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Comparison Multiple Linear Regression and MODFLOW Simulations of Constant Pumping of Wells Exempt from Turn-Off Provisions of the Water Agreement

Staff Report

Introduction

Several Inyo County reports have pointed out deficiencies in the Green Book and have recommended an effort be undertaken to develop a replacement strategy to manage groundwater pumping. Foremost among the conceptual weaknesses in the Green Book is attempting to protect phreatophytic vegetation by prescribing pumping amounts and locations without considering the changes in depth to water table (DTW) caused by pumping. Several studies have been conducted by Inyo County and Los Angeles to develop groundwater models to assess alternative groundwater management scenarios to guide future improvements in management.

The Green Book exempts certain wells from the turn-on/turn-off provisions (On/Off) of the Inyo/Los Angeles Water Agreement. These wells provide a consistent water supply for specific uses or were judged to have a negligible effect on the water table under groundwater-dependent vegetation. Pumping management under the Drought Recovery Policy retained this distinction, and the majority of pumped water since 1991 has been from exempt wells (Harrington, 2005). Exempt well pumping averaged approximately 54,945 ac-ft yr^{-1} from 1991-2004, approximately 10,500 ac-ft yr^{-1} less than exempt well capacity (65,476 ac-ft yr^{-1}). Identifying the appropriate provisions of the Green Book that need revision requires that exempt well pumping and pumping for export be evaluated individually and cumulatively.

Steinwand and Harrington (2003) completed simulations using multiple linear regression (MLR) models to estimate the water table depth at permanent On/Off monitoring sites under steady-state conditions of average runoff and constant pumping. Pumping in the model simulations approximated minimum pumping from wells exempt for uses dependant on pumping (approximately 45,600 ac-ft yr^{-1}). The simulations did not include exempt well pumping in Lone Pine (no available MLR models) or pumping from wells exempt for no impact. That study concluded that the water level would be below the target depths based on root zone depth and soil water observations at about half the permanent monitoring sites even at relatively low rates of constant pumping. These results suggested that water levels may infrequently attain depths necessary to wet the root zone of groundwater-dependent vegetation in some areas. The permanent monitoring sites were purposefully located near pumping wells, and the steady-state MLR model results of Steinwand and Harrington (2003) are only point-scale predictions. A comparison with numerical model results is necessary to determine the spatial extent of exempt well pumping effects. Two modeling efforts in the Owens Valley that examined the effects of similar quantities of pumping are discussed below.

Danskin (1998) developed a MODFLOW numerical groundwater model for the Owens Valley as part of a cooperative study by Inyo County and Los Angeles. He completed steady state simulations of several pumping alternatives and concluded that water levels would approximate the 1984 levels with about 70,000 ac-ft yr^{-1} of constant pumping. Danskin's valley-wide pumping total was similar to the current exempt well pumping capacity, but the distribution of pumping among wellfields was substantially different from the actual distribution of exempt well capacity (Harrington, 2005). Danskin's steady-state simulation assigned greater pumping in Laws, Bishop, Taboose-Aberdeen, and Symmes-Shepherd wellfields and less pumping in Big Pine, Thibaut-Sawmill, Independence-Oak, and Lone Pine wellfields. Danskin's general conclusion that drawdown will be centered on concentrations of pumping is probably correct, but the location and magnitude of drawdown in his study may not correspond with drawdown from current exempt well management.

Harrington (2005) examined the effects of exempt well pumping using the MODFLOW model and stochastic time series methods. Harrington's study suggested that average water levels will be at or a few feet below the baseline (1985-87) depth to water where exempt well pumping occurred during the baseline period. Areas such as Independence and Symmes-Shepherd wellfields where exempt well pumping didn't occur during baseline would have water tables well below baseline. He also concluded that some wells granted exemptions for no impact may affect groundwater dependent vegetation.

Wellfield pumping and target depths for comparison in Harrington's MODFLOW analysis were not equivalent to previous MLR model analysis by Steinwand

and Harrington (2003), and the results of the two studies are not directly comparable. The objective of this study was to complete MLR model simulations constructed to allow valid comparison with MODFLOW modeling by Harrington (2005) to examine the effects of constant exempt well pumping.

Methods

This analysis relied on MLR models and Monte Carlo methods to assess the multiple year effects of constant pumping of exempt wells (Harrington, 2001). Models for indicator wells rely on the observed relationship between runoff or McNally canal diversions, pumping, and previous water levels to forecast future water levels. Predictions at monitoring sites were prepared using regression models of the water levels at a monitoring site and a nearby indicator well (Steinwand and Harrington, 2003). All MLR and indicator/monitoring site regression models were updated using data through the 2003-04 runoff year. Predictions included randomly generated error values (SEY) to preserve model variance. It was computationally impractical to resample the model coefficients using Monte Carlo methods as done in previous analyses to quantify that source of error. Generally, the error in regression coefficients was less than model error (Harrington, 2001), and it was ignored in this analysis.

The modeling strategy adopted was to generate a sufficiently long time series of runoff values to feed the MLR models to construct a sample of predicted water levels for which the statistical properties can be determined (Harrington, 2001). Length of the time series was 6000 years. Pumping was held constant at the levels in Table 1. This model simulation is not a prediction of water levels six thousand years in the future, rather the

Table 1. Pumping rates for MLR and MODFLOW stochastic simulations from Table 3 of Harrington (2005).

Wellfield	Constant pumping rate (af yr^{-1})
Laws	3324
Big Pine	26162
Taboose-Aberdeen	2096
Independence-Oak	17052
Symmes-Shepherd	1445

predicted water level each year of the time series was compared to a target water table elevation to determine the percent of time above the target and the typical period between water table recovery to the target.

The average of the 1985-87 April water level (baseline DTW) was chosen as the target depth for comparison with predicted water levels. Some wellfields experienced pumping for export during the baseline period, especially in 1986, and the baseline presumably represents impacted water levels. The primary reason for selecting baseline DTW as the target was to be consistent with the MODFLOW analysis (Harrington, 2005). The value is familiar and simple to calculate, but reliance on this value has disadvantages as well. Drawbacks of the 1985-87 baseline DTW were explained in Steinwand and Harrington (2003). Most monitoring site wells were installed after the baseline period. For these wells, the regression models and measurements at indicator wells were used to estimate 1985-87 water levels. Indicator well 572T was installed after April 1985, and the baseline for BP1 only included 1986-87 water levels.

The MLR models for the Laws wellfield include diversions into the McNally canals as the variable related to recharge. Danskin (1998) estimated canal seepage recharge based on measured and estimated loss rates, channel length, and average period

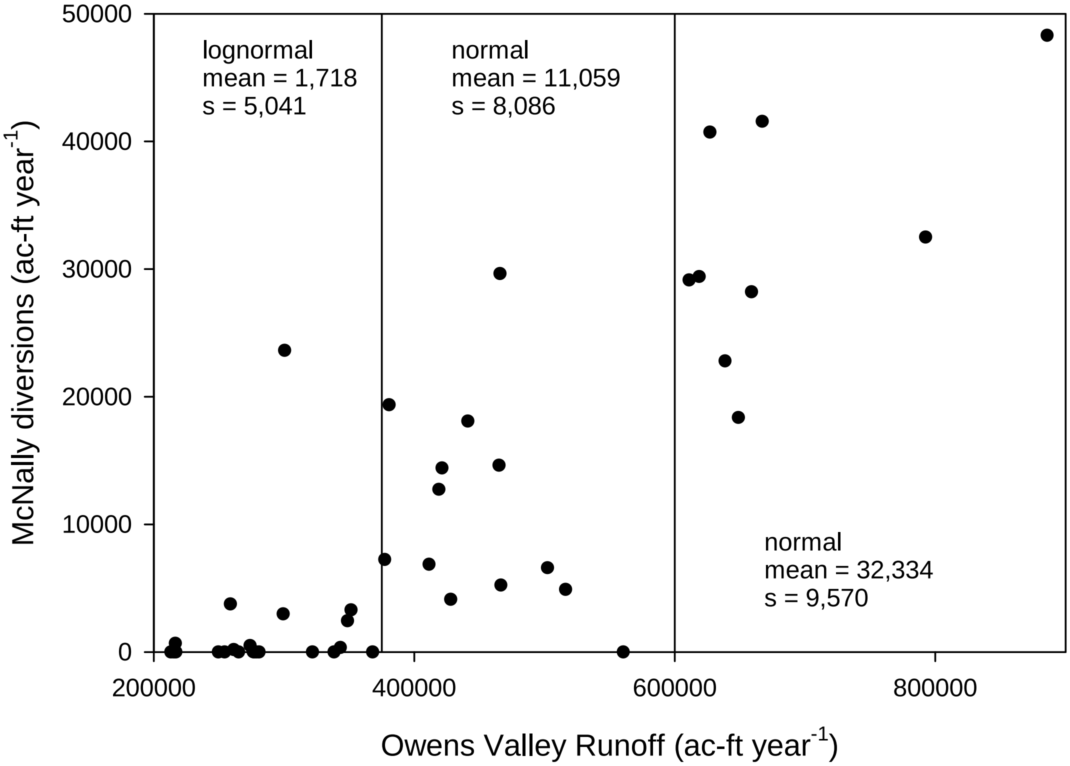

Figure 1. Total McNally diversions (1960-2003 runoff years) as a function of OVRO. The period was chosen to correspond with the MODFLOW model. The type and statistical parameters of distribution functions assigned to each bin are also shown. McNally runoff was set to zero when OVRO was less than 200,000 ac-ft.

of operation. Harrington's model retained Danskin's recharge estimates for Laws. The MODFLOW model included 5,325 ac-ft of recharge annually from the McNally canals. Recharge quantities were also included for portions of Laws operations, E/M project infiltration, and spreading. The quantity of recharge in the MODFLOW model is not directly convertible into a quantity of McNally canal diversions required by the MLR models. The values should be correlated, however, because the various recharge sources are primarily supplied from the Owens River via the McNally canals.

McNally canal diversions are related to Owens Valley runoff (OVRO), with generally greater diversions during years of high runoff when aqueduct capacity becomes limiting (Figure 1). Because operational and environmental conditions vary, the relationship is not precise. For this analysis, water levels in Laws were simulated by randomly drawing a value for McNally diversions from distributions developed for a specific range of OVRO (Figure 1). McNally diversions were set to zero if OVRO <200,000 ac-ft yr^{-1}. The bin between 200,000 ac-ft yr^{-1} and 375,000 ac-ft yr^{-1} was approximated with a lognormal distribution; the other bins were approximately normally distributed. Samples drawn randomly from distributions could be negative or exceed the maximum diversion since 1960, 50,000 ac-ft yr^{-1}. Values outside that range were automatically reset to zero or 50,000 ac-ft yr^{-1}.

MLR model runs were initiated using April 2005 depth to water measurements. Each year thereafter utilized constant pumping, randomly selected OVRO, and the predicted water level from the previous year. The first interval until the water level exceeded baseline was excluded from the summary statistics to avoid model initialization effects. Similarly, the last interval was excluded to avoid assigning a value to an open ended interval. The final length of the simulated time series varied, but it was greater than 5000 years in all cases.

Results and Discussion

Results of the two modeling approaches generally agreed with a few informative exceptions. Both analyses suggested that water levels in most of the Big Pine, Independence-Oak, and Symmes-Shepherd wellfields would be below baseline on

Table 2. Mean water table elevation and DTW from soil surface of time series hydrograph for wells at permanent monitoring sites and indicator wells. Results from Harrington (2005) are included for comparison.

Test well, Mon. site	1985-87 Mean elevation	MLR Mean elevation	Mean minus Baseline, MLR	Mean minus Baseline, MODFLOW
	(ft amsl)	(ft amsl)	ft	ft
795T, L1	4119.81	4118.75	-1.06	9.86
493T	4115.73	4114.68	-1.05	
V001G, L2	4103.78	4103.36	-0.42	7.77
436T	4099.52	4098.83	-0.69	
574T, L3	4074.72	4073.92	-0.80	16.3
490T	4065.23	4064.51	-0.72	
798T, BP1	3938.30	3937.73	-0.57	-4.51
572T	3932.40	3931.63	-0.77	
799T, BP2	3888.58	3886.75	-1.83	-1.10
469T	3904.03	3902.12	-1.91	
567T, BP3	3875.50	3870.10	-5.40	-2.35
425T	3866.40	3861.21	-5.19	
800T, BP4	3862.64	3857.96	-4.68	-0.68
419T, TA1	3828.93	3833.75	4.82	4.70
505T, TA3	3816.93	3820.36	3.43	2.92
586T, TA4	3828.13	3831.81	3.68	5.26
801T, TA5	3829.28	3828.88	-0.41	1.09
502T	3837.23	3836.27	-0.96	
803T, TA6	3816.54	3818.99	2.45	-0.98
417T	3816.93	3819.69	2.76	
809T, IO1	3834.83	3826.59	-8.24	-2.16
412T	3811.87	3807.62	-4.25	
V009G, SS1	3820.50	3818.36	-2.14	-3.36
447T	3826.13	3823.89	-2.24	
646T, SS2	3822.53	3819.39	-3.14	-7.59
811T, SS4	3822.86	3823.74	0.88	-2.12
401T	3821.73	3825.02	3.29	

average. The average DTW was several feet below baseline for BP2, BP3, IO1, SS1, and SS2 (Table 2). Both modeling approaches predicted water levels would be at or above baseline for monitoring sites in the Taboose-Aberdeen wellfield with the exceptions discussed below. This was consistent with the distribution of exempt well pumping in these wellfields.

MLR models predicted higher water table elevations than modeled by the MODFLOW analysis at TA6, SS1, and SS2. This observation was consistent with the predicted water table elevations from exempt well pumping centered on the Blackrock and Independence areas extending across the arbitrary wellfield boundaries. The MLR models do not include pumping from neighboring wellfields, but the regression models implicitly include the historic impacts at a site from pumping in the neighboring wellfield. Effects from pumping in a neighboring wellfield would add to the noise in the MLR. Alternatively, neighboring wellfield pumping would not degrade the MLR model statistics if pumping from the two wellfields were correlated, pumping in the neighboring wellfield were constant, or if the effect of water level was small. The exempt well scenario modeled in this study had less than average historic pumping in TA and SS wellfields, and the locus of pumping was shifted away from TA6 and SS1 and SS2. The neighboring wellfields (TS and IO) had similar or increased pumping in the exempt well simulations compared with historic pumping. It is plausible that the combination of these characteristics would result in systematic underestimation of pumping effects in the MLR models compared with the MODFLOW results. If deemed necessary, the pumping variable in the MLR models for these sites could easily be revised although the statistics of the existing models suggest the improvement in prediction capability would be small.

Large differences between the model results were observed for the Laws wellfield. The MLR results predicted water levels will on average be deeper than baseline while the MODFLOW model predicted average water levels several feet above baseline. The difference is likely due to the different accounting for recharge between

Table 3. Comparison of MLR and MODFLOW results for the proportion of time the water table is above baseline and the median duration of the period water tables were below baseline in the simulated time series.

Site	MLR years above baseline	MODFLOW years above baseline	MLR median duration of periods below baseline	MODFLOW median duration of periods below baseline
	%	%	(years)	(years)
L1	38	100	3	–––
L2	40	100	2	–––
L3	33	100	3	–––
BP1	39	7	2	6
BP2	7	12	14	9
BP3	5	15	17	7
BP4	5	6	21	6
TA1	97	100	1	––––
TA3	77	98	2	2
TA4	97	100	1	––––
TA5	36	100	3	––––
TA6	72	36	2	4
IO1	5	0	15	>50
SS1	32	0	4	>50
SS2	23	0	4	>50
SS4	37	19	3	6

the models. Simulated McNally canal inflow for the MLR analysis approximated the average inflow (approximately 10,000 ac-ft yr^{-1} since 1970), but evidently the method did not replicate MODFLOW estimates of recharge. The MODFLOW estimates of recharge may approximate the long term average, but the model may underestimate water levels during the baseline because of high diversions immediately preceding and during the baseline period. Hence the MODFLOW results suggest water levels usually above baseline while the MLR results suggest fewer years with water levels higher than baseline. This hypothesis should be investigated to determine whether this is a needed improvement in the MODFLOW model.

The median duration of periods with water table below baseline were consistent with interpretations based on DTW comparisons (Table 3). The modeling approaches provided similar conclusions for Big Pine, Taboose-Aberdeen, Independence-Oak, and Symmes-Shepherd wellfields. The models produced differing results in Laws, the southern portion of Taboose-Aberdeen and northern portion of Symmes-Shepherd wellfields. In both modeling exercises, the fewer years with water levels above baseline, the longer the period between recovery to baseline levels. This observation seems a truism, but it is actually a result of the relatively weak autocorrelation of the OVRO time series (Harrington, 2001). This result would not be expected, for example, if pumping were periodically increased in the time series to simulate higher levels of pumping.

Conclusions

MLR analyses were completed to allow valid comparison with MODFLOW analyses to refine the assessment of impacts from exempt well pumping. In both modeling approaches, areas of greater constant pumping generally had water levels below that experienced in the baseline period (1985-87). Areas of potential concern were centered in the Big Pine, Independence-Oak, and northern Symmes-Shepherd wellfields. The relatively low exempt well pumping capacity of the Taboose-Aberdeen wellfield allowed water levels even with average runoff to exceed baseline. Discrepancies between the model results for Laws, southern TA and possibly the SS wellfields suggested possible avenues to improve the pumping variable in MLR models (TA6, SS1/SS2) and the accounting of recharge in the MODFLOW model (Laws).

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