and the Autoregressive Model.

Graph of EWS by Year

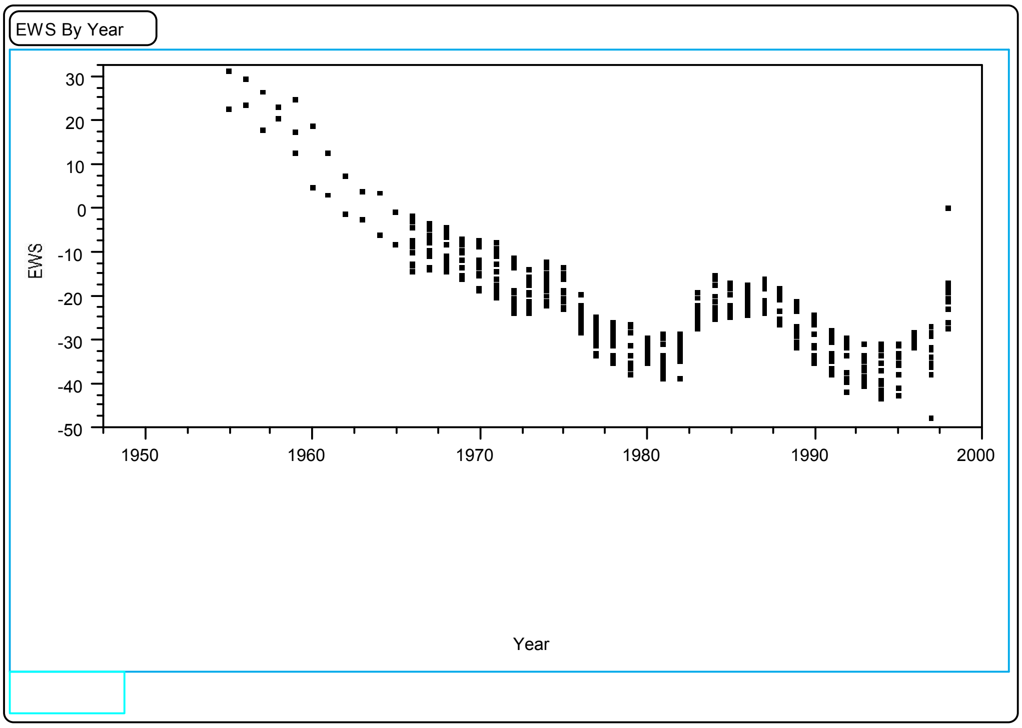


Figure 3: Graph of groundwater level change through time.

Graph of EWS by Month

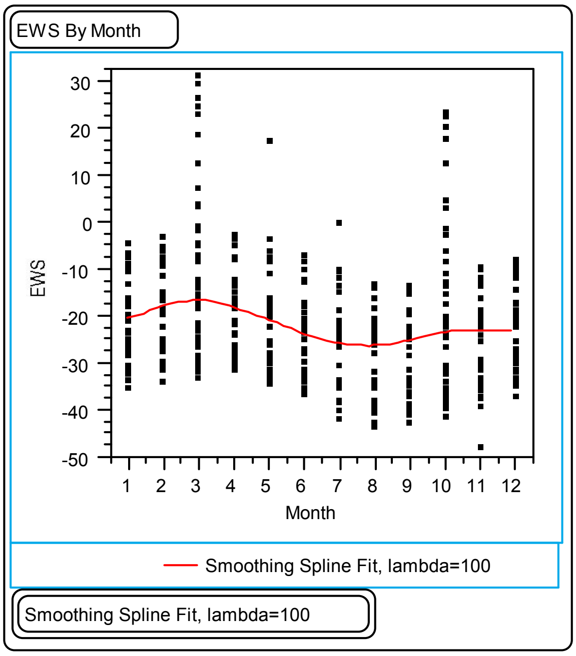
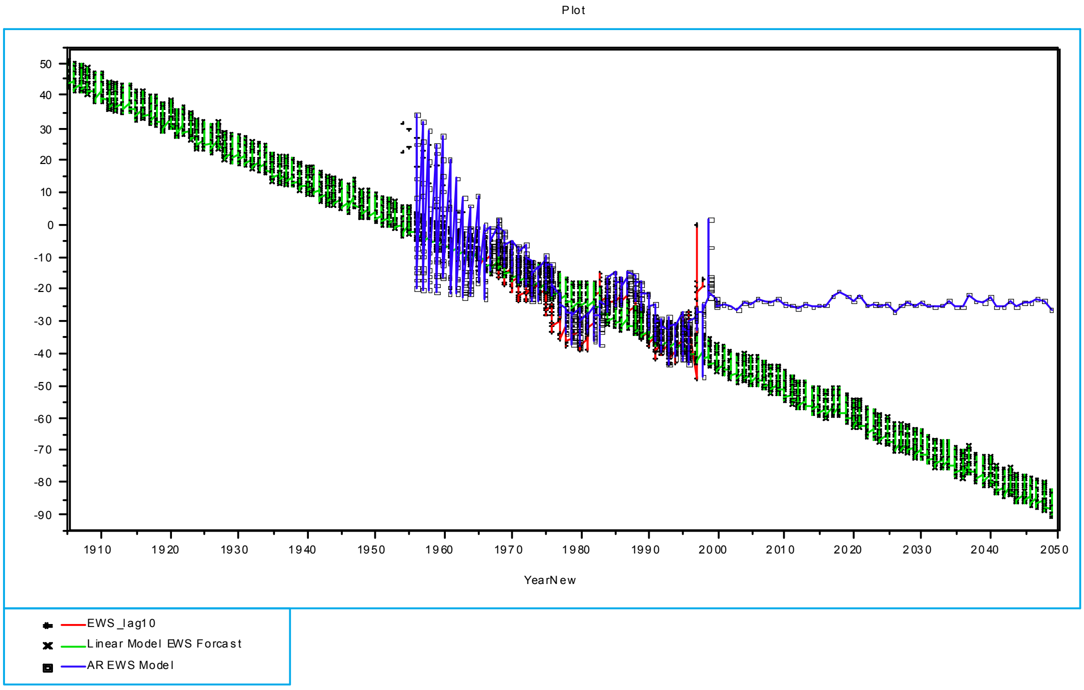


Figure 4: Graph of seasonal groundwater level variation.

Graph of Observed EWS, the Linear Model, and the Autoregressive Model



VI. References

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