

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/288753211>

Development and uncertainty analysis of an empirical recharge prediction model for Nevada's desert basins

Article · January 2010

CITATIONS

9

READS

149

4 authors, including:



[Justin L. Huntington](#)

Desert Research Institute

85 PUBLICATIONS 1,735 CITATIONS

[SEE PROFILE](#)



[Rosemary W.H. Carroll](#)

Desert Research Institute

57 PUBLICATIONS 553 CITATIONS

[SEE PROFILE](#)

Some of the authors of this publication are also working on these related projects:



Porter Canyon Experimental Watershed [View project](#)



California-Nevada Drought Early Warning System [View project](#)

Journal of the Nevada Water Resources Association

Summer 2010

A publication of the Nevada Water Resources Association
providing hydrologic information to the people of Nevada and adjacent states



Volume 5, Number 1

Morning photograph taken of the Truckee River in Verdi, Nevada

NEVADA WATER RESOURCES ASSOCIATION

Executive Director

Tina Triplett
Nevada Water Resource Association

President

Michael Widmer
Washoe County Department of Water Resources

Editor

Michael Widmer

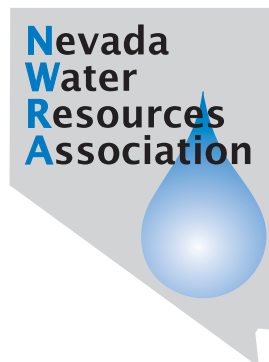
Assistant Editors

Scott Ball, MontgomeryWatsonHarza
Chris Benedict, Washoe County Department of Water Resources
David Berger, USGS-WRD-NV
Doug Maurer, USGS-WRD-NV
Douglas Sims, Sims & Associates

Correspondence: Manuscripts should be submitted to Michael Widmer, Washoe County Dept. Water Resources, 4930 Energy Way, Reno, NV. 89502. Inquires: (775) 954-4655, mwidmer@washoecounty.us

Responsibility: The Nevada Water Resource Association and the organizations of any of the editors or Board of Directors are not responsible for statement and opinions advanced in this publication. Papers were reviewed for technical and editorial quality, but represent the views of the authors and in no way should be attached to the NWRA or its editors, who remain neutral and impartial in the production of this publication.

Copyright @ 2010 NWRA



From the Editor

Without fanfare I would like to submit to our association the latest edition of the Nevada Water Resources Association Journal. As you might know, I took over the responsibilities of editor from Dr. Michael Strobel. Michael took a new position in Portland, Oregon and his work prevented him from these editorial duties. And while I am new to these duties, I anticipate fulfilling the obligations Michael set forth in 2004 with this journal.

We are publishing three articles in this edition. The first is a proposed methodology for estimating ground water recharge from precipitation. This article is a subset of a Master's Thesis by Brian Epstein (UNR, 200x) and co-authored by his thesis adviser Dr. Greg Pohll, with contributions from Justin Huntington and Rosemary Carroll (who recently finished her Ph.D.). The study focuses on uncertainty from model predictions using the Maxey-Eakin method, the bootstrap brute-force model, and Nichols method.

The second article is from Anpalaki Ragavan, Ph.D., who explores the non-linear relationship to total phosphorus concentrations in the Truckee River with three independent variables. Relatively high phosphorus concentrations are a major cause of eutrophication in natural water ways. Ana's work contributes to the modeling of remediation methods for the control of eutrophication.

The last article was submitted by yours truly and Vahid Behmaram. This article is really just a "paste" of two recent court rulings affecting Nevada water law. We submitted this article as a means to provide the association with two decisions that have sent reverberations from water law experts throughout Nevada. The first should become quite controversial as the United States Court of Appeals for the Ninth Circuit has made the distinction of the interaction between surface water and ground water in the Tracy section of the Truckee River Canyon. The second recent decision is from the Nevada Supreme Court that has ruled on the "inaction" by the Office of the State Engineer to act on water right applications within the statutory one-year time frame. The ruling was recently (June 17, 2010) clarified by this Court.

What's next from the Journal? I hope to support the association with another edition in the winter months, prior to our annual conference. In this next edition, I would like to provide articles with a more practical bent towards applications, particularly for the water purveyor. But of course, this requires article submittal from those in this industry. Get the hint?

Finally, I am hoping that the readers of this Journal will submit editorials, corrections, responses, or comments on this edition's articles or other issues. While not being intent on the controversial, this Journal and the Association respect legitimate opinions and are willing to provide a forum for such responses from our readership. Thank you for your attention to this journal.

Michael Widmer, Editor

Table of Contents

Development and Uncertainty Analysis of an Empirical Recharge Prediction Model for Nevada’s Desert Basins.....	1
Brian J. Epstein, Greg M. Pohll, Justin Huntington, and Rosemary W.H. Carroll	
Water Quality Data Modeling To Minimize Eutrophication in the Truckee River, Nevada.....	23
Anpalaki J. Ragavan	
Recent Judicial Court Decisions Affecting Nevada Water Law.....	38
Michael C. Widmer and Vahid Behmaram	

Development and Uncertainty Analysis of an Empirical Recharge Prediction Model for Nevada's Desert Basins

BRIAN J. EPSTEIN, Colorado Division of Water Resources, Office of the State Engineer, 1313 Sherman St. Room 818, Denver, CO.80203 (Brian.Epstein@state.co.us);

GREG M. POHLL, Desert Research Institute, Division of Hydrologic Sciences, 2215 Raggio Pkwy, Reno, NV. 89512 (Greg.Pohll@dri.edu)

JUSTIN HUNTINGTON, Desert Research Institute, Division of Hydrologic Sciences, 2215 Raggio Pkwy, Reno, NV. 89512 (Justin.Huntington@dri.edu)

ROSEMARY W.H. CARROLL, Desert Research Institute, Division of Hydrologic Sciences, 2215 Raggio Pkwy, Reno, NV. 89512 (Rosemary.Carroll@dri.edu)

ABSTRACT

Nevada is one of the driest and most urbanized state in the nation, where the mean annual precipitation is about 11 inches, and 88% of the state's population lives in either the greater Las Vegas or Reno metropolitan areas. As a result, appraisals of available water resources for both in-basin uses and inter-basin transfers are primary objectives for many hydrology studies. Hydrologists have focused on estimating available water resources in Nevada since the 1940s. The challenge associated with measuring recharge directly has lead to the use of indirect methods with most basin water budgets dependent on empirically derived recharge prediction methods (e.g. Maxey-Eakin, Nichols). The bootstrap brute-force recharge model (BBRM) optimization algorithm is developed to recalibrate empirical models by incorporating measurement error in precipitation, recharge variability and regression model uncertainty. The 1998 PRISM precipitation map more accurately reproduces observed precipitation compared to the 1965 Hardman precipitation map and is used in the BBRM development. Results show that, on average, the Maxey-Eakin model predicts the lowest recharge volumes while the Nichols model predicts the largest recharge volumes. The BBRM predicts recharge volumes in between the Maxey-Eakin and Nichols approaches. The Maxey-Eakin produces the lowest errors for basins with low expected recharge, but the mean behavior of the BBRM is capable of explaining the highest percentage of recharge variability (adjusted $r^2=0.76$). The resultant BBRM 95-percent confidence intervals show that uncertainty increases substantially at larger precipitation rates. Better quantification of basin discharge and precipitation will improve model prediction and reduce uncertainty in model behavior.

INTRODUCTION

The volume of average annual natural recharge or discharge serves as a basis for determining the upper bound of the perennial yield. The Nevada State Engineer (ruling #5726) defines the perennial yield of a groundwater reservoir as the,

“Maximum amount of ground water that can be salvaged each year over the long term without depleting the ground-water reservoir. Perennial yield is ultimately limited to the maximum amount of natural discharge that can be salvaged for beneficial use. The

perennial yield cannot be more than the natural recharge to a ground-water basin and in some cases is less.”

It is recognized that the amount of water available for capture without steady decline in storage is limited to the sum of the changes in recharge and discharge during groundwater development (Bredehoeft et al., 1982; Bredehoeft, 1997; Sophocleous, 1997), not the recharge or discharge volume itself. Even though it is the change that is important, estimating the natural recharge or discharge provides a basis as to the maximum that could be hypothetically captured under Nevada water law. It should be noted that Nevada is one of the only states in the western US to follow the doctrine of limiting the available water for appropriation to the perennial yield.

Because Nevada water law relies on the perennial yield to assess potential water availability, knowledge about the uncertainty in recharge is important when considering appropriation of water resources in Nevada. With Nevada being one of the driest states in the nation, its hydrographic basins are predominately arid and semi-arid in character. It has been shown that with greater aridity, natural groundwater recharge becomes smaller and more variable (De Vries and Simmers, 2002). Conceptually, mountain fronts surrounding alluvial valleys are considered the zones from which precipitation and ephemeral runoff has the most potential to contribute to the basin fill groundwater system. Local climate, geology, vegetation, and geomorphology exhibit control over groundwater recharge. This adds a spatial element of heterogeneity to the system. The difficulties of identifying temporal and spatial variability and direct measurement of recharge have lead researchers to use indirect estimation techniques, including empirical relationships based on precipitation. An empirical relationship between precipitation and natural groundwater recharge for Nevada basins was first established in Water Resource Bulletin No. 8 (Maxey and Eakin, 1949) and remains a common technique for estimating recharge in Nevada today. Updated, daughter techniques, such as the Nichols method (2000), are also available.

Using an empirical model, such as the Maxey-Eakin method, to estimate recharge imparts some error. Currently this error is not well understood. The objective of this study is to better understand the statistical uncertainty in basin-wide recharge in Nevada by building on the general Maxey-Eakin approach to include error in precipitation estimates, observed variability associated with independent estimates of natural recharge, and uncertainty in model structure.

EMPERICALLY BASED RECHARGE MODELS

The methods presented are simple, additive linear models that can rapidly estimate the quantity of water recharging aquifer storage at the basin-scale. These models lump many physical processes into one set of coefficients.

Maxey-Eakin

Maxey and Eakin (1949) developed coefficients to relate zonal precipitation into basin-wide recharge estimates using a trial-and-error balance of the estimated basin-wide discharge volumes and zonal precipitation volumes for 13 to 21 hydrographic areas in Nevada (Maxey and Eakin, 1949; Watson et. al, 1976). Mathematically, the Maxey-Eakin method is,

$$\hat{Y} = \sum_{i=1}^N \beta_i P_i \quad (1)$$

where N is the number of precipitation zones, $\hat{Y}$ is predicted recharge (acre-feet per year), β_i is the recharge coefficient (dimensionless) for a given precipitation zone (i) and P_i is the annual zonal precipitation estimate (acre-feet per year) as determined by Hardman’s isohytl

precipitation map of Nevada (Hardman, 1936). Typical Maxey-Eakin coefficients are provided in Table 1.

Nichols

Nichols (2000) derived new recharge coefficients from updated groundwater discharge estimates. Groundwater discharge was updated by relating Landsat derived plant cover to groundwater evapotranspiration from phreatophyte covered areas, and considering subsurface outflow. An updated precipitation map reflecting more recent conditions from 1961-1990 was also used (Daly et al., 1994) in Nichols' analysis. Coefficients were calibrated using a multiple-linear regression type equation to fit estimates of natural discharge in 14 basins in east-central Nevada. Table 2 shows β -coefficients for each of the six defined precipitation zones calibrated by Nichols.

UNCERTAINTY INCORPORATED INTO EMPIRICAL MODELS

Regression models are only as good as the data that are used to create them. With that understanding, the independent (precipitation) and dependent (recharge) variables in the regression model have uncertainty. Uncertainty is allowed to propagate through the optimization process and be expressed in newly calibrated β -coefficients. Specifically, uncertainty is included by randomly selecting a subset of basins available for selection (with replacement), and randomly selecting error in the precipitation and independent recharge estimate (bootstrap) (Efron, 1979; Chernick, 1999). The best set of recharge coefficients are those that minimize error between predicted recharge and the independent recharge estimates with uncertainty added (brute-force). Sampling basins with replacement means that every basin is returned to the pool after sampling such that a single basin can appear in different bootstrap realizations.

Precipitation Error

Similar to Jeton et al., (2005), the error associated with precipitation estimates is calculated as the residual between the Hardman 1965 (Figure 1a) or PRISM 1998 (Figure 1b) precipitation maps, and observed precipitation. Areas between precipitation contour for both Hardman 3-5 inch and PRISM 2 inch contour maps were averaged to produce areas of average precipitation for comparison to observations. Observed precipitation is acquired from cooperative weather networks and Snow Telemetry (SNOTEL) stations using published normals from 1961 to 1990 (Western Regional Climate Center, 2003, Natural Resource Conservation Service, 2003a; 2003b). Precipitation sites are shown in Figure 2. When compared to point estimates of precipitation normals, the Hardman map is found to generally under predict observed values (Figure 3a). This is not a surprise since the Hardman map has an unbounded upper limit beginning at 20 inches per year. In addition, the Hardman map was based on measurements during a time when below average precipitation occurred in the early decades of the 20th century but is compared to a reference period (1961-90) of an almost-equal number of years of below- and above- the long term average precipitation. In contrast, Figure 3b shows that the PRISM map has no trend in error related to expected precipitation (e.g. the lack of increasing deviation with higher expected precipitation). Despite producing errors ranging from 5-percent to 33-percent, the PRISM map more accurately predicts observed long term precipitation totals than the Hardman map. For this reason, the 1998 PRISM map is selected for the new bootstrap model. Four precipitation intervals (0-10, 10-20, 20-30 and >30 inches per year) are found the most efficient break down of zones for use in the new bootstrap model.

Independent Recharge Estimates and Variability

There are different methods to estimate recharge independently of empirical models. These include estimating the discharge via evapotranspiration and subsurface outflow, estimating the recharge by performing a chloride mass balance, or application of water balance models. While all of these methods, including empirical approaches, require precipitation distributions, the term ‘independent’ is used in reference to the fact that empirically derived recharge estimates are not used to define recharge volumes for a given basin. Independent recharge estimates are obtained from Nevada Water Resource Bulletins, Nevada Ground-Water Resource Reconnaissance Series reports, United States Geological Survey Water Resources Investigations reports, Desert Research Institute reports, and other published studies. Sources are examined to insure that recharge estimates did not rely on empirical models in their analysis. Basins with multiple independent estimates of recharge are assigned a coefficient of variation (the standard deviation divided by the mean) to scale random uncertainty in the bootstrap brute-force regression. Ninety basins, out of 263 hydrogeographic areas and subareas in Nevada (Rush, 1968; Harrill and Prudic, 1998) have reported independent recharge estimates and are used in the analysis (Table 3 and Figure 4). A large portion of the independent recharge estimates are based on the reported discharge from bulletin and reconnaissance reports. Of these 90 basins, 22 basins have more than one reported recharge estimate with an average coefficient of variation (CV) equal to 0.368. This means that, on average, a reported recharge distribution has a standard deviation approximately one-third its mean value.

Bootstrap Brute-Force Algorithm

Figure 5 is a flow chart describing the bootstrap brute-force algorithm. As discussed earlier, bootstrapping is a technique of random selection and replacement of a subset of all available data. Monte Carlo type repetition of the bootstrapping approach helps delineate the distribution of each recharge β -coefficient used in the empirical model. ‘Brute-force’ is a simplistic but exhaustive approach to minimize an objective function (e.g. root mean squared error, *rmse*) in order to reduce error between predicted and independently estimated recharge. Adding error to precipitation and independently estimated recharge is done to account for the fact that the true values of precipitation and recharge are not estimated exactly or known with 100% certainty. A single bootstrap realization is preformed as follows,

1. Introduce error in independent recharge estimates for basin j using,

$$Y_j = \bar{Y}_j + z\sigma_j \quad (2)$$

where Y_j is the independent recharge estimate including error (acre-feet per year), $\bar{Y}_j$ is the mean of independent recharge estimates (acre-feet per year), z is the randomly selected standard normal variable and σ_j is the adjusted standard deviation for independently derived recharge volumes (acre-feet per year) equal to,

$$\sigma_j = (CV_j)\bar{Y}_j \quad (3)$$

where CV_j is the coefficient of variation (dimensionless). If basin j has only a single independent recharge estimate, then CV_j is assumed to equal the mean CV of 0.368 derived from 22 basins with multiple independent recharge estimates.

2. Introduce precipitation error by randomly selecting residuals for each PRISM precipitation zone (i) from a normal distribution with a mean of zero, and standard

deviation defined by the calculated residuals in each precipitation zone. Four precipitation zones are used in the BBRM methodology. Mathematically, precipitation with error (P_i^e , feet per year) for zone i is calculated as,

$$P_i^e = P_i + e_i \quad (4)$$

where P_i and e_i are the PRISM mean precipitation rate (feet per year) and randomly selected precipitation error (feet per year), respectively. The precipitation error is calculated as

$$e_i = z\sigma_i^p + \varepsilon_i \quad (5)$$

where z is the randomly selected standard normal variable, σ_i^e is the standard deviation in zonal precipitation residuals (feet per year), and ε_i is the average zonal residual (feet per year).

3. Randomly select the size (S) of the subset of basins used in the brute-force optimization processes. The size of the subset for each bootstrap realization is allowed to vary between one and ninety. Varying the size of the subset used in optimization incorporates uncertainty in model structure into model output.
4. Randomly select a subset of (S) basins from the ninety basins listed in Table 3, for coefficient inversion described in the following steps.
5. For each basin in subset (S) convert the zonal P_i^e rate (feet per year) to a volumetric precipitation estimate ($X_{i,j}$, acre feet per year) by multiplying P_i^e by the area (acres) of precipitation zone i contained within basin j .
6. Coefficients (dimensionless) for each precipitation zone (β_i) are randomly selected but are constrained such that $0 \leq \beta_i \leq 1$, and are required to increase with increased precipitation zone ($0 \leq \beta_1 \leq \beta_2 \leq \dots \leq \beta_N \leq 1$). Selected β_i are used to compute the *rmse* for (S) basins using the model's predicted recharge ($\hat{Y}_j = \sum_{i=1}^N \beta_i X_{i,j}$) and independently estimated recharge adjusted for error (Y_j), with $N = 4$ precipitation zones.

$$rmse = \left\{ \frac{\sum_{j=1}^S (\hat{Y}_j - Y_j)}{S} \right\}^{0.5} \quad (6)$$

7. For the selected bootstrap sample (S) of basins, subsequent iterations are performed where new sets of β -coefficients are randomly chosen and applied to zonal precipitation volumes to compute the predicted recharge volumes. The *rmse* is then computed for the

selected bootstrap sample of basins. After one million iterations, the single set of β -coefficients with the lowest *rmse* is assumed the best model for the subset of basins selected for the given bootstrap realization. One million iterations represents the peak efficiency of the algorithm in reducing the residuals while maintaining reasonable computing time (approx. 30 minutes) per bootstrap realization.

8. One thousand bootstrap realizations are performed in order to adequately compute the 95-percent confidence intervals for each β_i in the set, with confidence intervals based on a percentile method (Diciccio and Romano, 1988; Efron and Tibshirani, 1998). Likewise, standard descriptive statistics (mean and standard deviation) are calculated, with the mean of each coefficient expected to create the best prediction of recharge.

RESULTS

Mean recharge predictions for the Maxey-Eakin and Nichols approaches, and the new BBRM approach for all of Nevada's basins can be found at the Desert Research Institute web address (<http://bbrm.dri.edu>). Table 4 provides descriptive statistics for the BBRM coefficients. Figure 6 illustrates mean β -coefficients for the BBRM, with the Maxey-Eakin and Nichols coefficients. Also included in Figure 6 is the BBRM 95-percent confidence intervals for each calibrated β_i . Uncertainty in β_i increases with increasing precipitation, such that recharge estimates for basins containing large precipitation will also contain higher uncertainty based on the uncertainty in the calibrated β . Uncertainty of BBRM β_i coefficients at low and high precipitation rates encompasses all other empirical coefficients. At moderate precipitation rates (12 to 19 inches per year) the Maxey-Eakin and Nichols' coefficients are larger than the BBRM 95-percent confidence bounds. Regression analysis of predicted recharge against mean independent recharge estimates for the 90 basins analyzed found the mean set of BBRM β -coefficients capable of predicting 76-percent of recharge variability (adjusted $r^2 = 0.76$), while the Nichols model does a poorer job (adjusted $r^2 = 0.59$) and the Maxey-Eakin performs slightly worse than the Nichols model ($r^2 = 0.55$).

A residuals analysis was done to examine the predictive capability of the Maxey-Eakin, Nichols and the mean BBRM method. Residuals are calculated by subtracting the average of independent recharge estimates from the predicted recharge for each of the 90 basins analyzed. Figure 7a shows that all methods have increased error in prediction with increased expected recharge (i.e. mean of independent recharge estimates). In general, all models over predict (residuals > 0) recharge for small and medium recharge volumes ranging from 100 to 15,000 acre-feet per year. This has negative implications for water resource managers attempting to be conservative in their estimates of perennial yield. Conversely, for larger expected recharge volumes (> 40,000 acre-feet per year), most basins are under predicted by all empirical approaches, however results are variable. Normalizing residuals by the size of the basin (Figure 7b) removes the influence of basin size in estimated error. All models tend to over predict recharge volumes for basins with less than 15,000 acre-feet per year, but the Maxey-Eakin model has less error in recharge per acre compared to the Nichols and BBRM approaches. Normalized residuals in Figure 7b show that all empirical models mostly under predict recharge volumes for basins with greater than 15,000 acre feet per year.

Two basins are evaluated to demonstrate the BBRM approach in comparison to Maxey-Eakin, Nichols and the range of reported independent recharge estimates (RRE). Steptoe (Figure

8a) is a large basin (1,245,600 acres, 1,950 square miles) in east-central Nevada (observation # 77 in Figure 4) with an RRE of 70,000 to 129,500 acre-feet per year (refer to Table 3). The range of the RRE is approximately 60,000 acre-feet per year, which is 60-percent the expected mean of 99,750 acre-feet per year. Results show the Maxey-Eakin, Nichols and mean BBRM all lie within the reported RRE, with the mean BBRM recharge estimate of 101,340 acre-feet per year more closely predicting the expected mean of 99,750 acre-feet per year. The 95-percent confidence interval for the BBRM approach fully encompasses the observed variability in the RRE, with the error in PRISM precipitation and model development adding 26,000 acre-feet per year of uncertainty.

Dry Valley (observation #21 in Figure 4) is a small basin of 53,000 acres (82 square miles) located along Nevada's western boarder north of the city of Reno. Referring to Table 3, the Dry Valley RRE is 2,280 to 3,100 acre-feet (3,100 acre-feet is the average of 1,400 and 4,800 acre-feet presented by Thomas and Albright, 2003). The relatively small range of 820 acre-feet per year which is 30-percent the expected mean of 2,690 acre-feet per year (Figure 8b). The best predictor of the expected mean recharge is the Maxey-Eakin model at 2,409 acre-feet per year. In contrast, the BBRM mean estimate of recharge is 1.5 times larger than the mean of the RRE, and the Nichols model predicts volumes four times the expected mean. The BBRM 95-percent confidence interval encompasses most of the RRE, including the Maxey-Eakin estimate, but does not capture estimates below the Maxey-Eakin volume. The shift in both the BBRM and Nichols output toward larger than expected recharge is attributed to PRISM precipitation estimates possibly being too large for Dry Valley. Both the BBRM and Nichols models may also over predict the importance of precipitation as a predictor variable for recharge in Dry Valley (i.e. β -terms too large). Instead, other basin specific characteristics such as geology, not accounted in the model, is likely influencing (in this case reducing) recharge compared to average behavior in Nevada.

Evaluation of all Nevada basins finds that the Maxey-Eakin method predicts the least amount of recharge for 53-percent of the basins, and the Nichols model predicts the most recharge in 43-percent of the basins. The BBRM method predicts in the middle of these models 44-percent of the time. A comparison of total predicted recharge for the entire state is shown in Figure 9 with the mean of the RRE. As with the majority of individual basins, the Maxey-Eakin model predicts the least amount of state wide recharge of approximately 4.6 million acre-feet per year. The Nichols model predicts the greatest recharge amount of nearly 6.4 million acre feet per year. This is approximately a 50-percent increase over the Maxey-Eakin approach. The mean BBRM predicts recharge in the middle at 5.4 million acre-feet per year. The state-wide comparison does not help clarify which predictive technique is closer to the true recharge value, however it illustrates relative differences between methods.

DISCUSSION

Improving empirical recharge models largely rests in improving the data from which the models are created. In Nevada, most of the reported recharge estimates are based on groundwater budget approximations predominantly constructed from estimates of discharge by phreatophytes through evapotranspiration. The accuracy of each component of the groundwater budget needs to be tightened in order to produce an improved estimate. In terms of precipitation, observation stations exist mostly on or near the valley floors. Yet, nearly half of the hydrographic areas and subareas in Nevada are impacted by high elevation precipitation. Uncertainty in model prediction increases with the rate of precipitation. This uncertainty could be reduced

substantially by increasing the quantity of high altitude observations and incorporating these observations into more accurate isohyetal maps of Nevada.

Empirical recharge models currently available, including the BBRM, are relatively simplistic. Precipitation may be the primary source term but it is not the only factor controlling the amount of groundwater recharge. Using other explanatory variables to characterize mountain block and mountain front recharge processes such as geology, vegetation type and rooting depth, evapotranspiration, and soil properties of permeability and depth to bedrock might improve recharge predictions from empirical models. In addition, simple measures such as constraining random basin selection based on geology and climate to develop 'region' or 'flow system' specific recharge coefficients is a promising area of research.

The results of the present study are based on a more robust collection of reported recharge estimates than previous work of this type, however many new independent recharge estimates for several basins have been reported since this research was completed. Infusing earlier modeling approaches with more information adds understanding on the quality of recharge prediction. When the Maxey-Eakin, Nichols and new BBRM are used to predict recharge for all hydrographic areas and subareas in Nevada, it is clear that most often the Nichols equation predicts highest, the BBRM predicts in the middle and the Maxey-Eakin equation predicts lowest volume of groundwater recharge. This should be kept in mind any time one of these methods is selected as the recharge predictor. It is shown that the Maxey-Eakin approach predicts recharge closer to the average RRE for basins with lower expected recharge volumes. However, the adjusted coefficient of multiple determination indicates that the BBRM method predicts closer to the RRE mean more often than both the Maxey-Eakin and Nichols methods for all basins analyzed.

The main advantages of the BBRM technique over previous empirical models of recharge is that it incorporates precipitation error implicit in the PRISM estimates, variability in recharge volumes as defined by independent studies, as well as uncertainty in model structure. Consequently, the BBRM approach provides information on recharge prediction reliability. Despite constraints based on the number, magnitude, source and possible bias of independent recharge estimates, the BBRM can be a valuable tool in reducing predicted recharge uncertainty.

ACKNOWLEDGEMENTS

Funding for this research was made available by the Desert Research Institute's Division of Hydrologic Sciences. This document represents a consolidation of a Masters thesis at the University of Nevada, Reno (Thesis #5653). The authors would like to thank anonymous reviewers for adding valuable recommendations and insight.

REFERENCES CITED

- Berger, D. L. 2000. Water budgets for Pine Valley, Carico Lake Valley, and Upper Reese River Valley hydrographic areas, Middle Humboldt River Basin, north-central Nevada - Methods for estimation and results. Water-Resources Investigations Report 99-4272, United States Geological Survey prepared in cooperation with the Nevada Division of Water Resources, Carson City, Nevada.
- Bredehoeft, J. D. 1997. Safe yield and the water budget myth: *Groundwater* v. 35, no. 6, p. 929.

- Bredehoeft, J. D., Papadopoulos, S. S., and Cooper, H. H. Jr. 1982. Groundwater-The water-budget myth, in *Scientific basis of water-resource management*: National Academy Press, p. 51-57.
- Chernick, M. R. 1999. *Bootstrap Methods A Practitioner's Guide*. John Wiley & Sons, Inc., New York, New York.
- Daly, C., R. P. Neilson, and D. L. Phillips. 1994. A statistical-topographic model for mapping climatological precipitation over mountainous terrain. *Journal of Applied Meteorology* 33:140-158.
- Dettinger, M. D. 1989. Reconnaissance estimates of natural recharge to desert basins in Nevada, U.S.A., by using chloride-balance calculations. *Journal of Hydrology* 106:55-78.
- De Vries, J. J., and I. Simmers. 2002. Groundwater recharge: an overview of processes and challenges. *Hydrogeology Journal* 10:5-17.
- Diciccio, T. J., and J. P. Romano. 1988. A review of bootstrap confidence intervals. *Journal of the Royal Statistical Society, Series B (Methodological)* 50:338
- Efron, B. 1979. Bootstrap Methods: Another Look at the Jackknife. *The Annals of Statistics* 7:1-26.
- Efron, B., and R. Tibshirani. 1986. Bootstrap methods for standard errors, confidence intervals, and other measures of statistical accuracy. *Statistical Science* 1:54-75.
- Hardman, G., 1936. *Precipitation map of Nevada*: Nevada Agricultural Experiment Station.
- Harrill, J. R., and D. E. Prudic. 1998. *Aquifer systems in the Great Basin region of Nevada, Utah, and adjacent states - Summary report*: United States Geological Survey Professional Paper 1409-A.
- Jeton, A.E., Watkins, S.A., Lopes, T.J., and J. Huntington. 2005. Evaluation of precipitation estimates from PRISM for the 1961-90 and 1971-2000 data sets, Nevada. United States Geological Survey Scientific Investigations Report 2005-5291.
http://pubs.usgs.gov/sir/2005/5291/PDF/SIR2005_5291.pdf
- Kirk, S. T., and M. E. Campana. 1990. A Deuterium-Calibrated Groundwater Flow Model of A Regional Carbonate-Alluvial System. *Journal of Hydrology* 119:357-388.
- Maurer, D. K. 1997. *Hydrology and ground-water budgets of the Dayton Valley Hydrographic Area, West-Central Nevada*. Water-Resources Investigations Report 97-4123, United States Geological Survey prepared in cooperation with the Carson Water Subconservancy District, Carson City, Nevada.
- Maxey, G. B., and T. E. Eakin. 1949. *Ground water in White River Valley, White Pine, Nye, and Lincoln Counties, Nevada*. No. 8, State of Nevada Office of the State Engineer prepared in cooperation with the United State Department of the Interior Geological Survey, Carson City, Nevada.
- Nichols, W. D. 2000. *Regional Ground-Water Evapotranspiration and Ground-Water Budgets*. Professional Paper 1628, United States Geologic Survey, Reston, Virginia.
- Natural Resource Conservation Service. 2003a. SNOTEL Monthly Precipitation Averages – 30 Year Period (1961-1990): accessed September 2003, at <http://www.wcc.nrcs.usda.gov/snow/30yrprec.html>
- Natural Resource Conservation Service. 2003b. Nevada SNOTEL site list: accessed September 2003, at <http://www.wcc.nrcs.usda.gov/snow/sntllist.html>
- Prudic, D. E., and M. E. Herman. 1996. Ground-water flow and simulated effects of development in Paradise Valley, a basin tributary to the Humboldt River in Humboldt

- County, Nevada. Professional Paper 1409-F, United States Geological Survey, Washington D.C.
- Rush, F. E. 1968. Index of Hydrographic Areas. Report 6, United States Geological Survey in cooperation with State of Nevada Department of Conservation and Natural Resources, Division of Water Resources, Carson City, Nevada.
- Sophocleous, M. 1997. Managing water resources systems: Why “safe yield” is not sustainable. *Groundwater* v. 35, no. 6, p. 561.
- Thomas, J. M., and W. H. Albright. 2003. Estimated groundwater recharge to Dry Valley, Northeastern Nevada, using the chloride mass balance method. Publication No. 41191, Division of Hydrologic Science, Desert Research Institute, University and Community College System of Nevada.
- Watson, P., P. Sinclair, and R. Waggoner. 1976. Quantitative evaluation of a method for estimating recharge to the desert basins of Nevada. *Journal of Hydrology* 31:335-357.
- Western Regional Climate Center, 2003, Western U.S. Climate Historical Summaries: accessed September 2003, at <http://www.wrcc.dri.edu/summary/>

Table 1: Typical Maxey-Eakin β -coefficients for individual precipitation zones.

Precipitation Zone (inches per year)	β
Less than 8	0.000
8 to less than 12	0.030
12 to less than 15	0.070
15 to less than 20	0.150
≥ 20	0.250

Table 2: Nichols β -coefficients for individual precipitation zones.

Precipitation Zone (inches per year)	β
Less than 8	0.000
8 to less than 12	0.008
12 to less than 16	0.130
16 to less than 20	0.144
20 to less than 34	0.158
≥ 34	0.626

Table 3: Ninety selected hydrographic areas with reported independent recharge estimates. Note that observation #78 skipped. Observation #'s pertain to basin identification in Figure 4 and are correlated with hydrographic area numbers.

Obs. #	Hydrographic Area Number	Hydrographic Area Name	Hydrographic Subarea Name	Independent Recharge Estimate (acre-feet/year)	Source
1	111A	Alkali Valley	Northern Part	300	2
2	57	Antelope Valley		11,600	3
3	151	Antelope Valley		4,200	2
4	186A,B	Antelope Valley	Southern and Northern Part	16,000; 7,200	7,2
5	94	Bedell Flat		300	2
6	178A	Butte Valley	Northern Part	8,690	2,3
7	178A,B	Butte Valley	Total	70,500	7
8	178B	Butte Valley	Southern Part	11,925; 12,000	2,4
9	55	Carico Lake Valley		4,500; 8,650	2,3
10	180	Cave Valley		12,000	5
11	143	Clayton Valley		24,010	2
12	177	Clover Valley		20,700; 59,100; 87,100	1,7,3
13	171, 172	Coal Valley and Garden Valley		11,000	5
14	118	Columbus Salt Marsh Valley		3,800	2
15	210	Coyote spring Valley		5,300	5
16	54	Crescent Valley		29,850	3
17	103	Dayton Valley		22,500	6
18	182	Delamar Valley		1,800	5
19	31	Desert Valley		900; 10,900	2,3
20	181	Dry Lake Valley		6,700	5
21	95	Dry Valley		2,280; 3,100	2,9
22	16	Duck Lake Valley		7,000; 9,000	2,4
23	104	Eagle Valley		6,000	2
24	133	Edwards Creek Valley		7,300	2
25	122	Gabbs Valley		4,300; 5,200	2,4
26	187	Goshute Valley		41,000	7
27	71	Grass Valley		12,800	2
28	138	Grass Valley		12,700	2
29	3	Gridley Lake Valley		200	2
30	156	Hot Creek		10,600; 5,800; 6,100	1,7,2
31	24	Hualapai Flat		6,000	2
32	113	Huntoon Valley		300	2
33	188	Independence Valley		9,300; 50,200	1,7
34	135	Ione Valley		4,000	2

35	174	Jakes Valley		17,600; 20,700	7,5
36	132	Jersey Valley		300	2
37	206	Kane Springs Valley		1,000	5
38	66	Kelley Creek Area		27,200	3
39	139	Kobeh Valley		15,000	2
40	183	Lake Valley		11,500	2
41	212	Las Vegas Valley		30,000	1
42	92A,B	Lemmon Valley	Western Part and Eastern Part	1,500; 1,800	2,4
43	150	Little Fish Lake Valley		9,600; 10,200	7,2
44	155A,B,C	Little Smoky Valley	Northern, Central, and Southern Parts	11,500; 8,600	7,2
45	175	Long Valley		38,000	7
46	59	Lower Reese River Valley		55,350	3
47	8	Massacre Lake Valley		4,500	2
48	58	Middle Reese River Valley		14,300; 16,850	2,3
49	140A	Monitor Valley	Northern Part	8,000	2
50	140B	Monitor Valley	Southern Part	11,200	2
51	136	Monte Cristo Valley		370	2
52	154	Newark Valley		52,000	7
53	96	Newcomb Lake Valley		140	2
54	228	Oasis Valley		2,400	2
55	209	Pahrnagat Valley		1,500	5
56	208	Pahroc Valley		2,000	5
57	69	Paradise Valley		74,000	8
58	170	Penoyer Valley		13,500; 3,800; 3,200	1,2,4
59	29	Pine Forest Valley		14,000	2
60	53	Pine Valley		24,400; 62,850	2,3
61	130	Pleasant Valley		2,200	2
62	65	Pumpnickel Valley		29,800	3
63	173A	Railroad Valley	Southern Part	5,000	4
64	173B	Railroad Valley	Northern Part	67,000	7
65	123	Rawhide Flats		800	2
66	99	Red Rock Valley		850	2
67	119	Rhodes Salt Marsh Valley		300	2
68	62	Rock Creek Valley		14,400	3
69	176	Ruby Valley		68,000; 148,000	1,7
70	22	San Emidio Desert		3,300	2
71	20	Sano Valley		30	2
72	146	Sarcobatus Flat		3,700	2
73	134	Smith Creek		8,000	2
74	121A	Soda Spring Valley	Eastern Part	700	2
75	85	Spanish Springs Valley		1,000	2

76	184	Spring Valley		94,000; 74,000; 62,000	7,2,4
77	179	Steptoe Valley		129,500; 70,000	7,2
79	145	Stonewall Flat		200	2
80	86	Sun Valley		25	2
81	114	Teels Marsh Valley		1,490	2
82	189A,B,C,D	Thousand Springs Valley	Toano-Rock Spring Area, Rocky Butte Area, and Montello-Crittenden Cr. Area	21,000	2
83	185	Tippett Valley		11,900	7
84	56	Upper Reese River Valley		60,600	3
85	4	Virgin Valley		6,000	2
86	110C	Walker Lake Valley	Whiskey Flat-Hawthorne Subarea	4,600	2
87	84	Warm Springs Valley		2,025	2
88	89	Washoe Valley		9,700	2
89	60	Whirlwind Valley		15,750	3
90	207	White River Valley		53,000; 35,000	1,5
91	63	Willow Creek Valley		28,550	3

Sources: (1) Water Resource Bulletin (2) Water Resources Reconnaissance Series (3) Berger, 2000 (4) Dettinger, 1989

(5) Kirk and Campana, 1990 (6) Maurer, 1997 (7) Nichols, 2000 (8) Prudic and Herman, 1996 (9) Thomas and Albright, 2003

Table 4: BBRM β -coefficients descriptive statistics for individual precipitation zones.

Precipitation Zone (inches per year)	β		95 % Confidence Interval	
	Mean	St Dev	Lower	Upper
0 to less than 10	0.019	0.011	0.000	0.041
10 to less than 20	0.049	0.012	0.029	0.074
20 to less than 30	0.195	0.129	0.040	0.482
≥ 30	0.629	0.278	0.127	0.999

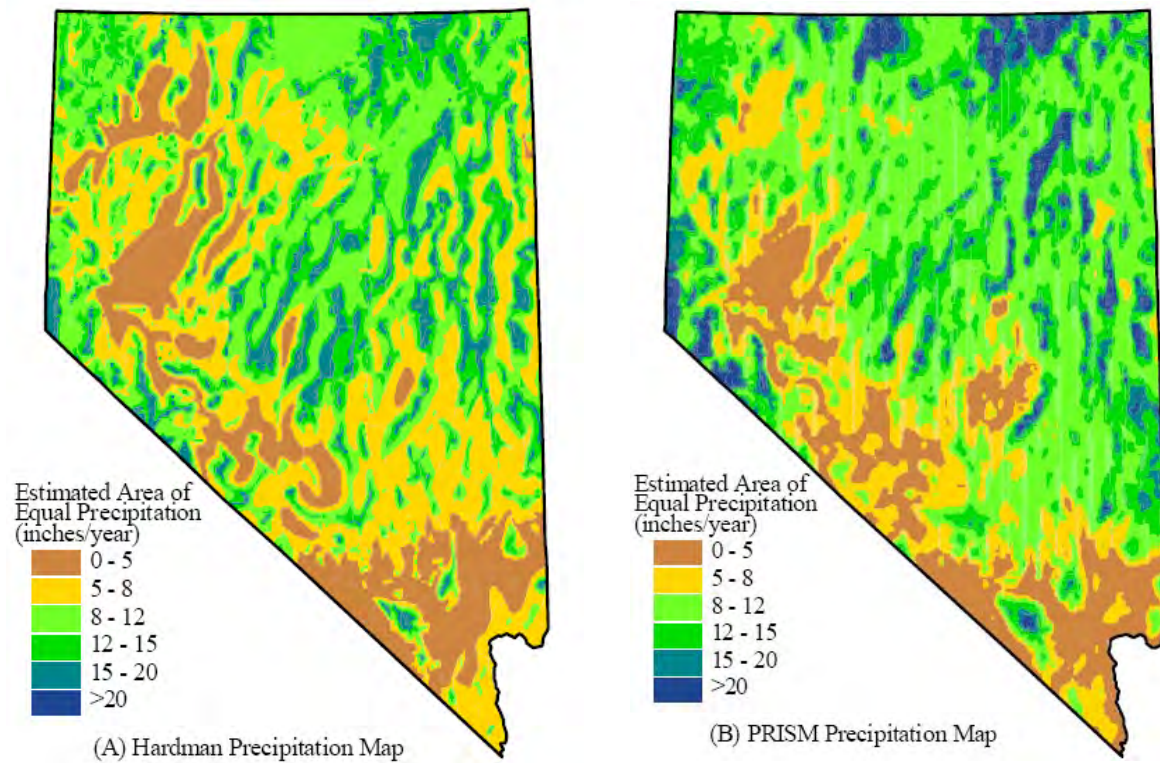


Figure 1: Equal precipitation intervals for the (a) 1965 Hardman precipitation map and (b) 1998 PRISM precipitation map. Overall, the PRISM map predicts more precipitation than the Hardman map.

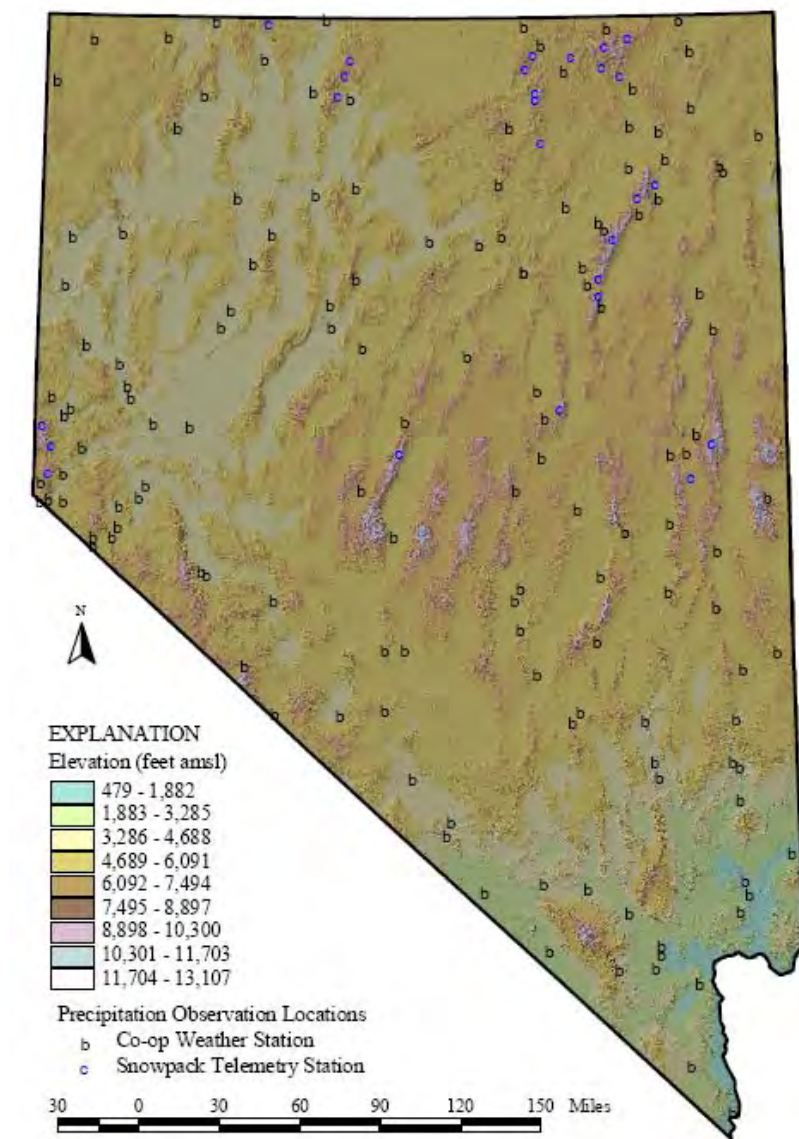


Figure 2: Location of Cooperative National Weather Service and Snow Telemetry (SNOTEL) precipitation observations.

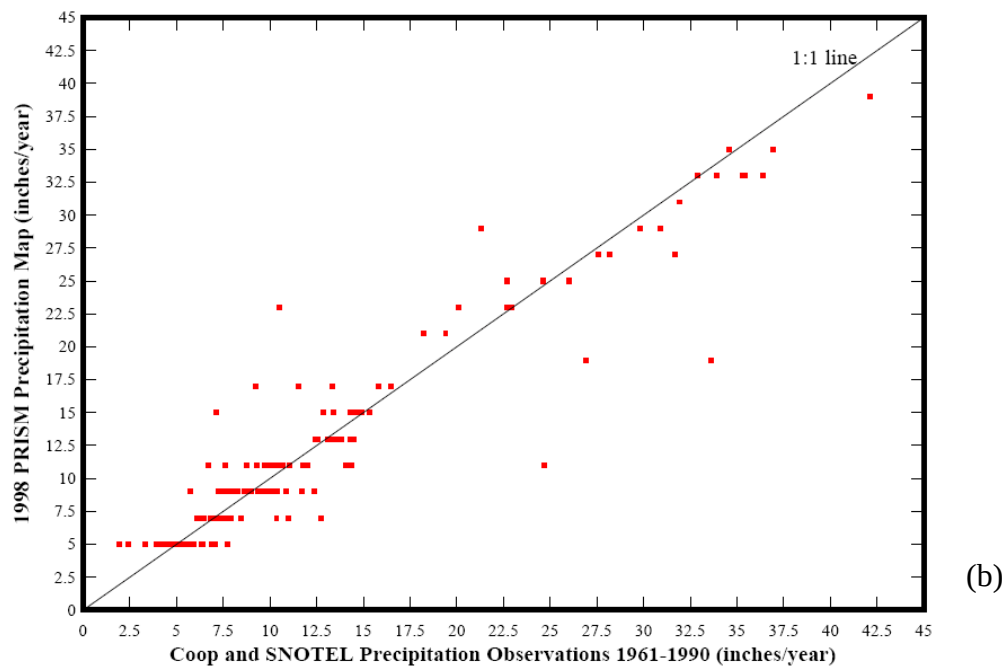
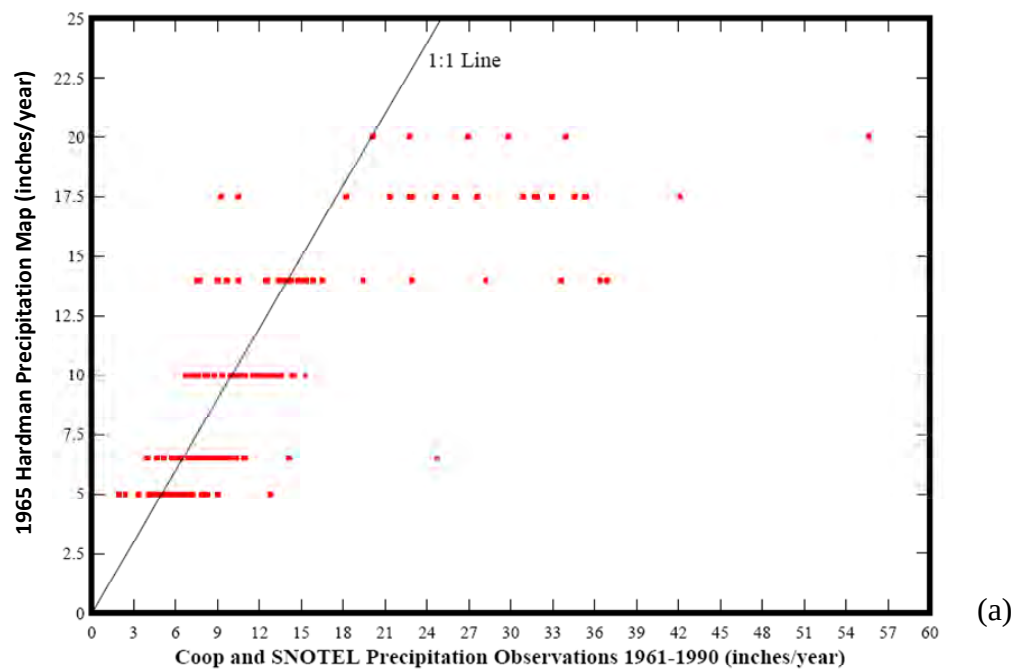


Figure 3: A comparison of thirty-year (1961-1990) normalized precipitation observations at Nevada weather stations with the (a) 1965 Hardman and (b) 1998 PRISM map precipitation predictions.

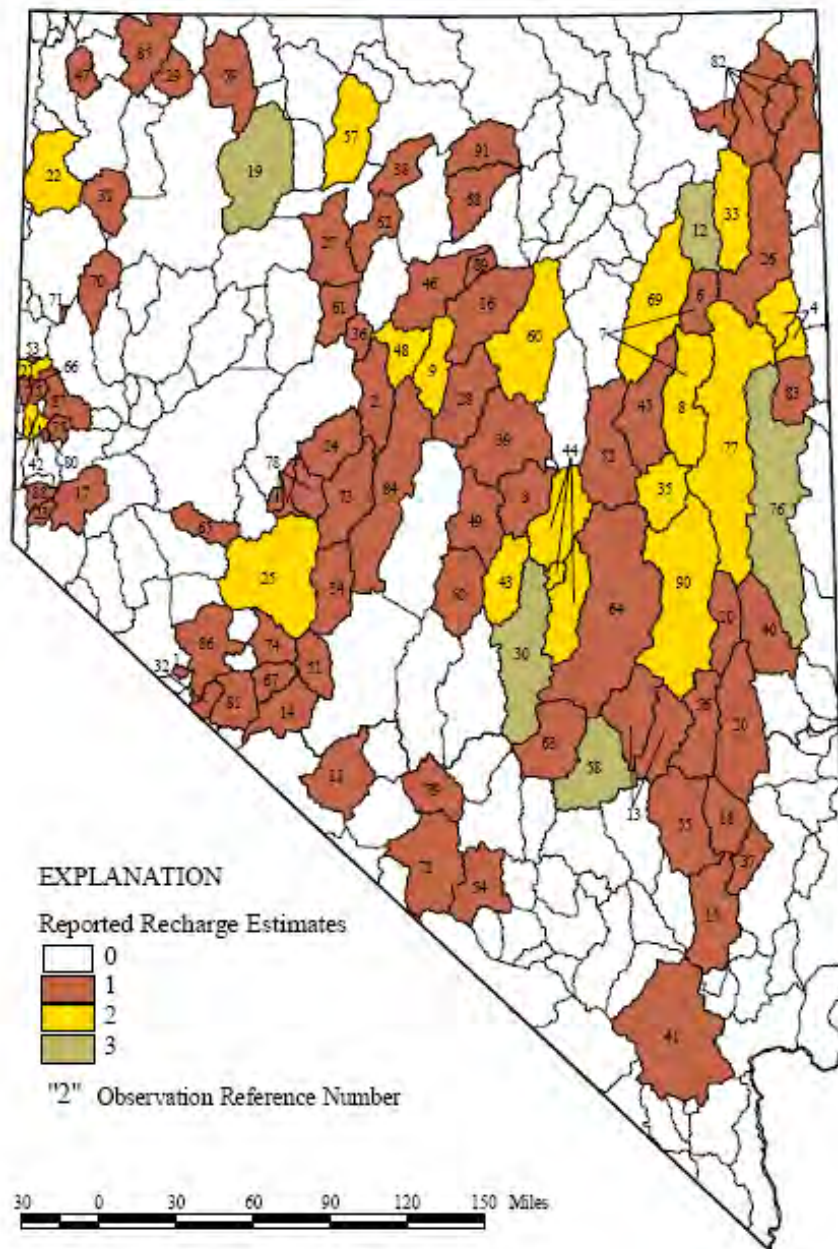


Figure 4: Ninety hydrogeographic areas used to calibrate BBPM β -coefficients. The number of independently reported recharge estimates are color coded. Basin observation numbers are correlated to hydrographic area identification numbers in Table 3.

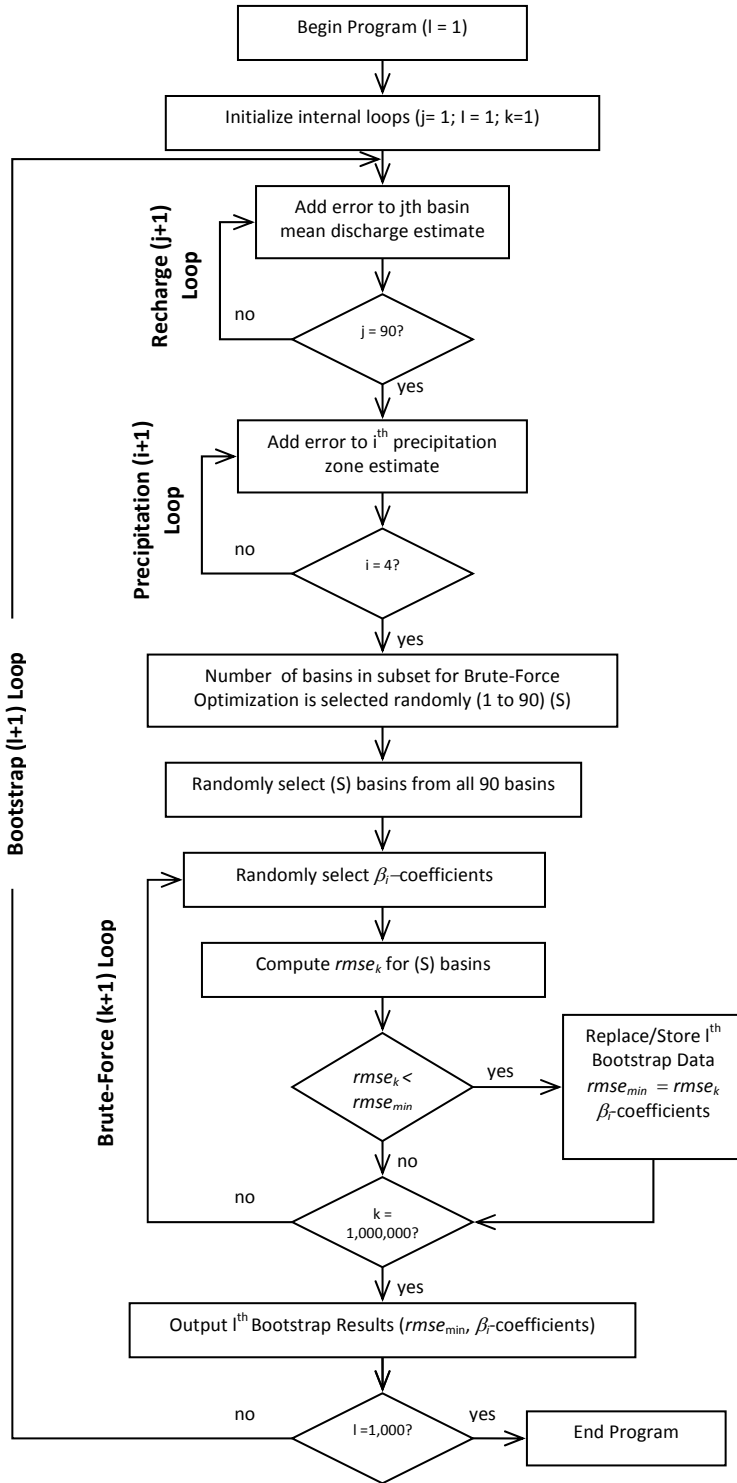


Figure 5: Schematic of the bootstrap brute-force approach.

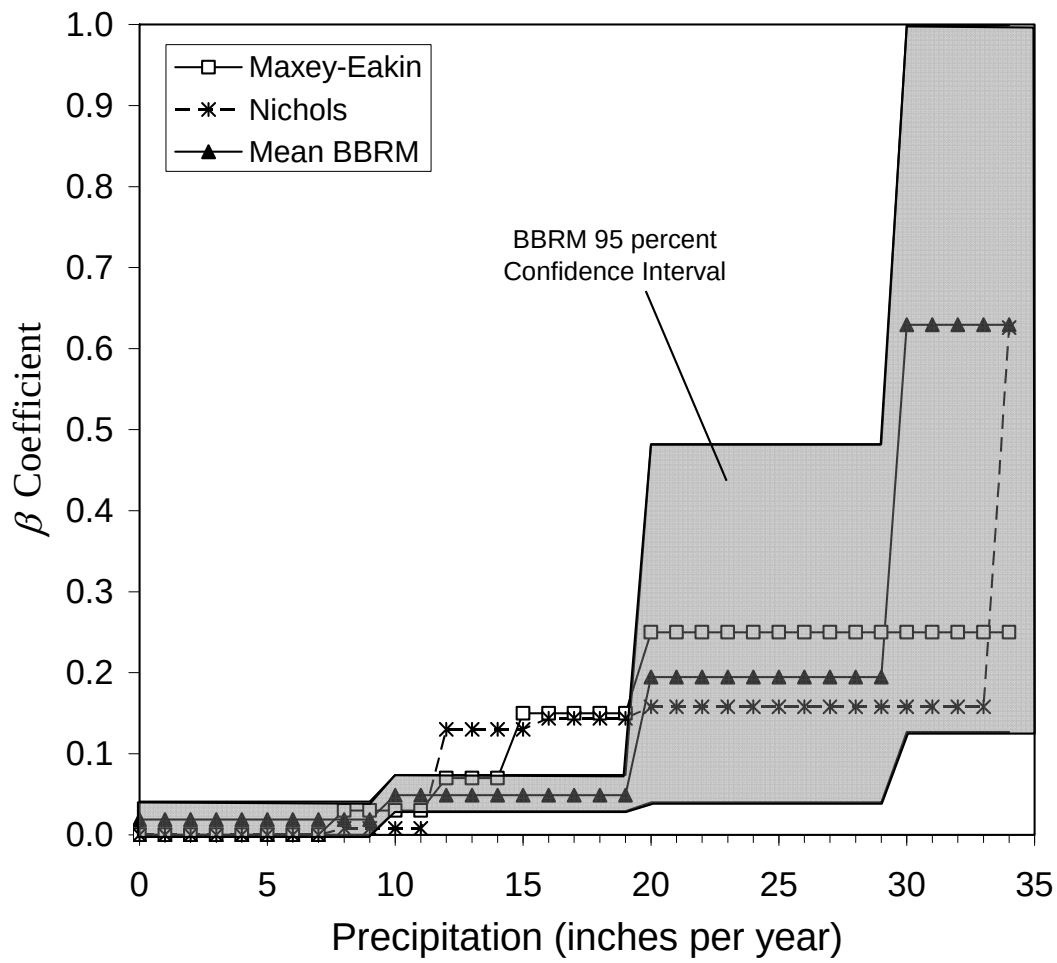


Figure 6: Comparison of calibrated β -coefficients for different empirical models.

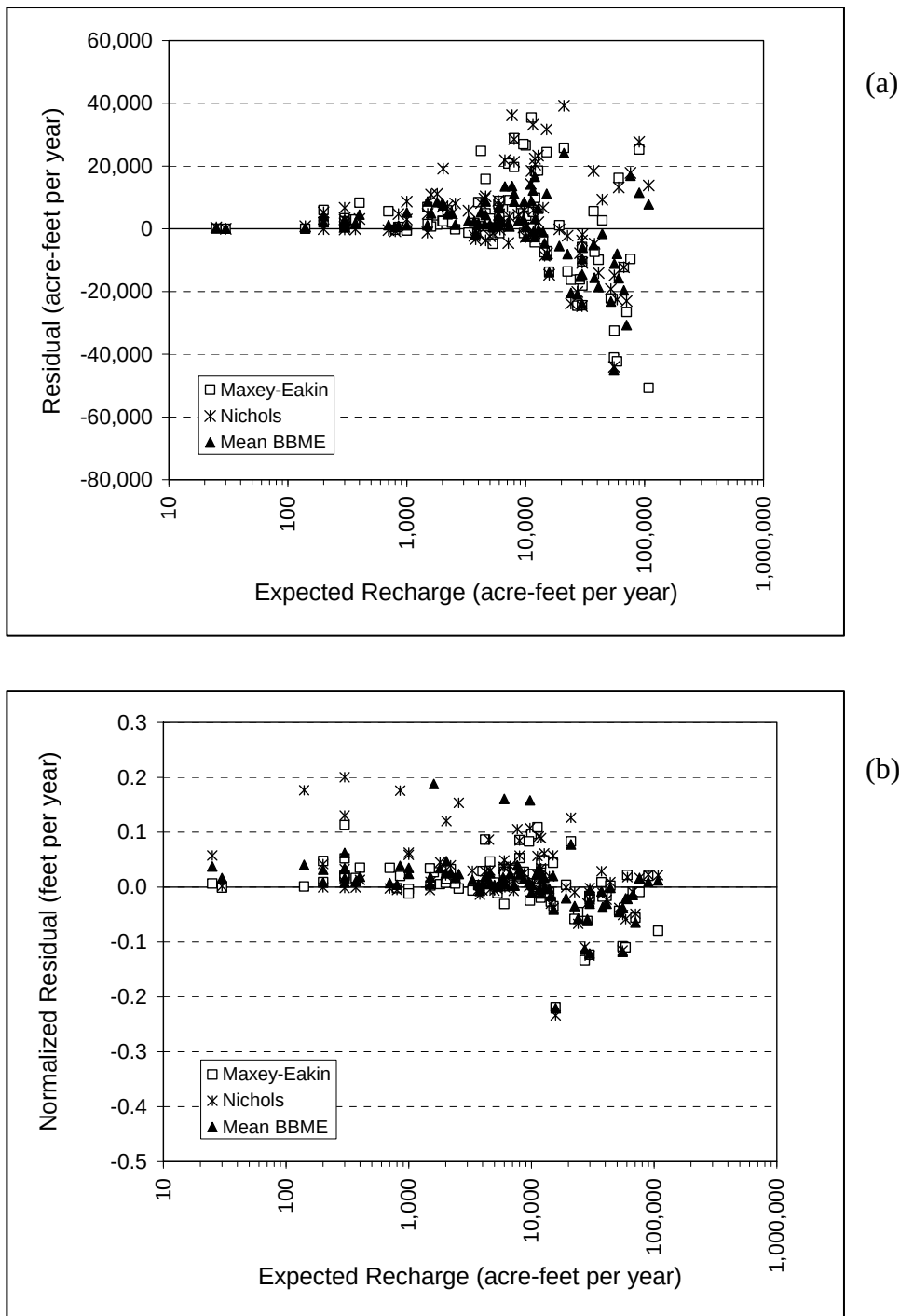


Figure 7: (a) Residuals (predicted minus expected mean) and (b) normalized residuals (residual divided by basin area) for the three empirical models examined.

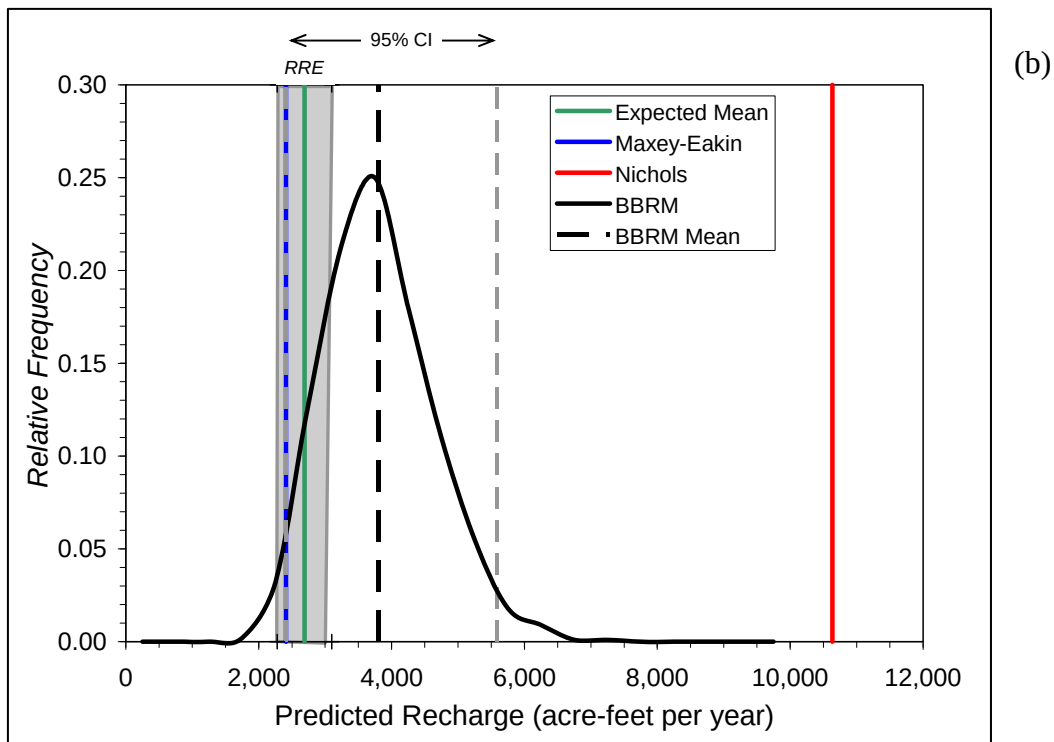
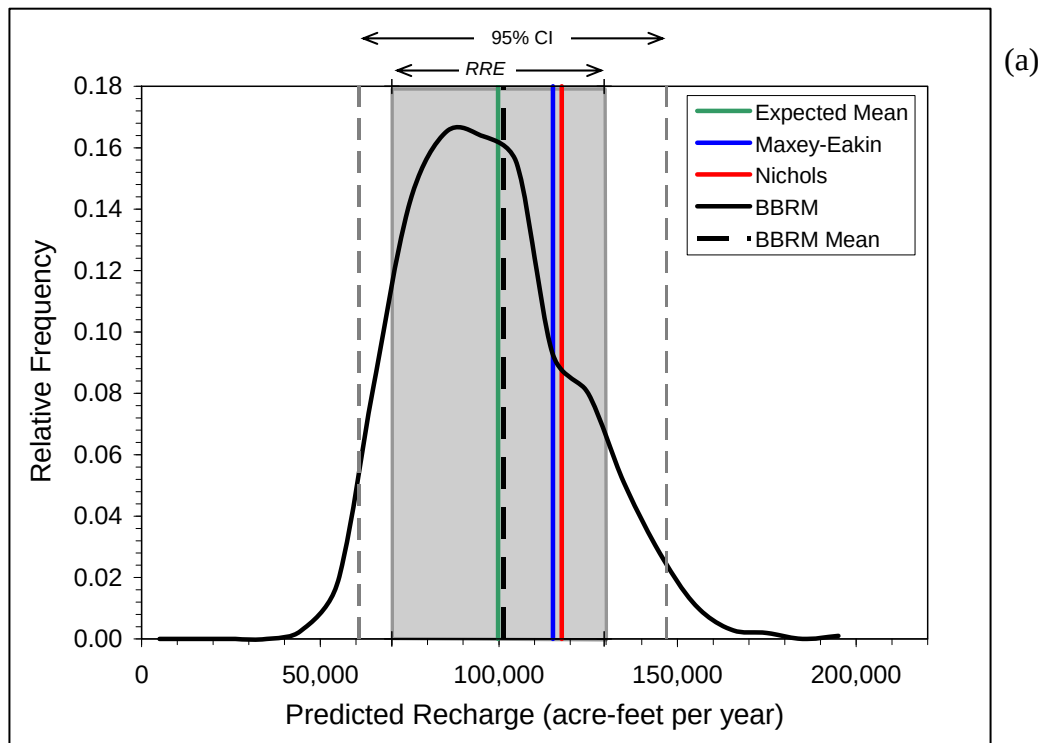


Figure 8: Model predicted recharge for (a) Steptoe Valley (observed #77 in Figure 4), and (Dry Valley (observed #21 in Figure 4). The bell shaped curves represent the recharge predicted by the BBRM using all 1000 coefficient sets.

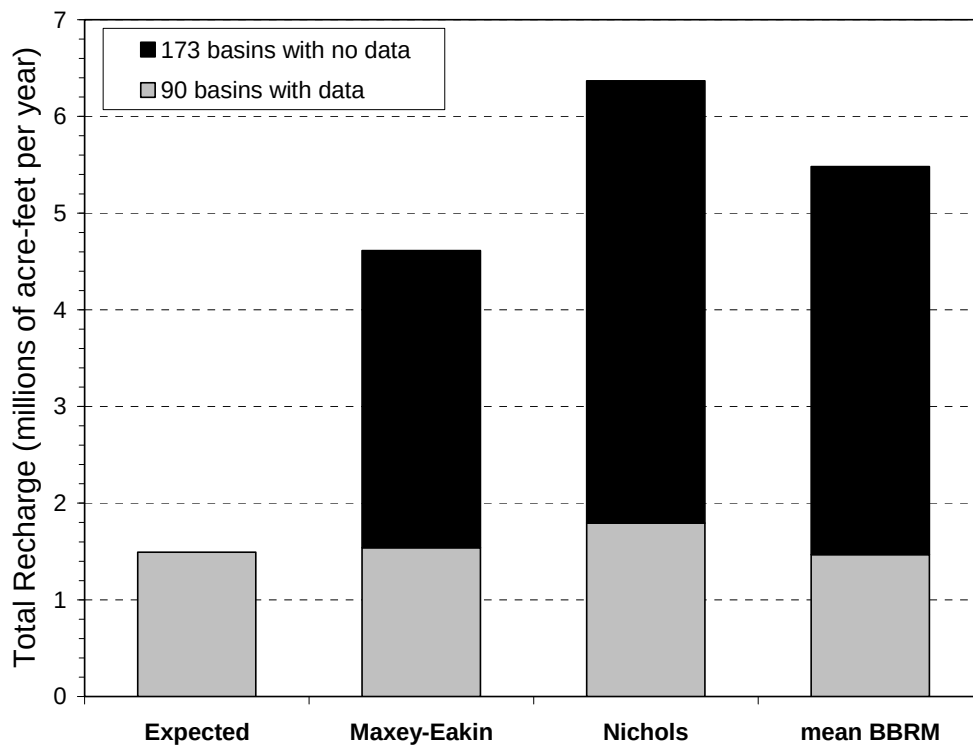


Figure 9: Total recharge (millions of acre-feet per year) for the state of Nevada.

WATER QUALITY DATA MODELING TO MINIMIZE EUTROPHICATION IN TRUCKEE RIVER, NEVADA

ANPALAKI J. RAGAVAN, Departments of Mathematics and Statistics, and Civil and Environmental Engineering, University of Nevada, Reno, NV 89557 (ragavan@unr.edu)

ABSTRACT

High total phosphorus concentrations (TP) are the major cause for eutrophication which leads to poor water quality in Truckee River, Nevada. Identifying the exact pattern of relationship among multiple independent variables related to high TP is important to implement remediation methods. In this study linear and non-linear relationship of multiple independent variables to TP in Truckee River were modeled. Independent variables included alkalinity(ALK), total soluble phosphorus concentrations(STP), stream flow(SF), water pH (pH), water temperature(TEMP), Dissolved oxygen(DO) and dissolved organic carbon(DOC) sampled monthly at the same time as TP (from January 1997 to December 2007) over six monitoring sites (McCarran Bridge(MB), Wardsworth Bridge(WB), Steamboat Creek(SC), Derby Dam(DD), Lockwood(LW), and North Truckee Drain(NTD)) along Truckee River, Nevada. Seasonal variations and man-made intervention in TP were included in the analysis. A non-linear multiple regression model built for the dependent variable (TP), as a function of the independent variables was optimized with respect to TP, subject to non-linear constraints and boundary values. Increase in SF, DO and TEMP resulted in decreased TP by non-linear relationships. Increases in STP, DOC and ALK increased TP linearly. Fitted non-linear regression model closely predicted TP in the river explaining 97% of total variation ($R^2 = 0.908$) in TP. Model forecasted TP agreed well with observed TP. All independent variables influenced TP significantly at 1% significance level ($p < 0.0001$). All six sites contributed significantly towards overall TP at 5% significance level ($p < 0.0001$). Site SC is currently the major contributor of high TP followed by NTD in Truckee River.

INTRODUCTION

Water quality management involves issues related to municipal, industrial and amenity irrigation practices. Historical agricultural practices and river diversions have lead to increased concentrations of total phosphorus (TP) in the Truckee River and the subsequent heavy growths of aquatic weeds and benthic algae, caused by the high nutrient loadings and the low stream flows resulting in poor quality of water. In addition the recent deposition of effluent from waste water treatment plants into the river have modified the natural cycle of phosphorus, the relationship of which to soil use and agricultural, domestic and industrial activities are expected to rise in the future. Increased TP has been reported in the past to result in decreased levels of dissolved oxygen (DO) in the river due to plant respiration and decaying biomass (EPA, 1994). Low DO levels have also reported to impair the river's ability to support populations of Lahontan cutthroat trout, a threatened species, and cui-ui (kwee-wee), a national endangered species (EPA, 1994). There is also spatial variability in different catchments in phosphorus loading into Truckee River which imposes tremendous uncertainty in pollution load estimation. Determination of relationship among factors affecting or causing variation of total phosphorus concentrations can provide a robust solution to quantify total phosphorus pollution in developed areas in Nevada where agricultural activities and treated waste water effluent may have an effect on surface water quality.

This study evaluates the relationship between TP and nine independent variables (soluble total phosphorus concentration(STP), stream flow(SF), dissolved organic carbon(DOC), dissolved oxygen(DO), alkalinity(ALK), water pH(H^+), water temperature (TEMP) and seasonal and cyclical variations in TP) in the Truckee River was modeled as closely as possible through fitting an optimized non-linear multiple regression model (NLMR). The optimized model will enable designers to target and

manage TP in the Truckee River accurately. The developed model can provide guidance to probable range and type of TP loads generated and deposited into the Truckee River and the type and level of influence of the several water quality factors on TP levels, hence on eutrophication.

Study area

The Truckee River flows from south of Lake Tahoe, 140 mi (225 km) long into the northern basin's of Nevada and California, draining part of the high Sierra Nevada and emptying into Pyramid Lake in the Great Basin (USEPA, 1991). It flows generally northwest through the mountains to Truckee, California, and then turns sharply to the east and flows along the northern end of the Carson Range into Nevada past the Reno Sparks metropolitan area (Figure 1). Within and east of the Truckee Meadows, fourteen ditches remove water for irrigation. The most significant diversion is the Derby Dam, where at least 32% of the river's water is diverted annually (Peternel and Laurel, 2005). TMWRF currently maintains 11 continuous monitoring stations within the Truckee water system. These stations are located at: Mogul, SC, MB, NTD, LW, Patrick, Waltham, Tracy, Painted Rock, Wadsworth and Marble Bluff Dam. The Lockwood (LW) monitoring site is currently chosen as the compliance site for assessing total maximum daily loads (TMDL) for phosphorus into the Truckee River because most controllable sources are thought to be upstream. LW monitoring site is located in the lower Truckee River basin 65.6 river miles from Lake Tahoe located down stream, of MB, NTD, and SC monitoring sites and Vista (www.tmwrf.com) (Figure 2).

Background and hypothesis

Truckee River's waters are an important source of drinking and irrigation for people in Nevada. As discussed previously, heavy agricultural activities and the prevalence of water diversions in the past have caused a decline in Truckee River's water quality and the subsequent detrimental effects on habitats. Added to this are the recent increased urbanization and the discharge of effluent from waste water treatment plants especially from the state of California into the Truckee River. The water quality in the Truckee River is very good near Lake Tahoe, although Lake Tahoe is listed in the 2006 NDEP 303(d) list of impaired waters (for clarity), but as it descends, the levels of nutrients and suspended solids increase. NDEP has listed the Truckee River (from the state-line to the Wadsworth) as impaired for one or more of the following parameters: temperature, turbidity, or total dissolved solids. The California State Water Resources Control Board (State board) has classified the middle reach of the Truckee River as "impaired" under Section 303(d) of the Clean Water Act. The more recent increased treated effluent discharge into the Truckee River from the town of Truckee, CA has intensified the problem. Clearly there is a need to restore Truckee River to a more natural condition to improve habitat, water clarity and the river's overall health.

In addition, currently there is a need for a consistent, scientifically defensible approach for assigning nutrient criteria for Truckee River water, to control eutrophication. Until now, exceedances of TP in Truckee River, has been considered to be the major cause of eutrophication in the River (EPA, 2007) which has lead the beneficial use criteria of EPA to focus on phosphorus (not nitrogen) for eutrophication control. Recently, researchers are reporting other variables such as DO, SF, TEMP and H^+ to affect biomass activity and growth in the river hence eutrophication. All the above factors that affect biomass in the river also directly or indirectly influence TP. The relationship of these variables to TP in the Truckee River has not been studied and not fully understood. In many cases the impacts of phosphorus levels on the beneficial uses, e.g. aquatic life, recreation, etc are not known. Some algae are a necessary component of the ecosystem, while excessive algae can impact the beneficial uses in a variety of ways. Inadequacy of information regarding TP in Truckee River currently limits the ability of NDEP to revise the values to impose design criteria for phosphorus in the Truckee River (required for determining, use status for the 303(d), Impaired Waters List (Category 5 of the Integrated Report)) (NDEP, 2007). Subsequently, implementing the beneficial use criteria is challenged. The eutrophication problem still persists.

The TMDL compliance level for TP in the Truckee River is currently 0.075 mg l^{-1} (214 lbs day^{-1}) set at the Lockwood (LW) monitoring site although the spatial variation (variations among monitoring sites) of TP in Truckee River has not been studied well. This level of compliance may need to be revised in terms of value and location to make more stringent regulations for phosphorus to protect Truckee River water.

In addition, phosphorus has been classified by the Environmental Protection Agency (NDEP, 1994) as a conservative pollutant (conservative pollutants and not reactive and persist in the water segment of the aquatic environment over time remaining essentially constant in concentration), hence not expected to be perturbed by seasonal variations or other short term cyclical and non-cyclical variations in the system. Conservative pollutants are expected to vary in concentrations directly only with the volumes of flows of discharges of the receiving water body. However, it is possible that TP in Truckee River can be affected by seasonal urban activities, periodic diversions and other cyclical and non-cyclical man made disposals. This classification needs revising in the future too.



Figure 1: Truckee River in Reno, Nevada



Figure 2: TMWRF Monitoring Stations
(Source: <http://truckeetriverinfo.org/gallery>).

OBJECTIVES

1. To closely study the relationship of total phosphorus concentration to multiple independent variables (alkalinity, total soluble phosphorus concentration, stream flow, H^+ , water temperature, dissolved organic carbon, dissolved oxygen and seasonal and cyclical variations) in Trucker River, Nevada.
2. Using non-linear multiple regression with optimization to forecast TP as a function of multiple independent variables influencing TP in the Truckee River.

LITERATURE REVIEW

Because of the endangered species present and due to the fact that Lake Tahoe Basin comprises the headwaters of the Truckee River, the Truckee River has been the focus of several water quality investigations, the most detailed starting in the mid-1980s. Under the direction of the U.S. Environmental Protection Agency, comprehensive dynamic studies have been undertaken to study the impacts of a variety of land use and wastewater management decisions throughout the 3120 square mile Truckee River Basin and also to provide guidance to other U.S. river basins (USEPA, 1991). Analytes mostly addressed include nitrogen, phosphorus, DO, and total dissolved solids. Impacts upon, the receiving waters of Pyramid Lake has also been analyzed (Truckee River Geographic Response Plan, 2005).

According to EPA (2000), nitrogen and phosphorus are the main nutrients that cause excessive algal growth in Truckee River. Elevated phosphorus loads have encouraged the proliferation of aquatic plants and benthic algae (EPA, 2000). Respiration by these plants and the decay of their associated detritus can

decrease dissolved oxygen (DO) in the water column, resulting in violations of the DO standard (EPA, 2000). However, violations of the in-stream DO standard have continued in spite of nutrient removal enhancements by the TMWRF (NDEP, 1993). Jeppesen et. al., (2005) have also reported reduction of external total phosphorus (TP) loading to result in significantly lower in-lake TP concentration, lower chlorophyll *a* concentration and higher Secchi depth in a number of lakes. When nutrient concentrations were high enough effective growth of biomass was independent of aeration and subsequent increase in dissolved oxygen concentrations (Jeppesen et. al., 2005).

According to Tetra Tech, (2005) the use of nutrient concentrations alone are poor predictors of assessing eutrophication impacts. The following results are in support of their statement. Dodds and others, (2002) found by examining data from over 600 streams that nutrient concentrations to account for less than half of the variability in the benthic algae biomass. They speculated that other factors, such as flow, light availability, temperature, channel conditions, and grazing, were responsible for the remaining variability. In a detailed study of Colorado streams, Lewis, Jr. and McCutchan (2005) found even less of a relationship between nutrient concentrations and benthic biomass, with dissolved inorganic nitrogen accounting for only 15% of the variance. No significant relationship was found between benthic biomass and other nitrogen and phosphorus species. Biggs (2000) have explained 62 percent of the variance in peak biomass by the time since the last flood event.

Increased water temperature increased biological activity, including algae growth (Tetra Tech, 2002). However, *Cladophora* algae, has been found to die-off at temperatures exceeding 23.5°C (Dodds and Gudder, 1992). These die-off events also lead to low DO levels as the algae decayed. Lewis, Jr. and McCutchan, Jr. (2005) identified an inverse relationship between periphyton biomass and elevation, therefore a positive relationship between biomass and temperature. In another experiment on the effects of temperature (five 4-day cycles for 21 days, to represent: 7°C ⇒ 13°C ⇒ 23°C ⇒ 13°C ⇒ 7°C) on water column TP concentrations, TP was significantly higher under low-temperatures and significantly lower under high-temperatures (23°C) (Spears et. al., 2008). According to Bores et. al., (2008), alkaline waters with high levels of TOC and DOC resulted in hypotrophic levels of TP, although the nitrogen-phosphorus ratio was below 1. It was concluded that the low N/P ratio was caused by high pH (pH > 9). Plankton community increased as acidification of lake was increased (Boros et. al., 2008). Most aquatic organisms tolerate a limited range of pH, and most fish require a pH of 5.5 or higher for successful growth and reproduction.

From the above studies it can be conceptualized that a non-linear complex relationship exist among TP, biomass growth and several water column parameters affecting biomass growth in lakes. The interactive relationship of TP to multiple water quality parameters require careful further studies if phosphorus is to be used as criteria for eutrophication control in Truckee River. Identifying the relationship among STP, SF, DO, H⁺, DOC, ALK, TEMP and TP closely in Lake Tahoe with an optimization technique could help identify the level and type of impact of TP on eutrophication.

METHODS

Software used

SAS® software was used to perform all the analyses and to generate all the plots and all the tables presented in this paper except Figure 1 and Figure 2.

Data evaluation

Monthly values of the seven independent variables (STP, SF, DO, H⁺, DOC, ALK, TEMP) studied and of TP for the period from January of 1995 through December of 2007 for the 6 monitoring locations (MB, WB, SC, DD, LW and NTD) were obtained from Truckee Meadows Water Reclamation Facility (TMWRF, www.tmwrf.com). The TP concentration included a total of all the dissolved phosphorus species. The data from January of 1997 through December of 2004 were used to fit the NLMR model. The data from January of 2005 through December of 2007 were used to validate the fitted NLMR model through forecasting. The data from January 1995 through December 1996 were excluded from the

analysis since more than half of the values for TP were missing and data for several of the independent variables were not available.

All variables were tested and corrected for missing values, non-stationarity and multicollinearity for the following reasons. Regression analyses with time series data (data collected over discrete time intervals) require that the data modeled are stationary, which means that the statistical properties and variations in the data at any time are similar to those of the time-shifted data. All regression models also require that the independent variables are not correlated among themselves. When an independent variable is a linear combination of other independent variables in the model, the predicted regression estimates are unstable and the fitted model will have high standard errors. This problem is called variance inflation or multicollinearity. No multicollinearity among independent variables was detected in the data. In addition, missing values for any observation in any of the independent variables can lead to missing values in the objective function and non-stability of the fitted model.

Statistical analysis

Pearson correlation (simple linear relationship between two variables, not necessarily linear dependence) coefficients among pairs of independent variables were calculated. A cross sectional regression (significance of contribution of data from each site in predicting the overall TP, tested separately at 5% level of significance through standard Chi-square tests; Appendix: SAS® Code 1) was fitted to study spatial variability in overall TP in the Truckee River. An unobserved components analysis (data were decomposed into trend, seasonal and cyclical components and their significance tested at 5% level of significance using standard Chi-square tests; Appendix: SAS® Code 1) was performed to study the significance of overall trend and seasonal and cyclical variations in TP. Relationship among dependent (TP) and the independent variables were predicted through scatter plots, correlation coefficients, hypothesis testing and simple linear regression.

A non-linear multiple regression (NLMR) model (Harville, 1988; Searle, 1988) was fitted to establish the relationship between the dependent (TP) and the independent variables. An alpha level equal to 0.01 was used for estimating the regression coefficients (Appendix: SAS® Code 1). An alpha level of 0.05 was used for all other tests. Diagnostic statistics and residuals from the final selected model were tested for adequacy of the final fitted model. The following equation (objective function) was found appropriate and the best to predict TP as a function of the studied independent variables (Eq. 1).

Objective function

$$\begin{aligned} \text{TP} = & \text{beta1} + \text{beta2} * \text{DOC} - \text{beta3} * (\text{EXP}(\text{DO})) - \text{beta4} * (\text{LOG}(\text{SF})) + \text{beta5} * \text{pH} + \\ & 1.2065 * \text{STP} + \text{beta7} * (\text{EXP}(\text{Season}-12)) + \text{beta8} * (\text{EXP}(\text{Intervention}-12)) + \\ & \text{beta9} * (1/(1-\text{TEMP})) + \text{beta10} * \text{ALK} \end{aligned} \quad (1)$$

Sensitivity analysis

Sensitivity of the fitted NLMR model to changes in the regression coefficients and constraints in independent variables was analyzed through non-linear optimization with respect to minimum TP using Least Squares Minimization (LSQ) (Appendix: SAS® Code 2). Arithmetic averages of independent variables were used as initial values and varied subject to linear and non-linear constraints and boundary values of regression coefficients and values of independent variables. The following constraints of independent variables include all probable range of observed values for the independent variables: H^+ between 1 and 14, $\text{STP} \geq 0$, $\text{DO} \geq 0$, $\text{SF} \geq 0$, $\text{DOC} \geq 0$, and $\text{ALK} \geq 0$, subject to the following model constraints: $\text{Log}(\text{SF}) > 0$ and, $\text{TEMP} < 1$. Boundary values of estimates of regression coefficients were chosen accordingly. A list of all boundary values and linear and non-linear constraints used are shown below.

Boundary values

$$-3.2\text{E-}10 \leq \text{beta3} \leq 3.2\text{E-}10.$$

$$0 < \text{beta7} \leq 1.$$

$$0 < \text{beta8} \leq 1.$$

Non-Linear Constraints

$$\text{Log}(\text{SF}) > 0.$$

$$\text{TEMP} < 1.$$

$$1 \leq \text{pH} \leq 14.$$

$$\text{DOC, STP, ALK} \geq 0.$$

$$6.14421\text{E-}06 \leq \text{EXP}(\text{Season-12}) \leq 1.67017\text{E-}05.$$

$$6.14421\text{E-}06 \leq \text{EXP}(\text{Intervention-12}) \leq 1.67017\text{E-}05.$$

$$1 \leq \text{EXP}(\text{DO}) \leq 5.18471\text{E+}21.$$

Forecasting

The fitted NLMR model was used to obtain monthly forecasts for TP for the period from January 2005 through December 2007. Forecasted TP values were plotted along with observed TP values for the time period of forecast.

RESULTS AND DISCUSSION

Description of observed variables and relationship

Significant positive correlations were observed between DOC and STP (0.729, $p < 0.0001$), DOC and ALK (0.593, $p < 0.0001$) and STP and ALK (0.749, $p < 0.0001$) indicating alkaline conditions (usually high in DOC) can lead to high phosphorus concentrations and eutrophication in Truckee River. Significant negative correlation were observed between DO and TEMP (-0.788, $p < 0.0001$) indicating that high temperatures can favor the growth and decay of biomass in the Truckee River. No other correlations among independent variables were significant ($p > 0.05$). The overall mean TP ($0.117 \pm 0.096 \text{ mg l}^{-1}$, Table 1) in Truckee River was above the current compliance level for TP of 0.075 mg l^{-1} . The overall mean DO ($10.0 \pm 1.8 \text{ mg l}^{-1}$) met the NV water quality standards despite the high values of TP. The overall mean SF ($643.8 \pm 900.9 \text{ CFS}$) was low with standard deviation larger than the mean indicating the presence of extreme values (Table 1). Scatter plots of TP against the continuous independent variables (DO, DOC, STP, SF, TEMP, H^+ and ALK) are shown in Figures 3a through 3g.

The overall trend of TP in Truckee River is significantly ($p < 0.0001$) increasing. TP in Truckee River increased at a moderate rate until the beginning of 1999, showed a sudden large increase during 1999 and increased at a much faster rate than before 1999 until the end of December of 2004 showing values above the overall mean TP of 0.017 mg l^{-1} (Figure 4a). Significant ($p < 0.05$) periodic seasonal variations were observed in TP with a value of period equal to 12 months (Figure 4b). A significant long term cyclical variation ($p < 0.05$) was observed in TP with a value of period equal to 195.94 months, which could be due to periodic man-made disposals and/or diversion practices that were present in the Truckee River during the study period (Figure 4c).

Spatial and annual variations in TP

Largest values in TP (mean value of $0.252 \pm 0.081 \text{ mg l}^{-1}$) were observed at the monitoring site located at Steamboat Creek (SC) followed by the one at North Truckee Drain (NTD) (mean value of $0.208 \pm 0.073 \text{ mg l}^{-1}$) (Figure 5). The mean values of TP observed at SC and NTD were much above the compliance level for TP of 0.075 mg l^{-1} .

Table 1: Observed values of dependent and independent variables studied

Variable	N	Mean (mg/L)	Standard Deviation (mg/L)	Minimum (mg/L)	Maximum (mg/L)
TP	560	0.117	0.096	0.001	0.512
SF	560	643.8	900.9	5.0	5790.0
DO	574	10.0	1.8	4.5	14.4
DOC	575	3.1	2.1	0.1	22.4
STP	575	0.1	0.1	0.0	0.4
ALK	575	101.6	67.6	29.0	374.0
pH	574	8.0	0.3	7.0	9.0
TEMP	574	10.9	6.0	0.1	24.7

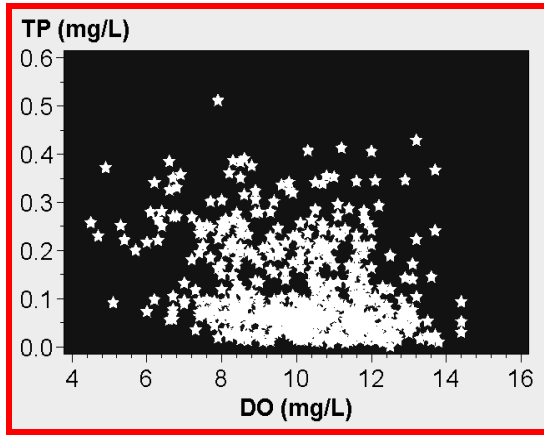


Figure 3a: Observed TP versus DO

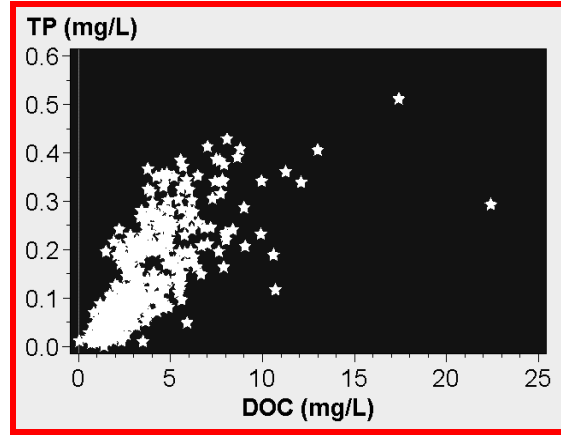


Figure 3b: Observed TP versus DOC

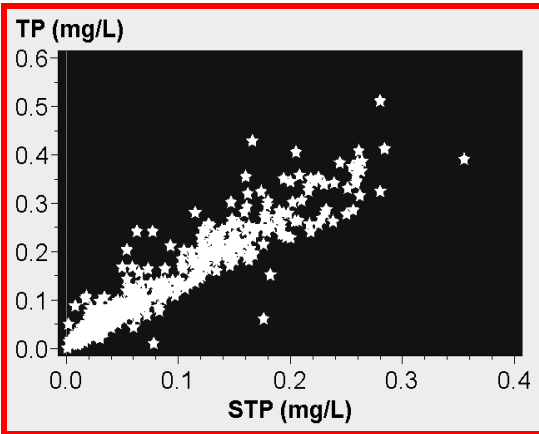


Figure 3c: Observed TP versus STP

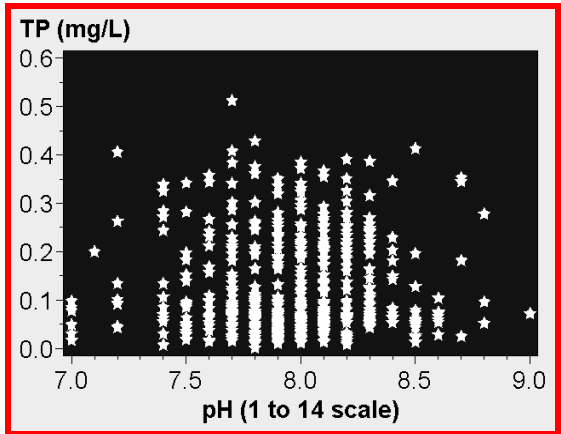


Figure 3d: Observed TP versus H^+

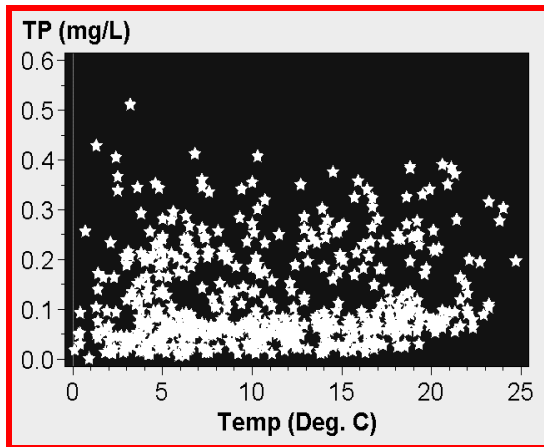


Figure 3e: Observed TP versus TEMP

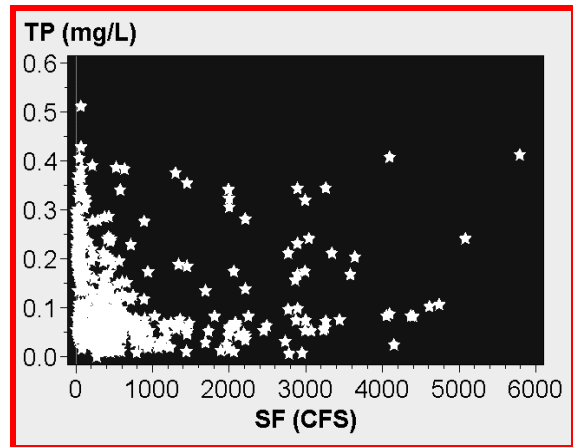


Figure 3f: Observed TP versus SF

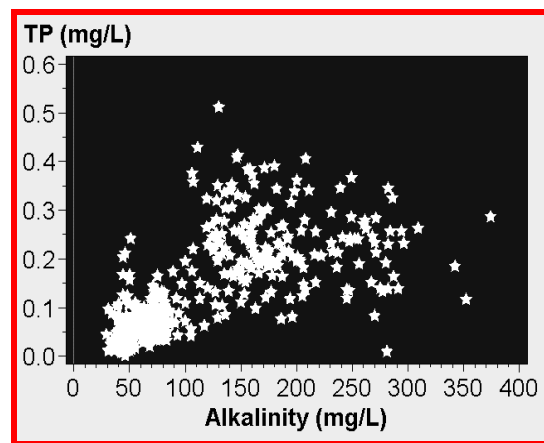


Figure 3g: Observed TP versus ALK

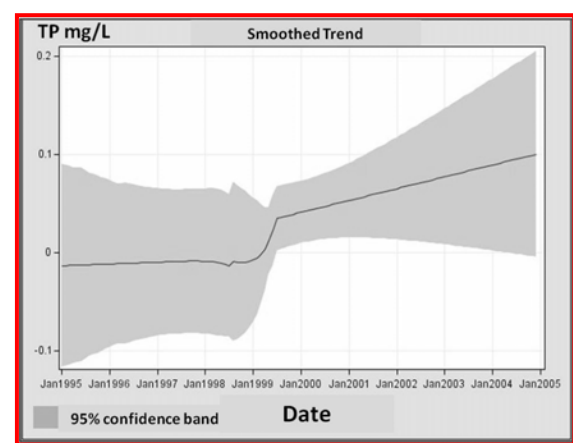


Figure 4a: Long term trend in observed TP with 95% confidence band (shaded area)

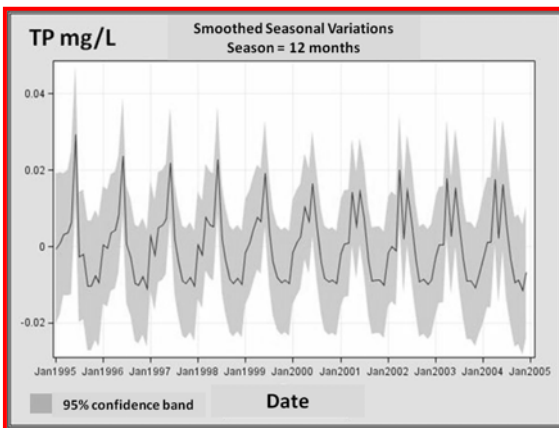


Figure 4b: Seasonal variations in observed TP with 95% confidence band (shaded area)

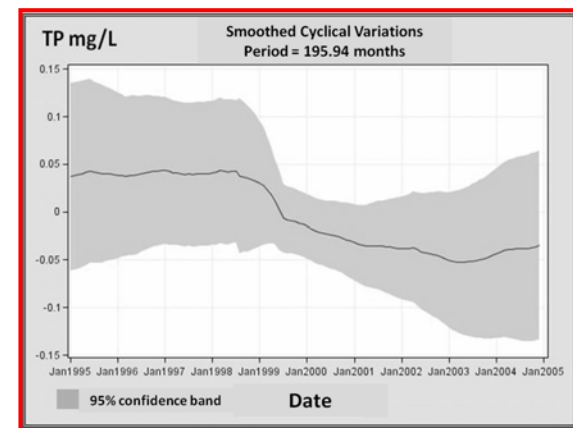


Figure 4c: Cyclical interventions in observed TP with 95% confidence band (shaded area)

The mean TP at Lockwood (LW) ($0.078 \pm 0.092 \text{ mg l}^{-1}$) was close to the compliance level (Figure 5). All sites contributed significantly ($p < 0.05$) towards overall TP in Truckee River (Table 2). Annual mean values at all sites were below the compliance level until 2000, increased to values much above the

compliance level between 2000 and 2002 and decreased thereafter until the end of 2004 (Figure 6). The maximum mean TP was observed during 2002 at all monitoring sites.

Spatial variations in DO and SF

Mean of observed stream flow (SF) did not vary significantly among sites. Site SC showed the most variation in SF with 50 percent of the observed SF values showing values less than 60 cubic feet per second (Figure 7a). Several extreme values of SF could be observed at all sites. No significant ($p>0.05$) differences were observed among monitoring sites in mean DO. Mean DO values were larger than 7.5 mg/L at all sites (Figure 7b). Lowest mean DO was observed at monitoring site SC.

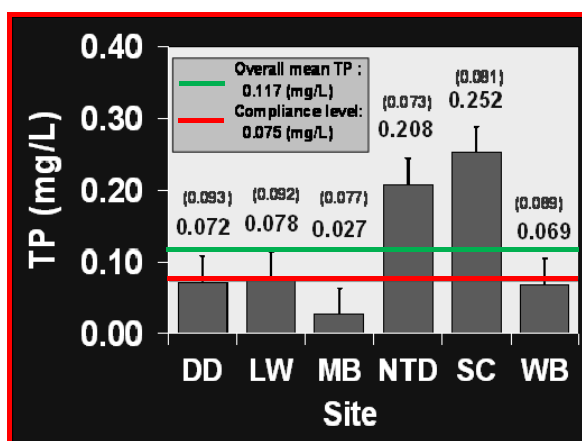


Figure 5: Observed mean values of TP by site (mean and standard deviations above bars)

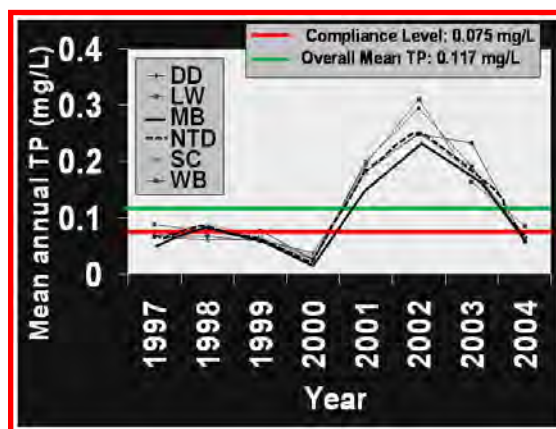


Figure 6: Annual variations in observed TP shown as a mean plot by year.

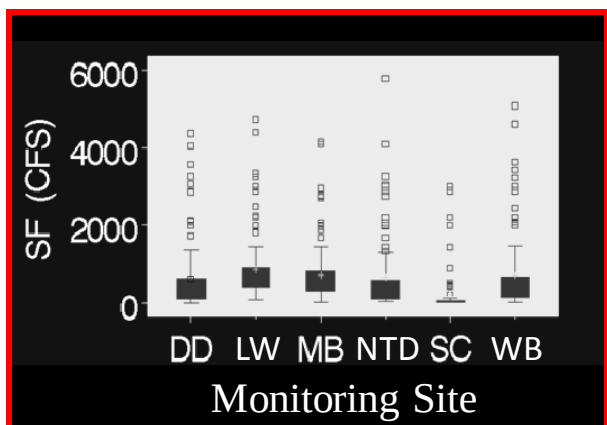


Figure 7a: Box plot of observed SF by site

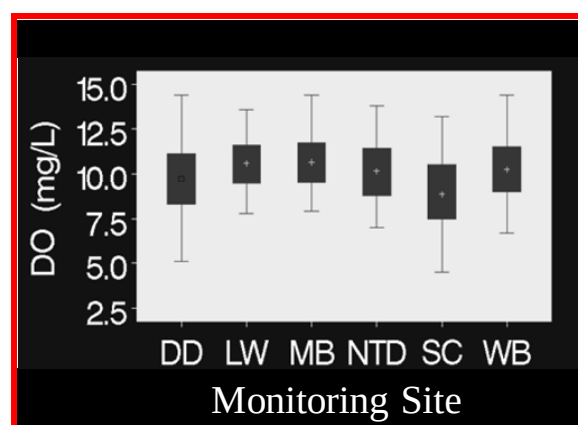


Figure 7b: Box plot of observed DO by site

Results from the NLMR model

Estimated regression coefficients of all studied independent variables were statistically significant ($p<0.05$) (Table 3). TP increased exponentially as SF decreased ($p<0.0001$) and DO decreased ($p<0.0001$) in the Truckee River and increased linearly as DOC, STP, pH or ALK increased ($p<0.05$) in the Truckee River. TP in the Truckee River was also affected significantly ($p<0.05$) by seasonal variations and cyclical intervention events ($p<0.05$) (Table 3). The fitted NLMR model explained 96.7 % of the total variation in TP in the Truckee River and predicted observed TP very closely ($R^2=0.908$, $n=559$) (Figure 8). The model predicted overall mean ($0.113 \pm 0.089 \text{ mg l}^{-1}$) agreed well with the observed overall mean ($0.117 \pm 0.096 \text{ mg l}^{-1}$) in the Truckee River. The predicted mean TP at individual sites also

agreed closely well with the observed mean TP values at the sites (Table 4). Sites SC and NTD showed significantly larger predicted mean TP than other sites.

Table 2: Significance of contribution by individual sites towards overall TP

Site	Estimated TP	Standard Error	DF	t Value	Pr> t
MB	0.02696	0.00514	569	5.25	<.0001
WB	0.06892	0.00514	569	13.4	<.0001
SC	0.2517	0.00514	569	48.7	<.0001
LW	0.07804	0.00514	569	15.2	<.0001
DD	0.07227	0.00514	569	14.1	<.0001
NTD	0.2075	0.00514	569	40.4	<.0001

Table 3: Estimates of regression coefficients and probabilities from NLMR model

Variable	Estimate	Standard Error	DF	Pr > t
Intercept	-0.397300	0.000306	559	<.0001
DOC	0.005812	0.002377	559	0.0148
DO	-3.20E-08	0.000000	559	<.0001
SF	-0.008830	0.003100	559	0.0046
pH	0.037410	0.002664	559	<.0001
STP	1.206500	0.000043	559	<.0001
TEMP	-0.016160	0.006658	559	0.0155
ALK	0.000390	0.000078	559	<.0001
Season	0.100000	0.000000	559	<.0001
Intervention	0.036740	0.000000	559	<.0001

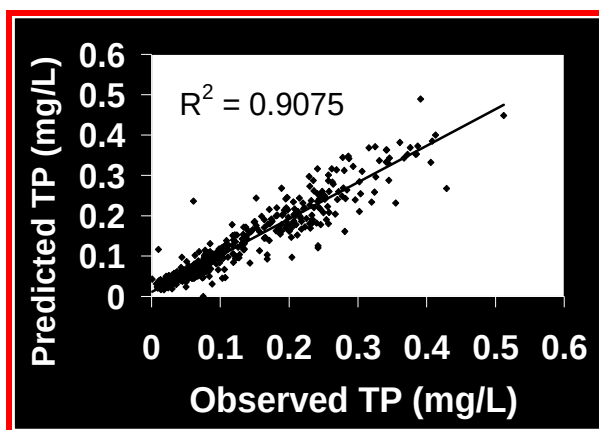


Figure 8: Observed TP versus TP predicted by the fitted NLMR model

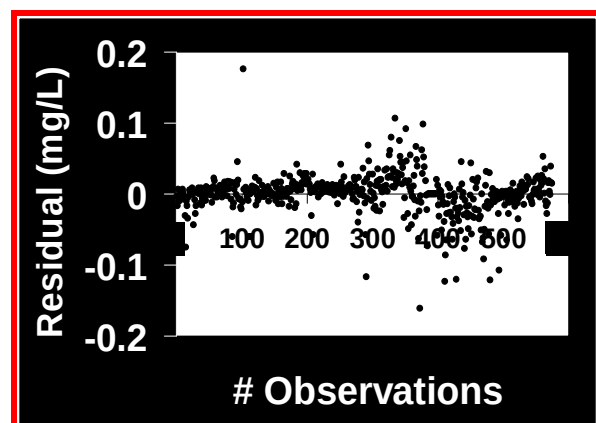


Figure 9: Pattern of model residuals

Model validity and forecasts

Regression coefficients were not altered by the non-linear optimization of the NLMR model. The fitted model was not sensitive to changes and constraints in values of independent variables (Table 5). Diagnostic statistics obtained from the best fitted NLMR model were sufficient. The Residuals obtained from the mode did not show any significant pattern (Figure 9).

Trend of forecasted TP decreased during the period between January 2005 and December of 2006, and slightly increased thereafter. The observed ($0.1386 \pm 0.045 \text{ mg l}^{-1}$) and forecasted ($0.1373 \pm 0.027 \text{ mg l}^{-1}$) mean TP values during the forecast period agreed well.

Table 5: Estimates of parameters after LSQ minimization

Variable	Parameter	Estimate	Gradient Lagrange Function
Intercept	beta1	-0.3973	0.372619
DOC	beta2	0.005812	1.173749
DO	beta3	-3.20E-10	0
SF	beta4	-0.00883	2.207488
pH	beta5	0.03741	2.98095
STP	beta6	1.2065	0.028319
Season	beta7	0.1	1.012883
Intervention	beta8	0.03674	1.012883
TEMP	beta9	-0.01616	-0.037487
Alkalinity	beta10	0.00039	37.865512
Least squares minimization solution to objective Function = 0.0694223467			

Table 4: Observed and NLMR model predicted mean TP by monitoring site

Site	Observed Mean TP (mg l^{-1})	Predicted Mean TP (mg l^{-1})
DD	0.072 ± 0.093	0.072 ± 0.028
LW	0.078 ± 0.092	0.081 ± 0.017
MB	0.027 ± 0.077	0.034 ± 0.006
NTD	0.208 ± 0.073	0.22 ± 0.046
SC	0.252 ± 0.081	0.223 ± 0.015
WB	0.069 ± 0.089	0.067 ± 0.009
Overall	0.117 ± 0.096	0.113 ± 0.089

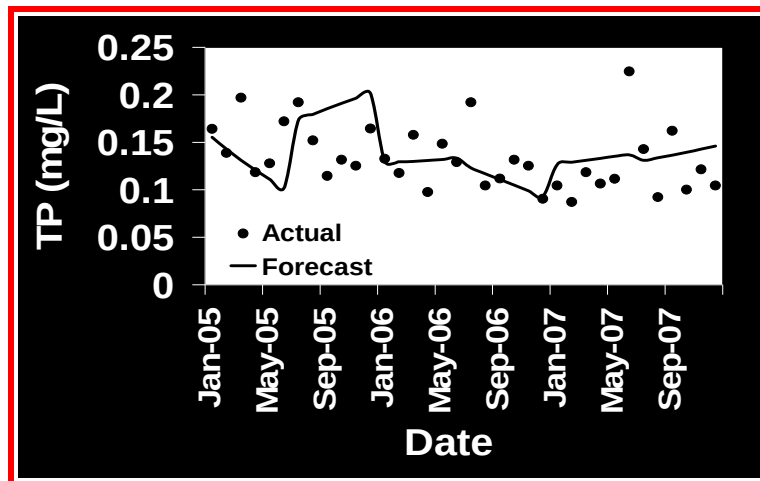


Figure 10: Observed TP and TP forecasted by the NLMR model

CONCLUSIONS

Observed TP levels in the Truckee River have significantly increased from the beginning of 2000 up to the end of 2004. The TP levels since then have decreased to values observed prior to 2000 until the end of 2006. The trend of TP has again shown slight increase during 2007. TP loading into the Truckee River from all 6 monitoring sites are significant. Steamboat Creek is currently the major contributor of TP to the Truckee River followed by North Truckee Drain. TP loading from these two sites require careful monitoring to reduce build up of TP and subsequent eutrophication in the waters of the Truckee River. High levels of TP in the Truckee River are favored by low temperatures ($p < 0.05$), high alkalinity ($p < 0.0001$) and high H^+ ($p < 0.0001$) and low stream flows ($p < 0.05$). Dissolved oxygen concentration decrease exponentially as TP in the Truckee River waters increase ($p < 0.0001$). TP levels in the Truckee River waters increase exponentially as stream flows in the Truckee River decrease ($p < 0.05$). TP in the Truckee River are also affected significantly ($p < 0.0001$) by seasonal variations and cyclical intervention events. The TP values in Truckee River significantly increase during summer when river diversions and return flows are at their maximum and river flows are low and decreases during winter when the opposite is true. TP in Truckee River can be predicted accurately (explaining 96% of total variation) as a function of the seven decision variables listed using their linear and non-linear relationship to TP ($R^2 = 0.908$). The forecasted mean TP value is above the compliance level for TP indicating that eutrophication problem still persists and management practices should be increased towards lowering TP values in the Truckee River especially from Steamboat Creek and North Truckee Drain areas.

REFERENCES

- Akaike, H., 1974, A new look at the statistical model identification, IEEE trans.: Autom. Control AC-19, p. 716-723.
- Boros, E., Nagy, T., Pigniczki, C., Kotyman, L., Balogh, K.V., and Voros, L., 2008, The effect of aquatic birds on the nutrient load and water quality of soda pans in Hungary, Acta Zoologica Academiae Scientiarum Hungaricae, v. 54 (Suppl. 1), p. 207–224.
- Box, G.E.P., and Jenkins, G.M., 1976, Time series analysis forecasting and control, (2nd ed.): Holden-Day, San Francisco, Ca.
- Buse, A., 1973, Goodness of fit in generalized least squares estimation, American Statistician, v. 27, p. 106-108.
- DaSilva, J.G.C., 1975, The analysis of cross-sectional time series data, Ph.D. dissertation, Department of Statistics, North Carolina State University.
- Dodds, W.K., Smith, V.H., and Lohman, K., 2002, Nitrogen and phosphorus relationships to benthic algal biomass in temperature streams, Can. J. Fish. Aquat. Sci., v. 59, p. 865-874.
- Dodds, W.K., and Gudder, D.A., 1992, The Ecology of Cladophora, Journal of Psychology, v. 28, n. 4, p. 415-427.
- Fuller, W., 1978, Introduction to time series, New York: John Wiley & Sons, Inc.
- Harville, D.A., 1988, Mixed-model methodology: Theoretical justifications and future directions, Proceedings of the Statistical Computing Section, American Statistical Association, New Orleans, p. 41-49.
- Jeppesen, E., Søndergaard, M., and Jensen, J.P., et., al., 2005, Lake responses to reduced nutrient Loading: An analysis of contemporary long-term data from 35 case studies, Freshwater Biol, v. 50, p. 1747–1771.
- Lewis, W.M. Jr., McCutchan, Jr., J.H., December 2005, Environmental thresholds for nutrients in streams and rivers of the Colorado Mountains and Foothills Report.
- NDEP, 1994, Truckee River final total maximum daily loads and waste load allocations: Nevada Division of Environmental Protection, Carson City, Nevada.
- NDEP, 2007, Nevada's nutrient assessment protocols for Wadeable streams: Nevada Division of Environmental Protection, Carson City, Nevada.

- NDEP, 1993, Truckee river strategy: Nevada Division of Environmental Protection, Carson City, Nevada.
- Parks, R.W., 1967, Efficient estimation of a system of regression equations when disturbances are both serially and contemporaneously correlated, *Journal of the American Statistical Association*, v. 62, p. 500-509.
- Peternel, K., and Laurel, S., May 15-May 19, 2005, Truckee River Restoration Modeling, World Water and Environmental Resources Congress. Anchorage, Alaska, USA.
- Ragavan, A., 2008, Data Mining Application of Non-Linear Mixed Modeling in Water Quality Analysis, Proceedings of the Data Mining and Predictive Modeling Section, SAS® Global Forum, San Antonio, TX, Paper 140-2008.
- Salas, J.D., and Obeysekera, J.T.B., 1988, ARIMA models Identification of Hydrologic Time Series, *Water Resources Research*, v. 18, no. 4, p. 1011-1021.
- Schafer, J.L., 1999, Multiple Imputation: A Primer, *Statistical Methods in Medical Research*, v. 8, p. 3-15.
- Schafer, J.L., 1997, *Analysis of Incomplete Multivariate Data*, New York: Chapman and Hall.
- Searle, S. R., 1988, Mixed Models and Unbalanced Data: Wherefrom, Whereat, and Whereto?, *Communications in Statistics - Theory and Methods*, v. 17, n. 4, p. 935-968.
- Searle, S.R., Casella, G., and McCulloch, C.E., 1992, *Variance Components*, New York: John Wiley & Sons, Inc.
- Spears, B.M., Carvalho, L., Perkins, R., and Paterson, D.M., 2008, Effects of light on sediment nutrient flux and water column nutrient stoichiometry in a shallow lake, *Water Research*, v. 42, n. 4-5, p. 977-986.
- Tetra Tech Inc., 2005, Technical Approach to Develop Nutrient Numeric Endpoints for California, U.S. EPA Region, IX.
- Truckee Meadows Water Reclamation Facility: www.tmwrf.com
- Truckee River Geographic Response Plan, 2005: http://ndep.nv.gov/bca/emergency/truckee_river_plan05.pdf
- USEPA, 1991, Guidance for water quality-based decisions: The TMDL process EPA 440/4-91-001, U.S.EPA, Office of Water, Washington, DC.
- USEPA, July 2000, Nutrient Criteria Technical Guidance Manual: Rivers and Streams, U.S.EPA-822-B-00-002.
- USEPA, March 2007, N-Steps: <http://n-steps.tetrachffx.com/NTSCHome.com>

APPENDIX

SAS® CODE 1

```

/* Testing and correcting data for stationarity */
PROC ARIMA DATA=Monthly; IDENTIFY VAR= TP STATIONARITY=(ADF=(1,2,4,6,12));RUN;
DATA Monthly; SET Monthly; TP =DIF(TP); RUN;

/* Testing and correcting data for missing observations */
PROC MI DATA=Monthly SEED=21355417 NOINT NIMPUTE=6 MU0=50 10 180 OUT=outmi;
MCMC CHAIN=multiple DISPLAYINIT INITIAL=em(ITPRINT);
VAR TP Alkalinity D02 DOC STP SF pH Temp; RUN;

/* Unobserved component analysis of observed TP */
PROC UCM DATA=Monthly PRINTALL; ID Date INTERVAL=Month; MODEL TP;
IRREGULAR plot=smooth; LEVEL variance=0 noest plot=smooth;
SLOPE variance=0 noest plot=smooth; CYCLE rho=1 noest=rho plot=smooth;
SEASON length=12 plot=smooth; RUN;

/* Time series cross sectional regression analysis */
PROC TSRSREG Data=Monthly OUTEST=out1 COVOUT CORROUT;
ID site date;
MODEL TP=Alkalinity DOC D02 SF pH STP Summer X1 Temp /NOINT
RANTWO DaSilva;
TEST MB =0; TEST WB=0; TEST SC=0; TEST LW=0; TEST DD=0; TEST LW=0; RUN;

/* Hypothesis testing, variance inflation and correlation analysis */
DATA Monthly; SET Monthly;
sflog=Log(ABS(SF));doexp=EXP(D02); summer=exp(summer-12); x11= exp
summer-12); Temp=(1/(1-Temp)); RUN;
PROC REG DATA=Monthly;
MODEL tp= sflog doexp DOC STP pH Alkalinity Temp1 X11 Summer1 /VIF;
RUN;
PROC CORR DATA=comp; VAR SF D02 DOC STP Alkalinity pH Temp; RUN;
TEST sflog =0; TEST doexp =0; TEST summer =0; TEST x11=0; TEST Temp=0;
RUN;

/* Fitting a non-linear multiple regression model */
PROC NLMIXED DATA=Monthly QPOINTS=10 ALPHA=0.01 TECH=QUANEW; UPDATE=DDFP;

PARMS
beta1=0.000246 beta2=0.006199 beta3=-0.000000548 beta4=-0.000001
beta5=-0.0000002455 beta6=-0.7867 beta7=0.1 beta8=0.03665 beta9=-
0.00066 beta10=-0.002 g11=-0.001428 to 0.02 by 0.001 g12=-0.001 to
0.01 by 0.001;

eta = beta1+ beta2*DOC + beta3*(exp(D0)) + beta4*(log(abs(SF))) +
beta5*pH + beta6*STP + beta7*(EXP(Summer-12)) + beta8*(EXP(X1-12))
+ beta9*(1/(1/Temp)) + beta10* (Alkalinity) + g12*b1;
num = eta; mu= num;

MODEL TP ~ NORMAL(mu,g12); RANDOM b1 ~ NORMAL(0,g11) SUBJECT=SITE;
PREDICT mu OUT=cdf; RUN;

```

SAS® CODE 2

```

/* Least squares minimization */
PROC NLP PALL TECH=quanew CLPARM=BOTH BEST=10 FD=Forward OUTMOD=model;
LSQ TP;

PARMS
  beta1= -0.3973, beta2= 0.005812, beta3 = -0.000000032, beta4=-
  0.00883, beta5= 0.03741, beta6= 1.2065, beta7= 0.1, beta8= 0.03674,
  beta9=-0.01616, beta10= 0.00039, sf =374.0, Temp=10.94, Summer=1,
  x11=1, do2=10.04, pH=8.0, doc=3.15, stp=0.076, Alkalinity=101.62;

BOUNDS
  -3.2E-10 <= beta3 <= 3.2E-10, 0 < beta7 <= 1, 0 < beta8 <= 1;

NLINCON
  nlc1-nlc2 > 0., 6.14421E-06 <= nlc3 <= 1.67017E-05,
  6.14421E-06 <= nlc4 <= 1.67017E-05, 1 <= nlc5 <= 5.18471E+21,
  1 <= nlc6 <= 14, nlc7-nlc10 >= 0.;
  nlc1 = Log(SF); nlc2= (1-Temp); nlc3=Exp(Summer-12);
  nlc4 = Exp(X1-12); nlc5=Exp(D0); nlc6=pH; nlc7=DOC;
  nlc8=STP; nlc9=Alkalinity; nlc10=D0; nlc11=(1/nlc2);

  TP = ((beta1 + beta2*nlc7 + beta3*nlc5 + beta4*nlc1 + beta5*nlc6+
  beta6*nlc8 + beta7*nlc3 + beta8*nlc4 + beta9*nlc11
  + beta10*nlc9));

RUN;

```

Recent Judicial Court Decisions Affecting Nevada Water Law

Michael C. Widmer, Washoe County Department of Water Resources, 4930 Energy Way, Reno, Nevada 89502. (mwidmer@washoecounty.us)

Vahid Behmaram, Washoe County Department of Water Resources, 4930 Energy Way, Reno, Nevada 89502 (vbehmaram@washoecounty.us)

Recent US Court of Appeals Opinion in the case of the Pyramid Lake Paiute Tribe vs. the Nevada State Engineer, et al.

Introduction

This Federal Court case was an appeal by the Pyramid Lake Paiute Tribe to the State Engineer's Ruling 5747. It revolves around the issue of ground water that naturally discharges to the Truckee River and therefore sustains the flow in the river. If a portion of this ground water is removed (through permitted pumping), are decreed surface water rights adversely affected? The State Engineer website, which contains his ruling, can be found at <http://water.nv.gov/>.

State Engineer Ruling 5747

The Truckee River and its tributaries were adjudicated in 1944 through the Orr Ditch Decree where surface waters were decided upon. The Truckee Canyon within the Tracy Section (hydrographic basin) lies to the east of Sparks, Nevada and west of Wadsworth, Nevada and tribal lands. Prior to 2006, the ground waters were estimated at 6,000af yet nearly 8,000af of permits had been issued. New applications were submitted between 1998 and 2003. In 2006, the U.S.G.S. released a ground water study of the canyon. This study gave a very wide range in estimates of the ground water resource, between 2,000af and 20,000af. The State Engineer decided that 11,000af was the appropriate estimate of the resource. Ruling 5747 permitted most of the applications despite the protests of the Pyramid Lake Paiute Tribe and Churchill County.

Basis for State Engineer Ruling

A previous ruling gave all remaining unappropriated water in the Truckee River to the Tribe after the Decreed and other rights were satisfied. Therefore the Tribe argued that granting the new ground water applications would reduce the base flow to the Truckee and thereby interfere with their decreed rights (No. 1 and No. 2). However, the State Engineer wrote that the granting of the rights would not conflict with the decreed rights. The State Engineer also stated that ground water was never contemplated as part of the decree. And that ground water was not contemplated as part of the "remaining flow" in the river granted to the Tribe in 1998.

Basis for District Court Dismissal

Because the issue revolved around the Orr ditch Decree, the Tribe appealed to the Federal Court. The Tribe's basis was that ground water supports flow to the river and therefore capturing this water would influence the Truckee River and hence affect the Tribe's Decreed rights. Whereas the State Engineered argued that the case should be dismissed because it dealt with the ground waters of the State of Nevada and was not a Federal issue. The Federal District Court agreed

with the State of Nevada. The Pyramid Lake Paiute Tribe then appealed to the United States Court of Appeals for the Ninth Circuit.

Outcome

The Appeals Court determined that they had two questions to answer. The first question was if the Orr Ditch Decree could interfere with the State Engineer's allocation of ground water if there was an adverse effect to decreed rights. The second question addressed whether the Federal courts or State courts should intervene in the matter. The Court made interesting statements for both and affirmed that the Orr Ditch Decree could intercede and that the Federal Court should decide contested matters.

The first question was answered with three basic points. That the Tribe had a reserved right to "a reasonable amount of water of the Truckee River" and that any diminution of that flow was in violation of the intent of the reservation. The Court continues with court case citations prior to the Orr Ditch Decree as to the fact of the interaction of surface and ground waters. The Court argued that the authors of the Orr Ditch Decree would have known these facts and that any explicit statements of ground water interaction in the decree were not necessary. Therefore, the Court held that the Orr Ditch Decree does protect the Tribe's rights against any diminution of flow in the Truckee.

The second question appears to have been quite easily answered in that the court that issues a decree has the jurisdiction to intercede in any dispute over that decree, in this case a dispute over the decision of the State Engineer. This is based upon NRS 533.450(1) that was quoted in the Opinion.

What does the future hold?

The Tribe may seek to remand this decision back to the State Engineer so that the granting of the ground water applications can be reconsidered. In a broader context, this decision formally links ground water to surface water for the first time in the Nevada State Engineer's Office. So, one question is "Does this set a precedent for all surface and ground waters in Nevada?" and if so, what are the implications for other contested surface water bodies in Nevada?

Great Basin Water Network, et al and the 1989 Eastern Nevada Water Right Applications of the Southern Nevada Water Authority

Introduction

This case is more about the State Engineer's statutory water right permitting process rather than the technical or legal findings in the State Engineer's Ruling 5726R. It revolves around NRS 533.370(2) that requires the State Engineer to approve or reject an application for water within one year of the closing of the protest period. This provision of the law was added to the NRS in 1947 and since then there has been several attempts to clarify or remove it since it is not complied with on regular basis. The 1947 law never identified the consequences if the 1 year time frame was not adhered to and it was commonly believed that applications would remain as "pending" beyond the 1 year time frame. The statute was revised by the 2003 Legislative Session to give the State Engineer the authority to postpone taking action indefinitely if the manner of use was for municipal purposes. The 2003 amendment was intended or believed to be retroactive to affect all applications filed back to 1947. However, the Supreme Court ruling could not find proof of the legislative intent for its applicability in a retroactive manner. Therefore, the Supreme Court remanded the case back to the District Court to determine whether the SNWA applications filed in 1989 which were not acted upon within the 1 year time frame are to be re-filed or the protest period to be re-opened.

Background

This case begins in 1989 when the Las Vegas Valley Water District filed 146 water right applications in eastern Nevada. The request was for 830,000af and later reduced to 190,000af per year of ground water pumpage. In 1990, the statutory protest period of 30 days resulted in 830 protests being filed. Some of these applications were withdrawn or ruled upon in the 1990s and into the 2000s. However, in the Snake, Spring, Delamar, Cave and Dry Lake valleys, 11 protestants had to wait until 2005 to be noticed of a 2006 hearing date of the 34 applications. And of course by this time, many of the protestants could not be located. And many new residents had by now occupied these valleys. Where they entitled to a standing? Were they denied their due process in a court of law?

During 2006, 54 appellants filed a petition to re-open the protest period. The State Engineer's hands were tied as he had no statutory authority to re-open the protest period. The Appellants then file in district court to have a new public notice re-published. The District Court agreed with the State Engineer stating that "...Nevada water law takes into account a time lapse between the original filing of an application and a hearing". But this was based upon the 2003 version of NRS 533.370(2) and assumed that the 2003 version was retroactive.

In April 2007 the State Engineer issued Ruling 5726r and this was not appealed. But the Appellants did file for a judicial review of their district court denial to a re-opening of the protest period. They stated that due process was denied. The Nevada State Supreme Court heard the case and issued an opinion in January 2010 in favor of the appellants. The State Engineer recently requested of the Supreme Court to reconsider and this was granted, followed by a clarification given on June 17, 2010.

Court Opinion

At issue here is that the State Engineer failed to rule on the applications within one year of closing of the protest period as per the NRS 533.370(2) statute as it existed in 1989. The Supreme Court found that the 2003 version of the statute was **not** retroactive. The District Court was then directed to determine if the Southern Nevada Water Authority is required to re-file new applications or if the State Engineer must re-notice and re-open the 30 day protest period. The June 2010 clarification given by the Supreme Court stated that the State Engineer must re-open the noticing and protest period.

What does the future hold?

The State Engineer has sent a letter to Governor Gibbons describing the actions taken since this Opinion. In this letter he describes a workshop that was held in March to take testimony and to hold general discussions on this matter with any interested party. These discussions and testimonies would be used to determine what course of action to take with respect to initiating legislative actions. These actions could involve a Special Session or simply to provide new language for adoption at the next regularly scheduled Session (February 2011). Furthermore, the State Engineer issued a letter on July 7th, 2010, setting forth their interpretation of the revised Supreme Court opinion and how they will apply it. The State Engineer website, which contains this document, can be found at <http://water.nv.gov/>.

It is clear that the State, SNWA and potential protestants will be gearing up for another round of hearings. And it is also clear that until changes are made to NRS 533.370 other applications and permits may be affected. The State Engineer recognizes over 13,000 actions taken on applications that were not acted upon within the one year time frame and many other current applications still pending after the one year time frame. Hopefully, common sense will prevail.

FOR PUBLICATION
UNITED STATES COURT OF APPEALS
FOR THE NINTH CIRCUIT

UNITED STATES OF AMERICA, <i>Plaintiff,</i> and PYRAMID LAKE PAIUTE TRIBE OF INDIANS, <i>Petitioner-Appellant,</i> v. ORR WATER DITCH CO., <i>Defendant,</i> NEVADA STATE ENGINEER, <i>Respondent-Appellee,</i> and GRAND SLAM ENTERPRISES, LLC; TRI WATER AND SEWER COMPANY, <i>Real-parties-in-interest-Appellees.</i>	}
--	---

No. 07-17001
D.C. No.
CV-73-00018-LDG
OPINION

Appeal from the United States District Court
for the District of Nevada
Lloyd D. George, District Judge, Presiding

Argued and Submitted
July 15, 2009—San Francisco, California

Filed April 7, 2010

Before: Cynthia Holcomb Hall, William A. Fletcher and
Richard A. Paez, Circuit Judges.

Opinion by Judge William A. Fletcher

UNITED STATES v. ORR WATER DITCH CO.

5263

COUNSEL

Don Springmeyer, ANGIUS & TERRY, Las Vegas, Nevada,
Stephanie Zehren-Thomas, HESTER & ZEHREN, Louisville,
Colorado, for the petitioner-appellant.

5264

UNITED STATES v. ORR WATER DITCH CO.

Michael Louis Wolz, OFFICE OF THE NEVADA ATTORNEY GENERAL, Reno, Nevada, Ross E. de Lipkau, PARSONS BEHLE & LATIMER, Reno, Nevada, for the respondents-appellees.

OPINION

W. FLETCHER, Circuit Judge:

This case concerns the extent of the federal courts' subject matter jurisdiction over the administration of water rights adjudicated in the Orr Ditch Decree ("the Decree"). The Decree allocates rights to water in the Truckee River. See *United States v. Orr Water Ditch Co.*, Equity No. A3 (D. Nev. 1944). The river begins at Lake Tahoe and runs most of its course in Nevada, ultimately flowing into Pyramid Lake, northeast of Reno. The Pyramid Lake Paiute Tribe of Indians ("the Tribe") alleges that Nevada State Engineer Ruling 5747, allocating groundwater in the Tracy Segment Hydrographic Basin ("the Basin"), adversely affects its water rights under the Decree. The Tribe appealed the decision by the Nevada State Engineer ("State Engineer" or "Engineer") to the federal district court for the District of Nevada. Appellees contended that, whatever the effect of the Engineer's allocations of groundwater on the Tribe's decreed water rights, the district court did not have jurisdiction over the appeal because the Decree adjudicated only rights to surface water in the river. The district court agreed and dismissed the appeal for lack of subject matter jurisdiction.

We reverse and remand. If the Tribe's allegations are true, the groundwater taken from the Basin pursuant to the Engineer's groundwater allocations will adversely affect the Tribe's decreed water rights. We hold, first, that the Orr Ditch Decree forbids groundwater allocations that adversely affect the Tribe's decreed rights to water flows in the river. We

hold, second, that the federal district court has jurisdiction over an appeal from groundwater allocations by the Engineer that are alleged to have such an adverse effect.¹

I. Background

The Truckee River is the principal source of water for Pyramid Lake. The lake is “widely considered the most beautiful desert lake in North America.” *Nevada v. United States*, 463 U.S. 110, 114 (1983) (quoting S. Wheeler, *The Desert Lake* 90 (1967)). “When first viewed by Captain John Fremont in early 1844, Pyramid Lake was some 50 miles long and 12 miles wide. Since that time the surface area of the Lake has been diminished by about 20,000 acres.” *Id.* at 115. The lake is situated entirely within the boundaries of the Pyramid Lake Paiute Tribe Reservation.

The history of the Orr Ditch Decree goes back over one hundred years. The Supreme Court recounted some of that history in *Nevada v. United States*. *Id.* at 113-18. We recounted it briefly in *United States v. Orr Water Ditch Co.* (*Orr Ditch I*), 914 F.2d 1302, 1304 (9th Cir. 1990):

The Reclamation Act of 1902 . . . authorized the federal government to pursue efforts to reclaim arid lands in certain western states. In one of these efforts, the Newlands Reclamation Project, the government planned to irrigate an area of western Nevada with water from the Truckee and Carson Rivers, which flow through and around Lake Tahoe and Reno, Nevada. Because private landowners and the Indians of the Pyramid Lake Indian Reservation had already-established water rights, the United States filed an action in 1913 to quiet title to all

¹In a separate memorandum disposition filed today, we address the cross-appeal of Tahoe Reno Commercial Center, LLC. *United States v. Orr Water Ditch Co.*, No. 07-17021.

water rights in the Project area. The resulting legal activity became known as the *Orr Ditch* litigation.

An appointed Special Master held hearings, then issued a report and recommended a proposed decree in 1924. Two years later, the district court issued a temporary restraining order enforcing the proposed decree. In 1934, after a lapse of interest in the litigation, a drought prompted more activity. In 1935, the major parties to the litigation signed an agreement similar to the proposed decree that had been in effect on a “temporary” basis. Finally, in 1944, the district court entered its final decree that approved and incorporated the settlement.

Under the Decree, the Tribe owns Claims No. 1 and 2, the two most senior water rights on the Truckee River. A substantial portion of the water held under these rights was recently transferred “temporarily” from irrigation to in-stream use in order to allow the water to flow into the Pyramid Lake. *United States v. Orr Water Ditch Co. (Orr Ditch III)*, 391 F.3d 1077, 1079 (9th Cir. 2004).

In November 1998, the Nevada State Engineer granted the Tribe the right to all of the water remaining in the river after the Orr Ditch Decree rights and other rights were satisfied. We are informed by the parties that, at the time of briefing to this court, an appeal of this ruling was pending in Nevada state court. The Tribe’s rights under the Engineer’s 1998 ruling are based on Nevada law rather than the Orr Ditch Decree.

We have consistently interpreted the Orr Ditch Decree, as well as the related Alpine Decree, to provide for “federal district court review of decisions of the State Engineer regarding applications to change the place of diversion or manner or place of use of water rights derived from the Alpine and Orr Ditch Decrees.” *United States v. Alpine Land & Reservoir Co. (Alpine II)*, 174 F.3d 1007, 1011 (9th Cir. 1999). Over the

past thirty years, numerous decisions of the Engineer pertaining to rights under these two decrees have been appealed to the federal district court and then to us. *See, e.g., United States v. Alpine Land & Reservoir Co. (Alpine I)*, 878 F.2d 1217 (9th Cir. 1989); *Alpine II*, 174 F.3d 1007; *United States v. Orr Water Ditch Co. (Orr Ditch II)*, 256 F.3d 935 (9th Cir. 2001); *United States v. Alpine Land & Reservoir Co. (Alpine III)*, 341 F.3d 1172 (9th Cir. 2003); *Orr Ditch III*, 391 F.3d 1077; *United States v. Truckee-Carson Irrigation Dist.*, 429 F.3d 902 (9th Cir. 2005); *United States v. Alpine Land & Reservoir Co. (Alpine IV)*, 510 F.3d 1035 (9th Cir. 2007).

The appeal now before us arises out of an allocation by the State Engineer of groundwater rights in the Tracy Segment Hydrological Basin. The Basin lies between the towns of Sparks in the west, Fernley in the east, and Virginia City in the south. The northern border runs roughly parallel to Interstate 80 between three and five miles north of the highway. At its northeastern tip, the Basin abuts the Pyramid Lake Paiute Tribe Reservation. A thirty-mile stretch of the Truckee River runs through the Basin on its way to Pyramid Lake. According to a study published by the United States Geological Survey in 2006 and relied upon by the State Engineer, the Truckee River is a gaining stretch as it runs through the Basin, receiving an average net gain of about 11,000 acre-feet per year from the Basin's groundwater unless there has been an over-allocation of that water.

Between 1998 and 2003, several parties applied for new groundwater allocations in the Basin. The Tribe and Churchill County opposed the majority of the applications, contending that the groundwater of the Basin was already fully appropriated and that the requested allocations would reduce the base flow of the Truckee River. They contended that this reduction would interfere, *inter alia*, with decreed water rights under the Orr Ditch Decree.

In June 2007, in Ruling 5747, the State Engineer granted most of the groundwater applications. The Engineer noted

that the United States Geological Survey had previously estimated that the “perennial yield” of the Basin is approximately 6,000 acre-feet per year resulting from groundwater recharge from precipitation. Even before the current applications were considered, groundwater allocations of 7,976 acre-feet per year had been granted. If the estimate of 6,000 acre-feet per year perennial yield is accurate, groundwater in the Basin was thus already over-allocated. After considering a wide range of estimates, the Engineer revised upward the estimated perennial yield of the Basin to approximately 11,500 acre-feet per year. Based on the revised estimate, the Engineer granted some of the new applications, concluding that they would not result in over-allocation of the groundwater in the Basin.

The Engineer concluded further that even if the new allocations were to result in over-allocation of the groundwater and a diminution of the base flow of the Truckee River, this would not conflict with any of the decreed rights to water in the river. Quoting an earlier Engineer ruling, the Engineer concluded “that the ground-water discharge to the Truckee River should not be counted as part of the [Tribe’s] surface-water rights in the Truckee River . . . established under Claims No. 1 and 2 of the Orr Ditch Decree.” The Engineer wrote that “there is nothing in the Orr Ditch Decree that indicates possible ground-water discharge to the Truckee River was even contemplated by the decree court as part of the water of the river.” The Engineer also concluded that the ground-water discharge to the river should not be counted as part of the Tribe’s rights established under the 1998 ruling in which the Tribe was granted, as a matter of state law, rights to the remaining flow of the river after all of the decreed water rights were satisfied.

The Tribe appealed the Engineer’s ruling to the federal district court. The Tribe argued broadly that the district court had jurisdiction to review the Engineer’s ruling, both as it affected its rights under the Decree and as it affected its rights under

the Engineer's 1998 ruling. The Engineer moved to dismiss for lack of subject matter jurisdiction.

The district court granted the motion to dismiss, writing:

At its essence, the issue before this court is whether appellate jurisdiction over the rulings of the State Engineer is determined by reference to the water right[s] of the applicant, or by reference to any water rights that might be affected by the State Engineer's ruling, including that of the applicant . . . As recognized by the Tribe, this court has exclusive jurisdiction over the Truckee River waters. See *United States v. Alpine Land & Reservoir Co.*, 174 F.3d 1107, 1011 (9th Cir. 1999). Section 540.450(1) [of Nev. Rev. Stat.] itself recognizes that, on stream systems on which a decree has already been entered, exclusive jurisdiction rests in the court issuing that decree.

If exclusive jurisdiction is determined by reference to any water rights affected by a State Engineer's ruling, such "exclusive" jurisdiction could conceivably rest in two or three or more courts. An applicant seeking to appropriate water rights from a decreed stream system could be protested by an owner of water rights in a different decreed stream system, placing "exclusive jurisdiction" of the appeal in two different courts. Or, an applicant seeking water from a non-decreed system could be protested by two persons, each having water rights on different decreed water systems. Or, an applicant could be protested by a single entity having water rights on different decreed water systems. Again, in either latter case, two different courts would have "exclusive" jurisdiction to hear the appeal to the detriment of the other. The potential for such absurd results is avoided entirely if appellate jurisdiction is

5270 UNITED STATES V. ORR WATER DITCH CO.

determined by reference to the applicant's water rights.

The Tribe timely appealed.

II. Standard of Review

We review *de novo* a dismissal for lack of subject matter jurisdiction. *Marceau v. Blackfeet Hous. Auth.*, 455 F.3d 974, 978 (9th Cir. 2006). We review a district court's factual findings for clear error. *Coyle v. P.T. Garuda Indonesia*, 363 F.3d 979, 984 n.7 (9th Cir. 2004). "The party asserting federal jurisdiction has the burden of establishing it." *Miguel v. Country Funding Corp.*, 309 F.3d 1161, 1164 (9th Cir. 2002).

III. Discussion

There are essentially two questions before us. First, does the Orr Ditch Decree forbid an allocation of groundwater by the State Engineer that has an adverse effect on the Tribe's decreed rights to water in the Truckee River? Second, if the Decree forbids such an allocation of groundwater, does the district court have subject matter jurisdiction over an appeal from a ruling of the Engineer that allegedly conflicts with the Decree? We answer "yes" to both questions.

A. Extent of the Tribe's Decreed Rights

The State Engineer concluded that the Tribe's water rights under the Orr Ditch Decree could be diminished by groundwater allocations without violating the Decree. In the view of the Engineer, the Decree granted the Tribe rights only to the surface water flowing in the Truckee River. In his view, the Decree provided no protection against allocations of groundwater that would diminish the amount of surface water and thereby adversely affect the Tribe's decreed rights. For the reasons that follow, we disagree.

The Decree provides:

IT IS HEREBY ORDERED, ADJUDGED AND
DECREED AS FOLLOWS:

That the parties, persons, corporations, intervenors, grantees, successors in interest and assigns and substituted parties above and hereinafter named and their successors in interest and assigns are, and each of them is, as against every other one, *hereby adjudged to be the owners of the water rights hereinafter specified and set forth and entitled and allowed to divert and use, from the Truckee River and its tributaries and from the streams, springs, drain and waste waters hereinafter mentioned[.]*

Decree at 10 (emphasis added). The Tribe is one of the parties named in the Decree.

The Decree granted the Tribe the two most senior rights to water from the Truckee River, Claims No. 1 and 2. Both claims provide water to the Tribe for use on the reservation. The Decree describes in Claim No. 1 the history leading to the grant of the rights conferred in the two claims:

By order of the Commissioner of the General Land Office made on December 8, 1859, the lands comprising the Pyramid Lake Indian Reservation were withdrawn from the public domain for use and benefit of the Indians and this withdrawal was confirmed by order of the President on March 23, 1874. Thereby and by implication and by relation as of the date of December 8, 1859, *a reasonable amount of the water of the Truckee River*, which belonged to the United States under the cession of territory by Mexico in 1848 and *which was the only water available for the irrigation of these lands, became*

reserved for the needs of the Indians on the reservation.

Id. (emphasis added).

[1] We recognize that there is no language in the Decree explicitly protecting the Tribe’s decreed rights in Claims No. 1 and 2 from diminution of the flow of the river resulting from allocation of groundwater to other users. But the Engineer overstated the matter when he wrote that “there is nothing in the Orr Ditch Decree that indicates possible groundwater discharge to the Truckee River was even contemplated by the decree court as part of the water of the river.” The Decree indicates that the water rights granted to the Tribe in Claims No. 1 and 2 were intended to fulfill the purpose of the United States in withdrawing land from the public domain for the Tribe’s reservation and reserving “a reasonable amount of water” for use on the reservation. It is inconsistent with that purpose to allocate water to other users if that allocation diminishes the Tribe’s reserved water supply.

[2] Surface water contributes to groundwater, and groundwater contributes to surface water. The reciprocal hydraulic connection between groundwater and surface water has been known to both the legal and professional communities for many years. The Supreme Court wrote in *Kansas v. Colorado*, 206 U.S. 46, 114-15 (1907), “If the bed of a stream is not solid rock, but earth, through which water will percolate, . . . undoubtedly water will be found many feet below the surface, and the lighter the soil the more easily will it find its way downward and the more water will be discoverable by wells” The Court wrote in *Snake Creek Mining & Tunnel Co. v. Midway Irrigation Co.*, 260 U.S. 596, 598 (1923), “The waters intercepted and collected . . . are percolating waters, which . . . found their way naturally . . . through the rocks, gravel, and soil of the mountain into open springs near the stream, and thence by surface channels into the stream.” In a law review article published two years before the entry of the

Orr Ditch Decree, the authors emphasized the importance of the hydraulic connection: “The significance of the fact that ground water never occurs as a stationary water body should be stressed. Ordinarily, the subsurface reservoir is continuously receiving additions by influent seepage from rainfall and surface water bodies and is always discharging water by natural processes. In the subsurface reservoir ground water is percolating toward the discharge area; no static ground-water bodies are known to exist.” C.F. Tolman & Amy C. Stipp, *Analysis of Legal Concepts of Subflow and Percolating Waters*, 21 Or. L. Rev. 113, 129 (1942).

[3] The district court entering the Orr Ditch Decree would have known about the relationship between surface water and groundwater. The Decree expressly states that Claims No. 1 and 2 fulfill the purpose of the United States in establishing the Tribe’s reservation. In the words of the Decree, that purpose was to withdraw from the public lands “the lands comprising the Pyramid Lake Indian Reservation,” and to “reserve” a “reasonable amount of water of the Truckee River” to meet the “needs of the Indians on the reservation.” This statement of intent to reserve a reasonable amount of water makes clear that the proper construction of the Decree is that the water rights granted in Claims No. 1 and 2 cannot be defeated by allocation of water to others—whether by allocation of surface water or groundwater.

Even without such an explicit statement, we would come to the same conclusion based on *Winters v. United States*, 207 U.S. 564 (1908), which dealt with water rights on the Fort Belknap Indian Reservation. The Court in *Winters* held that sufficient water was reserved to serve the needs of the Indians, despite the absence of clear words so specifying in the agreement establishing the reservation. The Court invoked a rule of interpretation that would further the purpose of the agreement:

By a rule of interpretation of agreements and treaties with the Indians, ambiguities occurring will be

resolved from the standpoint of the Indians. And the rule should certainly be applied to determine between two inferences, one of which would support the purpose of the agreement and the other impair or defeat it. On account of their relations to the government, it cannot be supported that the Indians were alert to exclude by formal words every inference which might militate against or defeat the declared purpose of themselves and the government[.]

Id. at 576-77.

[4] We therefore hold that the Decree protects the Tribe from allocations of groundwater that would adversely affect its decreed water rights under Claims No. 1 or 2.

B. Jurisdiction of the District Court

[5] The district court's subject matter jurisdiction over appeals from decisions of the State Engineer is an odd amalgam. The court's jurisdiction is based on the ability of a court of equity to enforce and administer its decrees. As we wrote in *Alpine I*:

[T]he federal district court acts as an appellate court for decisions of the state Engineer. Needless to say, such jurisdiction is highly extraordinary.

We specifically approved of this jurisdictional arrangement in *United States v. Alpine Land & Reservation Co.*, 697 F.2d 851, 858 (9th Cir. 1983), *cert. denied*, 464 U.S. 863 (1983). The district court's jurisdiction is established as an adjunct to its jurisdiction over the quiet title action originally filed by the United States. . . . The district court's equity jurisdiction was properly invoked to review the Engineer's decision in order to "provide full vindica-

tion of the admitted federal interests in the operation of federal reclamation projects.” *Id.* at 858.

878 F.2d at 1219 n.2 (some citations omitted).

[6] Nevada law also recognizes this unique jurisdictional arrangement. Specifically, it provides:

Any person feeling himself aggrieved by any order or decision of the State Engineer . . . when the order or decision relates to the administration of determined rights . . . may have the same reviewed by a proceeding for that purpose, insofar as may be in the nature of an appeal, which must be initiated in the proper court of the county in which the matters affected or a portion thereof are situated, but *on stream systems where a decree of court has been entered, the action must be initiated in the court that entered the decree.*

Nev. Rev. Stat. § 533.450(1) (emphasis added); *see also Orr Ditch I*, 914 F.2d at 1309 n.8 (“Nevada law thus supports the system adopted by the federal courts for appeals of Engineer decisions on federal-court-decreed water rights.”); *Alpine II*, 174 F.3d at 1011 (“[W]e have interpreted Nevada law, which provides for jurisdiction of appeals from decisions of the State Engineer ‘in the court that entered the decree,’ as providing for federal court review under the Orr Ditch Decree.”).

[7] We hold today that the Decree protects the Tribe’s water rights under Claims No. 1 and 2 from diminution resulting from allocation of groundwater rights. This holding necessarily means that any allocation of groundwater rights by the State Engineer that allegedly diminishes the Tribe’s decreed water rights comes within the clause of Nev. Rev. Stat. § 533.450(1) that provides for appellate review “in the court that entered the decree.” The decree in this case was entered by the federal district court for the District of Nevada. We

therefore hold that the district court has subject matter jurisdiction over the Tribe's appeal from Ruling 5747 insofar as that ruling may adversely affect the Tribe's decreed rights under Claims No. 1 and 2.

[8] We note, however, that the district court does not have jurisdiction over the Tribe's appeal from that ruling insofar as it may adversely affect the Tribe's rights under the Engineer's 1998 ruling granting the Tribe the right to water remaining in the Truckee River after decreed and other rights have been satisfied. The district court does not have jurisdiction because the Engineer's 1998 ruling was based on state law. The part of the Engineer's current ruling allegedly affecting the Tribe's rights under his 1998 ruling has no effect on the Tribe's rights under the Decree.

The district court accurately foresaw that practical difficulties would result from a conclusion that it has jurisdiction over an appeal from an Engineer's ruling allocating groundwater from the Basin. But the appeal will be limited, and the practical difficulties will be manageable. The district court was asked to decide only one question on appeal: Will the Engineer's allocation of groundwater rights adversely affect the Tribe's rights under the Decree? If the court concludes that the allocation will have an adverse effect on the Tribe's decreed rights, it will instruct the Engineer to reduce the amount of allocated groundwater rights by an amount necessary to eliminate that effect. If the court concludes that the allocation will not adversely affect the Tribe's decreed rights, it will simply affirm the Engineer's ruling. In neither case will the district court have the authority in the Tribe's appeal to tell the Engineer how to allocate groundwater rights among the various applicants. To the extent that groundwater may be allocated consistent with protection of the Tribe's decreed rights, the amount of the allocations and the distribution among the applicants are of no concern to the district court in the Tribe's appeal.

The district court also accurately stated that the exercise of subject matter jurisdiction by the federal courts would be inconsistent with the general principle of water law that a single court should have exclusive jurisdiction over an interrelated system of water rights. *See, e.g., State Eng'r v. S. Fork Band of the Te-Moak Tribe of W. Shoshone Indians of Nev.*, 339 F.3d 804, 809 (9th Cir. 2003) (referring to the “ancient and oft-repeated . . . doctrine of prior exclusive jurisdiction—that when a court of competent jurisdiction has obtained possession, custody, or control of particular property, that possession may not be disturbed by any other court” (citation omitted)). But that principle, while valid and important, is not an inviolable rule.

Indeed, we have seen already an exception to the general principle in this very matter. As noted above, the State Engineer in 1998 granted to the Tribe the right to take any water remaining in the Truckee River after decreed and other rights have been satisfied. It is undisputed that, as a general proposition, decisions of the State Engineer allocating the surface waters of the Truckee River are appealable to the district court. This is so because the district court administers the Orr Ditch Decree, which adjudicated rights to water in the river. But the appeal of the Engineer’s 1998 ruling did not go to the district court even though the ruling allocated rights to water in the river. Rather, it appropriately went to the Nevada state courts, for that ruling was based on state law and did not affect any rights under the Decree.

Conclusion

[9] For the foregoing reasons, we hold that the Tribe’s decreed rights to water from the Truckee River under the Orr Ditch Decree may not be adversely affected by allocations of groundwater in the Tracy Segment Hydrographic Basin. We hold, further, that the district court has subject matter jurisdiction to hear the Tribe’s appeal from the State Engineer’s Ruling 5747 insofar as the allocation of groundwater rights is

5278 UNITED STATES v. ORR WATER DITCH CO.

alleged to affect adversely the Tribe's decreed water rights under Claims No. 1 and 2.

REVERSED and REMANDED.

126 Nev., Advance Opinion 2
IN THE SUPREME COURT OF THE STATE OF NEVADA

GREAT BASIN WATER NETWORK, A
NONPROFIT ORGANIZATION;
DEFENDERS OF WILDLIFE, A
NONPROFIT CORPORATION; EDGAR
ALDER; CLARK W. MILES; RAYMOND
E. TIMM; THEODORE STAZESKI;
SHELDON M. EDWARDS; KATHRYN
HILL; KENNETH F. HILL; SCOTTY
HEER; BETH B. ANDERSON; SUSAN
L. GEARY; DONALD W. GEARY;
ROBERT EWING; PAMELA JENSEN;
BRUCE JENSEN; RENEE A. ALDER;
ROBERT J. NICKERSON; JOYCE B.
NICKERSON; EDWARD J. WEISBROT;
ALEXANDER ROSE, EXECUTIVE
DIRECTOR OF THE LONG NOW
FOUNDATION; ROBERT N.
KRANOVICH; PAMELA M. PEDRINI;
RICK HAVENSTRITE; TERRENCE P.
MARASCO; BRYAN HAMILTON; JOHN
B. WOODYARD, II; LAURIE E.
CRUIKSHANK; DONALD FOSS;
SELENA L. WEAVER; MARY E.
COLLINS; CANDI A. ASHBY; SALLY L.
GUST; BRUCE ASHBY; DANIEL MAES;
ROBERT N. MARCUM; TARA FOSTER;
DONALD A. DUFF; ELISABETH A.
DOUGLASS; JAMIE DENERIS; NOMI
MARTIN-SHEPPARD; VERONICA F.
DOUGLASS; ABIGAIL C. JOHNSON;
MARIE JORDAN; JAMES JORDAN;
RUTHERFORD DAY; THE GREAT
BASIN CHAPTER OF TROUT
UNLIMITED; WILDA GARBER; THE
UTAH COUNCIL OF TROUT
UNLIMITED; PANDORA WILSON;
PARKER DAMON; CAROL DAMON;
ANNA HECKETHORN; AND

No. 49718

FILED

JAN 28 2010

TRACIE K. LINDEMAN
CLERK OF SUPREME COURT
BY *[Signature]*
CHIEF DEPUTY CLERK

DEBORAH TORVINEN,
Appellants,

vs.

TRACY TAYLOR, IN HIS OFFICIAL
CAPACITY AS THE NEVADA STATE
ENGINEER; THE STATE OF NEVADA
DEPARTMENT OF CONSERVATION
AND NATURAL RESOURCES,
DIVISION OF WATER RESOURCES;
AND THE SOUTHERN NEVADA
WATER AUTHORITY,
Respondents.

Appeal from a district court order denying a petition for
judicial review in a water rights action. Seventh Judicial District Court,
White Pine County; Norman C. Robison, Judge.

Reversed and remanded.

Leah R. Wigren, Reno; Simeon Herskovits, Taos, New Mexico; Matthew K.
Bishop, Helena, Montana; Brian Segee, Washington, D.C.,
for Appellants.

Catherine Cortez Masto, Attorney General, and Bryan L. Stockton,
Deputy Attorney General, Carson City,
for Respondents State Engineer and Division of Water Resources.

Taggart & Taggart, Ltd., and Paul G. Taggart and Joseph C. Reynolds,
Carson City; Dana R. Smith, Las Vegas,
for Respondent Southern Nevada Water Authority.

BEFORE THE COURT EN BANC.

OPINION

By the Court, HARDESTY, J.:

In this appeal, we must determine a narrow, yet fundamental question: whether the State Engineer violated his statutory duty under NRS 533.370(2) by failing to rule on Southern Nevada Water Authority's (SNWA) 1989 water appropriation applications within one year. NRS 533.370(2), as it existed in 1989, required the State Engineer to approve or reject each water appropriation application within one year after the final protest date. The State Engineer, however, could postpone taking action beyond one year if he obtained written authorization from the applicant and protestants or if there was an ongoing water supply study or court action. None of those conditions occurred by the end of 1991. However, in 2003, the Legislature amended NRS 533.370 to permit the State Engineer to postpone action on pending applications made for a municipal use. The district court summarily determined, among other issues, that the amendment applied to SNWA's 1989 applications, thus enabling the State Engineer to take action on applications filed 14 years earlier.

The parties to this appeal dispute whether SNWA's 1989 applications were "pending" in 2003 under the legislative amendment and, therefore, whether the amendment applied retroactively to those applications. We conclude that "pending" applications are those that were filed within one year prior to the enactment of the 2003 amendment. And, in the absence of statutory language and legislative history demonstrating an intent that the amendment apply retroactively to SNWA's 1989 applications, we determine that the State Engineer could not take action on them under the 2003 amendment to NRS 533.370.

Because we determine that the 1989 water appropriation applications were not pending in 2003, we conclude that the State Engineer violated his statutory duty by failing to take action within one

year after the final protest date. Thus, we reverse the order of the district court and remand for a determination of whether SNWA must file new groundwater appropriation applications or whether the State Engineer must re-notice SNWA's 1989 applications and reopen the period during which appellants may file protests.

FACTS AND PROCEDURAL HISTORY

In 1989, the Las Vegas Valley Water Department (LVVWD) filed approximately 146 applications with the State Engineer to appropriate public water from groundwater sources in various areas in Nevada. LVVWD's intended purpose was to pump the water to the greater Las Vegas area. With nearly 800,000 acre-feet per year of groundwater at issue, the State Engineer referred to the project as "the largest interbasin appropriation and transfer of water ever requested in the history of the state of Nevada."¹

In 1990, the State Engineer published statutory notice of the applications in the counties in Nevada where the water was to be appropriated. In response, more than 830 protests were filed with the State Engineer. Although NRS 533.370(2), as it existed at the time, required the State Engineer to take action on applications within one year after the close of the protest period, unless he identified an ongoing water study or court action, the State Engineer did not rule on the applications at issue in this case or identify an exception that permitted postponement of action within the allotted time.

¹The quantity of water proposed to be pumped was later reduced to approximately 190,000 acre-feet per year.

In 1991, SNWA was formed to address and secure the water needs for the millions of residents of and visitors to the Las Vegas valley. SNWA acquired LVVWD's rights to the 1989 groundwater applications as a successor in interest. Thereafter, between 1991 and 2002, LVVWD withdrew some of the 1989 applications, and the State Engineer held hearings and issued rulings on several other 1989 applications. This appeal concerns 34 of SNWA's remaining 1989 groundwater applications in the Spring, Snake, Cave, Dry Lake, and Delamar Valleys. Although there are 54 appellants to this appeal, we have identified five groups of appellants. First, there are 11 "original protestants," who filed original protests in 1989 and 1990, but argue that because of the 16-year delay following the filing of the applications, they did not receive adequate notice of the 2005 prehearing conference or the 2006 hearings. Second, there are the "new" property owners, who moved to or established themselves in affected valleys after 1989. Third, there are five property owners who either inherited or purchased their property interest from an original protestant. Fourth, there are residents of Utah who live on the Utah side of Snake Valley, and argue that they never received notice of the applications in 1989 and thus did not file protests. Fifth, there are at least three national environmental and wildlife organizations that have evolved since 1989, and argue that the State Engineer has effectively blocked them from protecting their interests because they did not file protests in 1989 and 1990.

In October 2005, the State Engineer notified roughly 300 people by certified mail that a prehearing conference would be held in January 2006 to discuss issues related to protest hearings on the 34 groundwater applications. Hundreds of the certified mailings were

returned undelivered, including mailings to 11 of the appellants in this case. The State Engineer did not attempt to resend the mailings or follow up on those mailings that were returned. At the January 2006 prehearing conference, the State Engineer heard from people who filed formal protests in 1989,² along with others who expressed public comment.³ Because of the 16-year lapse between the filing of the applications and the hearings on the applications, some attendees, including appellant Abigail Johnson, through her attorney, requested that the State Engineer re-notice SNWA's applications and reopen the protest period.

In March 2006, the State Engineer issued an order denying the request to re-notice the applications and scheduled a September 2006 hearing for applications concerning the Spring Valley water basin. The State Engineer recognized the significant lapse of time between the filing of the applications and the hearings and acknowledged that the delay signified to the public that SNWA did not intend to pursue the pumping project. However, the State Engineer also found that, without the public's knowledge, SNWA had been dedicating substantial time to prepare for hearings on the applications. SNWA explained that the magnitude of the groundwater project and the number of protests required significant preparation during the 1990s and early 2000s. However, neither the State

²Only one appellant in this case, Abigail Johnson, participated as a protestant at the January 2006 prehearing conference because she had protested the Spring Valley applications in 1989. However, in this appeal, she is also a new property owner because now she seeks to also protest the Snake Valley applications.

³Only one appellant in this case, Nomi Martin-Sheppard, provided public comment at the January 2006 prehearing conference.

Engineer nor SNWA offered evidence that a water study had been ordered or that the applicant and protestants authorized the State Engineer to postpone taking action on the 1989 applications.

In July 2006, appellants filed a petition with the State Engineer, requesting, in part, that the State Engineer re-notice SNWA's remaining applications from 1989 and reopen the protest period. The State Engineer summarily denied the petition, reasoning that it was analogous to a request for reconsideration under NRS 622A.390, and reconsideration was not warranted.

In August 2006, appellants filed a petition for judicial review with the district court, seeking review of the State Engineer's order denying the request to re-notice SNWA's applications. In May 2007, the district court denied the petition for judicial review. The district court determined that the State Engineer did not abuse his discretion in denying the request because there is no statutory provision that requires or authorizes additional notice of water appropriation outside of the statutory time period. Citing the 2003 legislative amendment to NRS 533.370(2)—the statute that requires the State Engineer to take action on an application within one year—the district court stated that Nevada water law takes into account a time lapse between the original filing of an application and a hearing.

In April 2007, while the petition for judicial review was pending in the district court, the State Engineer ruled on the applications that concerned the Spring Valley water basin. The State Engineer upheld some protests and overruled others. Of the 54 appellants to this appeal, one participated in the Spring Valley hearing. No petition for judicial review was filed concerning the State Engineer's April 2007 Spring Valley

order, but appellants filed this appeal of the district court's May 2007 denial of the August 2006 petition for judicial review.

DISCUSSION

Appellants appeal the district court's denial of the petition for judicial review on multiple grounds, only one of which is pertinent to our disposition. The determinative issue in this appeal is whether SNWA's 1989 groundwater appropriation applications were still pending before the State Engineer in 2003, despite the State Engineer's failure to take action on them within one year of the closing of the protest period, as required by the former version of NRS 533.370(2). In denying appellants' petition for judicial review, the district court interpreted the 2003 version of NRS 533.370 to apply retroactively to the 1989 applications.⁴ We disagree.⁵ We review a district court's statutory construction determination de novo. Sonia F. v. Dist. Ct., 125 Nev. ___, ___, 215 P.3d 705, 707 (2009).

NRS 533.370 as it existed in 1989

Appellants argue that the State Engineer violated his statutory duty because he did not rule on SNWA's 1989 applications within one year after the final date for filing a protest and that the district court erred in failing to address this argument when it was raised below.

⁴NRS 533.370 has been amended twice since 2003, but such amendments do not substantively affect the provision at issue in this case.

⁵Because we reverse and remand on the issue of statutory construction, we do not reach the merits of appellants' other arguments on appeal.

In 1989, NRS 533.370(2) required the State Engineer to take action on water appropriation applications within one year after the final date for filing a protest, subject to three exceptions:

The state engineer shall either approve or reject each application within 1 year after the final date for filing protest. However:

(a) Action can be postponed by the state engineer upon written authorization to do so by the applicant or, in case of a protested application, by both the protestant and the applicant; and

(b) In areas where studies of water supplies are being made or where court actions are pending, the state engineer may withhold action.

(Emphases added.)

This court has determined that “[t]he word “shall” is a term of command; it is imperative or mandatory, not permissive or directory.” Blaine Equip. Co. v. State, Purchasing Div., 122 Nev. 860, 867, 138 P.3d 820, 824 (2006) (alteration in original) (quoting Adkins v. Oppio, 105 Nev. 34, 37, 769 P.2d 62, 64 (1989)). Therefore, we conclude that the State Engineer violated his duty by failing to act on the applications within one year of the closing of the protest period, unless, pursuant to the 1989 version of NRS 533.370(2)(a) or (b), the State Engineer properly postponed action on the applications beyond the one-year statutory requirement.

The State Engineer did not request written authorization to postpone action

In 1989, NRS 533.370(2)(a) permitted the State Engineer to postpone action on water appropriation applications if he received written authorization from the applicant and any protestants to the applications. Appellants assert that the State Engineer neither sought nor received written authorization from SNWA or any protestants to the 1989 applications to postpone action. Neither the State Engineer nor SNWA

dispute appellants' assertion.⁶ Because no evidence in the record indicates that the State Engineer obtained written authorization from either SNWA or the protestants, we conclude that the 1989 version of NRS 533.370(2)(a) did not provide a basis for postponement of action on the applications.

The State Engineer did not state that a water supply study or pending court action necessitated postponement of action

The State Engineer was also permitted to postpone action on SNWA's applications if a water supply study was being conducted or a court action on the applications was pending in 1989. See NRS 533.370(2)(b) (1989). Appellants contend that neither a water supply study nor a court action had occurred by 1991. SNWA concedes that there was no court action; however, SNWA argues that the State Engineer determined that a hydrologic study was necessary before taking action on the applications.

To support its argument, SNWA directs this court to two rulings made by the State Engineer in 2001 and 2002 regarding various 1989 applications seeking to appropriate water from basins and aquifers in other regions of Nevada. There is no evidence in the record to indicate that the State Engineer postponed action on the applications at issue in this appeal by 1991 because of the need for hydrologic studies. Consequently, we determine that the State Engineer's delay in taking action was not excused pursuant to the 1989 version of NRS 533.370(2)(b).

⁶SNWA argues that it would have been "unreasonable and unworkable" to require the State Engineer to obtain written authorization from the over 800 protestants in 1989. However, SNWA's impracticability argument does not alter the fact that a plain reading of the 1989 version of NRS 533.370(2)(a) required such authorization.

The 2003 legislative amendment to NRS 533.370 does not apply retroactively to the 1989 applications

SNWA maintains that a 2003 legislative amendment to NRS 533.370 empowers the State Engineer retroactively to postpone action on groundwater appropriation applications made for municipal use, thus excusing his failure to comply with NRS 533.370 as it existed prior to the 2003 amendment. Appellants contend that the 2003 amendment does not apply retroactively, and SNWA must file new applications or the State Engineer must re-notice the applications and reopen the protest period.

In 2003, the Legislature amended NRS 533.370 to permit the State Engineer to postpone action on applications made for municipal purposes. See 2003 Nev. Stat., ch. 474, § 2, at 2980-81. Importantly, the Legislature specified the following water appropriation applications to which the amendment in NRS 533.370(2) applies: “1. Each application . . . that is made on or after July 1, 2003; and 2. Each such application that is pending with the office of the State Engineer on July 1, 2003.” Id. § 18, at 2989 (emphasis added).

Therefore, because SNWA’s applications were made for municipal use, and the State Engineer did not rule on SNWA’s 1989 applications within one year after the final date for filing a protest, we must determine whether SNWA’s 1989 applications were pending in 2003. If the applications were pending, the State Engineer would have been statutorily authorized to postpone a ruling without approval from SNWA and the protestants.

Appellants argue that the 1989 applications were not pending in 2003 because they effectively lapsed one year after the protest period ended. They assert that the reasonable interpretation of the term “pending,” as used by the Legislature in regard to the application of the

2003 amendment to NRS 533.370, is that only applications filed within one year of the amendment's enactment in 2003 are still before the State Engineer. SNWA argues that the 1989 applications were pending because the Legislature intended that the municipal-use exception apply retroactively. SNWA infers this legislative intent from the fact that the Legislature included a provision specifying that the amendment applied to pending applications, instead of specifying only prospective application of the amendment.

To determine legislative intent, this court will not go beyond a statute's plain language if the statute is facially clear. Bacher v. State Engineer, 122 Nev. 1110, 1117, 146 P.3d 793, 798 (2006). An ambiguous statute is one that is capable of more than one reasonable interpretation. Id. at 1117-18, 146 P.3d at 798. When a statute is ambiguous, this court determines the Legislature's intent by evaluating the legislative history and construing the statute in a manner that conforms to reason and public policy. Attorney General v. Nevada Tax Comm'n, 124 Nev. ___, ___, 181 P.3d 675, 681 (2008). This court "avoids statutory interpretation that renders language meaningless or superfluous." Karcher Firestopping v. Meadow Valley Contr., 125 Nev. ___, ___, 204 P.3d 1262, 1263 (2009). Whenever possible, we interpret "statutes within a statutory scheme harmoniously with one another to avoid an unreasonable or absurd result." Allstate Insurance Co. v. Fackett, 125 Nev. ___, ___, 206 P.3d 572, 576 (2009).

Appellants' and SNWA's arguments demonstrate that the effective date applicable to the amendment made in subsection 2 of the 2003 version of NRS 533.370 regarding pending groundwater appropriation applications is ambiguous because it is susceptible to more

than one reasonable interpretation. Thus, we first turn to the legislative history to determine legislative intent. After examining the legislative history, it is clear that SNWA requested the 2003 municipal-use amendment, but, unfortunately, the legislative history provides no guidance regarding retroactive effect of the amendment to pending applications. See Hearing on S.B. 336 Before the Assembly Comm. on Natural Resources, Agriculture, and Mining, 72nd Leg. (Nev., April 30, 2003); see also Hearing on S.B. 336 Before the Senate Comm. on Natural Resources, 72nd Leg. (Nev., March 26, 2003).

We next consider legislative intent by construing the statute in a manner consistent with reason and public policy. Although the retroactive effect of NRS 533.370(2) evidences the Legislature's intent that the statute apply to applications for municipal use that were filed prior to the enactment of the amendment, we conclude that appellants' interpretation of the word "pending" is the more reasonable one for four reasons.

First, by setting a timeline for the approval or rejection of groundwater appropriation applications within one year in NRS 533.370(2), we determine that the Legislature intended to prevent a significant lapse of time before a ruling. There is no language in the statute or the legislative history that indicates an intention by the Legislature that the amendment for municipal use apply retroactively to applications made more than one year prior to the amendment's enactment. Requiring approval to postpone an application from both the applicant and the protestant demonstrates that the Legislature recognizes the significant interests of both parties and intended to ensure that both parties receive adequate notice of the postponement of action on

applications. Therefore, without the Legislature's explicit intent to the contrary, it would be inequitable to allow applications to linger for years without obtaining the parties' written authorization to postpone action or providing adequate notice of the initiation of hearings on stale applications.

Second, the 1989 version of NRS 533.370(2) mandated that the State Engineer rule on an application within one year, and the 2003 amendments do not contain a clear indication of retroactive effect. Thus, to determine that there would be no consequence for not issuing a ruling within one year would render the statutory timeline superfluous.

Third, a reading consistent with SNWA's interpretation of the 2003 amendment would deprive at least 11 appellants who are original protestants of SNWA's 1989 applications of their due process right to grant or withhold authorization to postpone action by the State Engineer on the 1989 applications. See Logan v. Zimmerman Brush Co., 455 U.S. 422, 428-29 (1982).

Fourth, there is no indication that the Legislature intended that the 2003 amendment to NRS 533.370(2) apply to every groundwater appropriation application ever filed in the office of the State Engineer. Such an interpretation would produce absurd results. Rather, in reading the statutory provisions together, the more reasonable interpretation of "pending" is that it refers to those applications in which the one-year period for the State Engineer to take action had not yet elapsed. Because the period had not occurred, the State Engineer would have been able to postpone action based on one of the exceptions in NRS 533.370(2). We therefore conclude that the Legislature intended to designate as "pending" on July 1, 2003, only those applications in which the one-year period

under NRS 533.370(2) had not arrived. We determine that the 2003 amendment to NRS 533.370(2) does not apply retroactively and that the district court erred when it found that the 2003 amendment applied to SNWA's 1989 applications. Therefore, we conclude that the State Engineer violated his statutory duty by failing to rule on SNWA's 1989 applications within one year of the close of the protest period.

Remedy for the State Engineer's failure to rule on SNWA's applications within one year of the close of the protest period

We conclude that the State Engineer violated his statutory duty by ruling on applications well beyond the one-year statutory limitation without first properly postponing action.⁷ Therefore, the district court erred in denying appellants' petition for judicial review. However, in the absence of any statutory remedy for noncompliance with the timing requirements of NRS 533.370, we cannot conclude that the State Engineer's inaction deems the applications either approved or rejected, or whether the applications must be re-noticed or the applicants be required to file new applications. Voiding the State Engineer's ruling and preventing him from taking further action would be inequitable to SNWA and future similarly situated applicants. And applicants cannot be punished for the State Engineer's failure to follow his statutory duty. Similarly, it would be inequitable to the original and subsequent protestants to conclude that the State Engineer's failure to take action

⁷We note that the record on appeal demonstrates that the State Engineer has ruled on the Spring Valley applications. The State Engineer held hearings on the Delamar, Dry Lake, and Cave Valley applications in February 2008, and a hearing on the Snake Valley applications has not been scheduled.

results in approval of the applications over 14 years after their protests were filed. These issues deserve full development before being adjudicated.

Instead, we reverse the district court's order denying appellants' petition for judicial review and remand to the district court. We instruct the court to undertake the necessary proceedings to adjudicate the proper remedy, namely whether SNWA is required to file new applications or whether the State Engineer is required to re-notice and reopen the protest period.

/s/ J. Hardesty, J.
Hardesty

We concur:

/s/ Parraguirre, C.J.
Parraguirre

/s/ Douglas, J.
Douglas

/s/ Cherry, J.
Cherry

/s/ Saitta, J.
Saitta

/s/ Gibbons, J.
Gibbons

/s/ Pickering, J.
Pickering