Development of Multiple Linear Regression Models for Prediction of Water Table Fluctuations

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Introduction.

Despite the ongoing development of numerical modeling tools, multiple linear regression models (MLRM) remain the most reliable and relied-upon tool for prediction of water table fluctuations in the operational implementation of the County of Inyo/City of Los Angeles Long Term Groundwater Management Plan. The County made extensive use of the MLRM during the recent disputes over the operation of the McNally canals and the Annual Operations Plan for 2001-2002, and will likely continue rely on them in the future; therefore, it is desirable to update, reevaluate, extend, and improve the MLRM.

The theory and development of the MLRM is described in Harrington (1998; 1999) and references therein. The general strategy of the MLRM is to use regional groundwater pumping and runoff as driving variables to predict fluctuations in the water table elevation. One of the primary questions regarding the MLRM is: what are the appropriate driving variables to use in the model? Pumping and runoff must be spatially and temporally averaged prior to being input into the model, and the optimum choice of averaging scale is not obvious at the outset of model development. For example, the first regression MLRM scheme applied to Owens Valley groundwater pumping utilized valley-wide pumping as a driving variable (Williams, 1978), whereas the current MLRM use wellfield pumping. In general, the more localized the input variables are, the greater the effort required to assemble the data and implement the model; therefore the optimum scale for averaging the input variable is the largest scale that does not degrade model performance. For example, splitting the runoff variable up so that each MLRM used runoff in a few specific streams near the indicator well would require considerably greater data assembly effort for little or no additional model performance, because of the very high correlation between flow in any single stream and Owens Valley runoff as a whole. Conversely, the MLRM can be
expected to perform better if there is a real and direct hydrological linkage between the indicator well and the driving variables. Clearly, if spatial averaging scales are too large, processes contributing to the averaged driving variable do not affect fluctuations in the indicator well.

The objectives of this report are to explore alternative renditions of the driving variables in the MLRM, develop additional indicator wells to extend the spatial coverage of the set of indicator wells, and explore alternatives for assessing the accuracy of the MLRM. This report documents several recent efforts the County Water Department has made to improve and extend the MLRM. These efforts specifically are:

1. Use of inflows into the McNally canals as a predictor variable in Laws area MLRM.
2. Implementation and comparison of various methods of assessing uncertainty in MLRM predictions.
4. Development of MLRM for wells useful for predicting water table fluctuations at permanent vegetation monitoring sites.

Each of these efforts is somewhat independent of the others, therefore each is described in a separate section.

Use of inflows into McNally canals as a predictor variable in Laws models.

Owens Valley runoff has been used as a predictor variable in the MLRM because it correlates well with recharge from stream channels and surface water conveyances, direct recharge from precipitation, artificial recharge operations, and ungaged mountain front recharge. Owens Valley runoff is more easily measured than recharge, so it serves as a spatially lumped variable that captures the deviation from normal that can be expected in recharge for a given year. The Laws wellfield is an exception to this reasoning because of its location east of the Owens River at the foot of the White Mountains. Other LADWP wellfields in the Owens Valley lie on or at the toe of alluvial fans issuing from the Sierra Nevada, and most recharge to those wellfields comes from snowmelt runoff recharging through stream channels or on the range-front slopes. In contrast, Laws lies on the other side of valley from the snowmelt recharge sources from the Sierra Nevada, and due to the rain shadow of the Sierra Nevada, the White Mountains receive a small fraction of the seasonal snow fall that the Sierra Nevada receives. Therefore, the natural recharge mechanisms that act in other LADWP wellfields are not as effective in the Laws area. The comparatively low amount of natural recharge on the east side of the valley is documented in the Green Book, Appendix B, Tables 1, 3, 4, and 5. The primary sources of recharge for the Laws wellfield are seepage losses from the canal system, percolating irrigation, and artificial recharge due to water spreading activities conducted by LADWP, rather than through natural recharge (Jorat, 2001). Thus motivated, the work presented here sought to determine whether there is another variable than Owens Valley runoff that could be used to better represent recharge in the Laws area.

The largest water conveyances in the Laws area are the Upper and Lower McNally canals, which are used to supply water from the Owens River to spreading areas and irrigated land in the Laws, and to
convey pumped water from production wells to irrigated land and mitigation projects. The canals undergo substantial channel losses when operated, and their operation is often associated with other recharge generating activities (Green Book, 1990; Danskin, 1998); therefore, their flows are likely to be well correlated to recharge and water table fluctuations in the Laws area.

The data used to develop MLRM for the Laws area using the McNally canals are given in Appendix 1. Diversions into the McNally canals from the Owens River are correlated to Owens Valley runoff due to LADWP's historical operational tendency to use of the canals for conveying surface water to Laws area irrigation leases and water spreading basins during non-drought conditions (Figure 1). From a statistical point of view, it is clear that use of either Owens Valley runoff or diversions into the McNally canals as driving variables in MLRM would produce viable models; however, two considerations suggest that diversions into the McNally canals are preferable to Owens Valley runoff. First, as discussed above, the McNally canals have a more direct physical relationship to Laws area recharge mechanisms than Owens Valley runoff. Second, if the relationship between runoff and canal diversions depicted in Figure 1 should change (e.g., if LADWP were to decide to diminish its use of the canals regardless of runoff conditions), then the correlation between Owens Valley runoff and Laws area recharge would no longer be as it has been in the past, rendering the MLRM invalid. In the event that operational management of the McNally canals should change, it is desirable that the driving variables used in the MLRM be causally related to processes effecting water table fluctuations.

![Figure 1. Owens Valley percent of normal runoff plotted against diversions into the McNally canals from the Owens River.](image-url)
Table 1 compares the statistics for regressions performed using Owens Valley runoff and diversions from the Owens River into the McNally canals for each Laws area indicator well. Appendix 1 contains the data. In every case, the coefficient of determination is higher and the standard error lower when diversions into the canals is used as the driving variable, which indicates that the MLRM have more predictive power when implemented with canal diversions as the driving variable related to recharge. Table 1 reveals a modest, but consistent, improvement in the regression statistics when canal diversions are used. If management decisions were to further diminish the correlation between runoff and canal operations, the improvement in modeling capability obtained through use of canal diversions will likely be greater than that shown in Table 1. Regression coefficients for the MLRM based on McNally canal diversions are given in Table 2.

Table 1. Comparison of regression statistics ($R^2$, coefficient of determination; SE, standard error of the regression) for Laws wellfield MLRM using Owens Valley runoff and diversions from the Owens River into the McNally canals.

<table>
<thead>
<tr>
<th>Well</th>
<th>N</th>
<th>$R^2$</th>
<th>SE</th>
<th>$R^2$</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>107T</td>
<td>17</td>
<td>0.894</td>
<td>2.419</td>
<td>0.942</td>
<td>1.786</td>
</tr>
<tr>
<td>436T</td>
<td>22</td>
<td>0.880</td>
<td>1.454</td>
<td>0.946</td>
<td>0.972</td>
</tr>
<tr>
<td>438T</td>
<td>25</td>
<td>0.799</td>
<td>1.951</td>
<td>0.880</td>
<td>1.508</td>
</tr>
<tr>
<td>490T</td>
<td>25</td>
<td>0.890</td>
<td>1.216</td>
<td>0.936</td>
<td>0.928</td>
</tr>
<tr>
<td>492T</td>
<td>20</td>
<td>0.901</td>
<td>3.417</td>
<td>0.938</td>
<td>2.693</td>
</tr>
<tr>
<td>493T</td>
<td>24</td>
<td>0.896</td>
<td>4.243</td>
<td>0.949</td>
<td>2.964</td>
</tr>
</tbody>
</table>

Table 2. Regression coefficients for MLRM for Laws area wells using diversions from Owens River into the McNally canals as driving variable (Appendix 1).

<table>
<thead>
<tr>
<th>Well</th>
<th>Intercept</th>
<th>Initial water level</th>
<th>Laws pumping</th>
<th>Diversions from Owens River into McNally canals</th>
</tr>
</thead>
<tbody>
<tr>
<td>107T</td>
<td>1940.7</td>
<td>0.5299</td>
<td>-0.0003347</td>
<td>0.00024434</td>
</tr>
<tr>
<td>436T</td>
<td>1813.3</td>
<td>0.5573</td>
<td>-0.0001308</td>
<td>0.00014643</td>
</tr>
<tr>
<td>438T</td>
<td>1929.0</td>
<td>0.5327</td>
<td>-0.0001166</td>
<td>0.00014452</td>
</tr>
<tr>
<td>490T</td>
<td>1065.0</td>
<td>0.7377</td>
<td>-0.0000505</td>
<td>0.00012906</td>
</tr>
<tr>
<td>492T</td>
<td>2045.1</td>
<td>0.5010</td>
<td>-0.0005186</td>
<td>0.00027338</td>
</tr>
<tr>
<td>493T</td>
<td>1505.5</td>
<td>0.6334</td>
<td>-0.0003439</td>
<td>0.00041436</td>
</tr>
</tbody>
</table>

Implementation and comparison of various methods of assessing uncertainty in the MLRM predictions.

Analytical methods exist for assessing the uncertainty of MLRM predictions, but the validity of these methods requires that the data and residuals generated by the model fully meet the assumptions underlying MLRM (Kufs, 1992). In practice, adherence to the assumptions is never perfect; therefore, it is desirable to compare alternative methods of assessing uncertainty in the MLRM predictions to the classical analytical method. Two uncertainty intervals were examined: the "confidence interval" which is the interval within which the mean value (i.e. regression line, or, in more than two dimensions, the regression hyperplane) of the dependent variable falls, and the "prediction interval" which is the interval within which a single prediction of the dependent variable falls. The uncertainty encapsulated by the confidence interval is related to uncertainty in the regression coefficients; the uncertainty encapsulated by the prediction interval is related to both the regression coefficients and the tendency for data to not lie
exactly on the regression hyperplane. If the regression coefficients were known exactly, the confidence interval would be zero, but the prediction interval would still be non-zero unless all the data lay exactly on the regression hyperplane. The tendency for the data to not lie exactly on the regression hyperplane is due to both measurement error and the fact that the model only approximates the actual hydrologic system. Harrington (1998) presented a method of using bootstrap resampling and Monte Carlo simulation to evaluate uncertainty in MLRM predictions. Here, three methods of evaluating the uncertainty in MLRM predictions are compared; one method is the classical analytical method (Holder, 1985), the other two are based on bootstrap resampling (Draper and Smith, 1988).

The analytical prediction interval is given by

$$\hat{h} \pm t(n-4,1-\alpha/2)(\hat{\sigma}^2(1+x(X'X)^{-1}x'))^{1/2}$$

where \(\hat{h}\) is the water level predicted by the regression, \(t(n-4,1-\alpha/2)\) is the \(t\) statistic for \(n-4\) degrees of freedom at \(1-\alpha/2\) significance, \(n\) is the number of data, \(\alpha\) is the confidence level of the prediction interval, \(\hat{\sigma}^2\) is the variance of the regression residuals, \(x\) is the data for the estimate, and \(X\) is the matrix of observations given by

$$\left[\begin{array}{ccc}
h_1 & p_1 & r_1 \\
h_2 & p_2 & r_2 \\
\vdots & \vdots & \vdots \\
h_n & p_n & r_n
\end{array}\right]$$

where \(h_i\), \(p_i\), and \(r_i\) are the initial water table elevation, wellfield pumping, and Owens Valley runoff for year \(i\). As discussed above, diversions into the McNally canals are substituted for runoff in Laws wellfield MLRM.

Bootstrap prediction intervals are generated by random resampling and repeated calculation of the regression model based on the resampled data. The first method, bootstrapping the residuals, is implemented by computing the regression model from the original data set, and then resampling with replacement the resulting residuals. The resampled residuals are then added to values predicted by the model and the model coefficients are recalculated. Repeating this process generates as many "realizations" of the model as desired, and the statistics of the set of realizations characterizes the confidence interval. The prediction interval then is derived by adding a normally distributed random number with zero mean and standard deviation equal to the standard error of the regression to each realization.

The second method of bootstrapping, bootstrapping the data, is carried out by resampling the predictor variables from the original data set to form new simulated data sets, and recomputing the regression coefficients from the new data sets. Again, the statistics of the set of realizations characterizes the confidence interval, and the prediction interval is derived by adding a normally distributed random number with zero mean and standard deviation equal to the standard error of the regression to each realization.

To compare the three methods of deriving prediction intervals, the three methods described above were applied to two representative indicator wells, well 493T (Laws wellfield, 24 years of data) and well 418T
Well 493T responds rapidly to pumping stress and recharge from the McNally canals, and fluctuations in its hydrograph range over span of forty feet. Well 418T fluctuates over a smaller range, about thirteen feet, and has a smoother hydrograph than well 493T. For each well, the three methods of computing prediction intervals were implemented and applied to the regression data set, generating a prediction interval for the modeled value for each year of the period of record. The bootstrap methods were applied using five thousand realizations. Table 3 lists the mean and standard deviation of the prediction intervals for each method and each well. Also given is the confidence interval calculated by the analytic method.

It can be concluded from Table 3 that all three methods produce similar prediction intervals, suggesting that the indicator well regression data meets the assumptions of linear regression sufficiently to use the analytic method to compute prediction and confidence intervals. For both wells, the analytic prediction interval was slightly greater than either of the bootstrap methods, the greatest difference being between the analytic method and the bootstrap residual method for well 493T of about 6%. These are encouraging results, in that all these methods produce similar enough prediction intervals that any one of them is sufficient to compute uncertainty estimates for MLRM predictions.

The confidence interval for the analytic method is about one-third of the prediction interval, which shows that the greater share of uncertainty in model predictions is due to scatter about the regression hyperplane, not due to uncertain or unstable regression coefficients. It is not surprising, then, that the three methods produce similar uncertainty estimates, because the largest part of the prediction uncertainty is embodied in the standard error of the regression, which makes a similar contribution to the prediction interval in each of the three methods.

Table 3. Mean and standard deviation of uncertainty intervals derived by analytic methods, bootstrapping residuals, and bootstrapping data. Standard deviation in parentheses.

<table>
<thead>
<tr>
<th>Well</th>
<th>Analytic</th>
<th>Prediction intervals</th>
<th>Bootstrap data</th>
<th>Confidence interval</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6.554(0.206)</td>
<td>6.193(0.208)</td>
<td>6.400(0.313)</td>
<td>2.111(0.579)</td>
</tr>
<tr>
<td>493T</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>418T</td>
<td>1.313(0.028)</td>
<td>1.264(0.035)</td>
<td>1.263(0.058)</td>
<td>0.406(0.088)</td>
</tr>
</tbody>
</table>

Investigation of methods for generating autocorrelated lognormal time series.

In order to predict water table fluctuations over time intervals of several years, it is necessary to provide the MLRM with groundwater pumping and Owens Valley runoff for the duration of the modeled time interval. Pumping is a variable that is controlled by management decisions. Therefore, it is most appropriately supplied to the MLRM deterministically, and is thus specified exactly in a given simulation. Owens Valley runoff, however, is unknown and varies stochastically. To provide the MLRM with realistic renditions of runoff for multiple years, it is desirable simulate Owens Valley runoff for the period of the simulation in a way that reproduces the important statistics of the historical runoff time series. For this application, the important statistics are the mean, standard deviation, skewness, and one-lag coefficient of autocorrelation. Seasonality of runoff can be neglected, because the MLRM are implemented with one-year time steps, and decadal-scale periodicities are beyond the concern of the one to four year simulations contemplated here.
Owens Valley runoff for each runoff year 1935 through 1999 were used to calculate the statistics of the runoff time series (Appendix 2). Figure 2 shows the histogram and Figure 3 shows the normal probability plot of the Owens Valley runoff data set. Table 4 gives the summary statistics for the runoff data set.
Table 4. Summary statistics for the Owens Valley runoff data set.

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>426205 AF</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>155403 AF</td>
</tr>
<tr>
<td>Median</td>
<td>393362 AF</td>
</tr>
<tr>
<td>Skewness</td>
<td>0.7775</td>
</tr>
<tr>
<td>One-lag autocorrelation coefficient</td>
<td>0.1416</td>
</tr>
</tbody>
</table>

Figure 2. Histogram of Owens Valley runoff.
It is clear from Table 4 and Figures 2 and 3 that the distribution of Owens Valley runoff is skewed to the right and should be treated as a non-normal distribution. Typically, runoff time-series can be modeled as lognormally distributed (Haan, 1977), and that appears to be a valid strategy for these data.

Runoff data also typically serially correlated due to climatological and watershed processes that cause the previous years' precipitation conditions to contribute to any given year's runoff. For example, remnant snowfields and moist soil following a year of high precipitation may cause the following year to have more runoff than would be expected based on precipitation alone, or climatological teleconnections such as the El Nino/Southern Oscillation may persist for more than one year. Figure 4 shows a correlogram for Owens Valley runoff. A correlogram is calculated by computing the correlation coefficient between a data set and the same data set off-set by one, two, three, etc. years, e.g., the correlogram at lag = 10 is the correlation coefficient for runoff separated by ten years. The most pertinent feature of Figure 4 for regression modeling is how rapidly the correlogram declines in the first few years. The correlogram for lag = 1 is 0.1416; for lag = 2, it is 0.2106; and for lag = 3, it is -0.0071, suggesting that the degree of serial correlation in the runoff time series is modest. To further evaluate the importance of serial correlation, simple linear regression of the runoff data versus the same data off-set by one year was performed. The slope of the regression line was significant at a $p = 0.2643$ level (for normally distributed data with a one lag autocorrelation coefficient equal to zero, there is probability $p$ that the slope would be this great or greater). This suggests that autocorrelation of the runoff data is not a critical concern, but may be present; therefore, a method is presented here for generating autocorrelated time series of lognormally distributed runoff data. The apparent periodicity in the correlogram suggests some sort of cyclical climatological process with a period of twelve to fifteen years. The MLRM are applied to forecast windows of up to five years, so the observed periodicity does not affect this application.
Figure 4. Correlogram for Owens Valley runoff.

To generate autocorrelated time series of runoff, it is assumed that the statistics of the time series are stationary. This assumption is necessary to estimate population parameters from the data set sample statistics, however it should be recognized that alterations such as land use change, changes in water management, or climate change could render this assumption invalid. The simplest model for simulating Owens Valley runoff that fulfills the requirements of reproducing the mean, variance, skewness, and first order autocorrelation coefficient is the first-order Markov process, given by

$$x_{i+1} = \bar{x} + \rho_x(1)(x_i - \bar{x}) + t_{i+1}\sigma_x\sqrt{1 - \rho_x^2}(1)$$

where $x_i$ is the time series being simulated, $\bar{x}$ is the mean of the time series, $\rho_x(1)$ is the one-lag autocorrelation coefficient, $t_{i+1}$ is a standard normal random deviate, and $\sigma_x$ is the standard deviation of the time series. Implementation of the first order Markov process requires estimation of the mean, standard deviation, and one-lag autocorrelation coefficient, and random generation of standard normal deviates.

Application of the first-order Markov model to log transformed data requires a correction so that the model preserves the statistics of the original data rather than the statistics of the log transformed data. The correction has the form

$$y_i = \ln(x_i + \alpha)$$

and the correction factor $\alpha$ is chosen such that the statistics of the original data set are reproduced. Following the procedures cited by Haan (p. 295, 1977) yields $\alpha = -186298$ AF. Monte Carlo simulations were done to test the performance of the correction. Five thousand values were generated using normally distributed runoff, lognormally distributed runoff with the correction, and lognormally...
distributed runoff without the correction. The statistics of these simulations were computed and compared to the statistics of the original data (Table 5). The mean values and standard deviations of all of the simulated runoff time series compare well with the original data, however only the corrected simulation reproduces the both skewness and first order correlation coefficient of the original data.

Table 5. Statistics of original and simulated Owens Valley runoff.

<table>
<thead>
<tr>
<th></th>
<th>Original data</th>
<th>Simulated with normal distribution</th>
<th>Simulated with lognormal distribution and correction</th>
<th>Simulated with lognormal distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (AF)</td>
<td>426205</td>
<td>422356</td>
<td>427524</td>
<td>429828</td>
</tr>
<tr>
<td>Standard dev. (AF)</td>
<td>155402</td>
<td>156603</td>
<td>156822</td>
<td>157184</td>
</tr>
<tr>
<td>Skewness</td>
<td>0.77748</td>
<td>-0.05652</td>
<td>0.74668</td>
<td>1.0860</td>
</tr>
<tr>
<td>One-lag autocorrelation</td>
<td>0.141614</td>
<td>0.14208</td>
<td>0.14220</td>
<td>0.24684</td>
</tr>
</tbody>
</table>

Development of additional MLRM for wells for predicting water table fluctuations at permanent monitoring sites.

In order to develop the ability to predict water table fluctuations at vegetation monitoring sites, it is desirable to develop MLRM for wells near monitoring sites, but proximity or relation to vegetation monitoring sites has not heretofore been one of the criteria for choosing wells for MLRM development (Harrington, 1998; 1999). Data and regression diagnostics for several wells that appear favorably situated for developing this capability are presented below (Table 6) and in Appendix 3. The wells were chosen by comparing the potential indicator well hydrograph to the monitoring well at the vegetation monitoring site; if the hydrographs were parallel for their common period of record, the well was considered useful for predicting fluctuations at the monitoring site. Additional work, not presented here, is necessary to relate water table fluctuations at the indicator wells to fluctuations at the vegetation monitoring site. Regression models were developed for the following wells: V271 (Laws wellfield), 572T (Big Pine wellfield), 507T (Thibaut Sawmill wellfield), and V097 (Bairs George wellfield).

LADWP wells that have a "V" designation are usually deep monitoring wells. Use of V-designated wells in the Laws and Bairs George wellfields is justified by the close correspondence between the hydrographs of the potential indicator well and nearby shallow wells situated at the vegetation monitoring site. Well V271 is over 195 ft deep according to LADWP's well database, however its well log indicates it was drilled to 113 ft and screened from 91 to 111 ft. Well V097 was drilled to 321 ft and its screened interval is unknown.
Table 6. Regression diagnostics and coefficients for additional indicator wells.

<table>
<thead>
<tr>
<th>Well</th>
<th>N</th>
<th>$R^2$</th>
<th>SE (ft)</th>
<th>Regression coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td>V271</td>
<td>28</td>
<td>0.871</td>
<td>4.380</td>
<td>Intercept: 2360.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Init. head: 0.42443</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Pumping: -0.0004362</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Canal flows: 0.0003883</td>
</tr>
<tr>
<td>572T</td>
<td>14</td>
<td>0.861</td>
<td>1.990</td>
<td>Intercept: 2171.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Init. head: 0.44770</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Pumping: -0.0001993</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>OV runoff: 0.00001179</td>
</tr>
<tr>
<td>507T</td>
<td>22</td>
<td>0.929</td>
<td>0.469</td>
<td>Intercept: 1082.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Init. head: 0.71572</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Pumping: -0.0001489</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>OV runoff: 0.0000013071</td>
</tr>
<tr>
<td>V097</td>
<td>28</td>
<td>0.871</td>
<td>3.239</td>
<td>Intercept: 2686.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Init. head: 0.29496</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Pumping: -0.0025717</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>OV runoff: 0.000010172</td>
</tr>
</tbody>
</table>

Conclusions and Recommendations

1. Use of the McNally canals as a predictor variable provides both better model performance and a more sound hydrological basis for Laws area MLRM. Diversions from the Owens River into the upper and lower McNally canals should be used as a predictor variable in these models in place of Owens Valley runoff.

2. Prediction intervals based on analytical methods and those based on bootstrap resampling provide similar estimates of uncertainty in MLRM predictions. Either method is suitable for evaluation of MLRM results. The choice of method can be left to convenience of the modeler, for example in MLRM applications where Monte Carlo methods are used to simulate runoff for multiple years into the future, it may be easier to implement bootstrap based methods; alternatively, in simple applications of the MLRM to make predictions one year into the future, use of the analytical method will provide faster model run times and perhaps be more familiar to other parties examining the model results.

3. For multiple year MLRM simulations, the method presented here for generating time-series of Owens Valley runoff reproduced the mean, standard deviation, skewness, and one-lag coefficient of autocorrelation, and is recommended for generating time series of autocorrelated lognormally distributed Owens Valley runoff.

4. MLRM were developed for wells V271, 572T, 507T, and V097. These models had adequate regression diagnostics, and may prove useful in developing linkages between indicator wells and permanent vegetation monitoring sites.
References


Harrington, R. F., Multiple regression modeling of water table response to pumping and runoff, Inyo County Water Dept. Report, 1998

Harrington, R.F., Updated Regression Models for Forecasting Pumping-Induced Water Table Fluctuations, Inyo County Water Dept. Report, June 1999.


Appendix 1: Regression model data for Laws wellfield indicator wells

This appendix contains data used for development of multiple linear regression models in the Laws wellfield using diversions from the Owens River into the McNally canals. Initial water table is the elevation above sea level of the water table measured during April of the year in the first column; pumping is runoff-year (April 1 through March 31) pumping for the Laws wellfield (acre feet); diversions to canals are the runoff-year diversions from the Owens River into the upper and lower McNally canals (acre feet) at the OVPA station; final water table is the water table elevation at the end of the runoff year. The fifth column is regressed against the second, third and fourth columns. The data were provided by LADWP.
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Figure A2.1. Owens Valley runoff-year runoff.
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Well 572T, Big Pine wellfield; R.P. elevation: 3944.54 ft.; Land surface elevation: 3944.3 ft.

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Well V097, Bairs George wellfield; R.P. elevation: 3828.15 ft.; Land surface elevation: 3827.7 ft.

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