Evaluating the Impact of Truckee River Operating Agreement (TROA) Alternatives on Pyramid Lake Algal Production and Hypolimnetic Oxygen: Final Alternatives

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ABSTRACT

The factors controlling nitrogen availability, and hence algal productivity, in Pyramid Lake differ from those in the Truckee River, and therefore, an assessment of the impacts of water management strategies must reflect those differences. As a lake, algal production in Pyramid is affected by total available nitrogen from external sources, internal sources, and the nitrogen concentration of lake waters. This dependence of production on a variety of nitrogen sources means that nitrogen availability for a given year depends on the supply of nitrogen to the lake over several years rather than simply during the current year. The Davis Limnology Group developed in 1994 a computer simulation modeling tool that predicts the eutrophication response of Pyramid Lake as a whole to nitrogen loadings. In the past, the U.C. Davis Tool was used to evaluate how different Truckee River Operating Agreement (TROA) alternatives may affect the coldwater fishery of Pyramid Lake for the report to the negotiators (1995) and the DEIS/EIR (1996) compared with current conditions and the No Action Alternative. This study evaluates the TROA alternative developed for the TROA EIS/EIR and compares predictions with current conditions, the No Action Alternative, and a Local Water Supply Alternative (LWS).

Simulated water quality for the lake under current conditions are similar to conditions reported during the 1970's and 1980's. Mean lake concentrations for dissolved inorganic (DIN) and dissolved organic (DON) nitrogen during the final 87 years of the simulation were 0.091 and 0.69 mg/l, respectively, while average algal production was 173 g C/m^2Ayr. Spikes in the simulated values for the DIN concentration in the lake and annual algal production were associated with years of high river inflow.

The impact of the Alternatives on food availability and habitat for the coldwater fish population of Pyramid Lake was evaluated by comparing values for No Action with values determined for current conditions and by comparing the TROA and LWS Alternatives with the No Action Alternative. Conditions for the No Action Alternative were similar to current conditions, with lower river inflow and corresponding coldwater fishery habitat. Under the TROA Alternative, Truckee River inflow to Pyramid Lake increased by 11,500 acreAft/yr causing mean lake level for 1913-1999 to be 3.2 ft higher than under the No Action Alternative. This increase in river inflow for the TROA Alternative corresponded with higher predicted DIN loading (3.9 Mg N/yr) and DON loading (13.1 Mg N/yr). Differences in lake characteristics for TROA and the No Action Alternative were relatively small but generally benefited the coldwater fishery of Pyramid Lake. The LWS Alternative provided results similar to the No Action Alternative.

INTRODUCTION

The stimulation of algal production in aquatic systems (i.e. eutrophication) has been a topic that has received a tremendous amount of scientific and regulatory attention over the past 30-40 years. For Pyramid Lake, concern over potential eutrophication was one of the prime driving forces which initiated water quality studies conducted by the University of California at Davis (UC Davis) during 1989-1993. Work was sponsored by the Pyramid Lake Paiute Tribe with funding from the U.S. Environmental Protection Agency (US EPA) and focused on understanding nutrient cycling and algal production.

Two important goals from the inception of the UC Davis project were to prepare nutrient budgets for the lake and to assess the relative importance of external and internal sources of nutrients. In Pyramid Lake, algal production and hence eutrophication are linked to nitrogen availability. The importance of nitrogen for algal production in the lake was clearly documented in project study reports (see Lebo et al., 1993a, 1993b, 1993c, 1994) and prior work. Thus, the simulation Tool developed as part of the UC Davis study and used for this modeling study is based solely on nitrogen cycling and excludes phosphorus from consideration. The model is based on empirical relationships developed from data collected at the lake during 1989-1993 and the late 1970's. The Tool was recoded to utilize Microsoft Excel as its interface in 2002.

The factors controlling nitrogen availability and hence algal productivity in Pyramid Lake differ from those in the Truckee River, and therefore, an assessment of the impacts of water management strategies must reflect those differences. As a lake, algal production in Pyramid is affected by total available nitrogen from external sources, internal sources, and the nitrogen concentration of lake waters (Lebo et al., 1994). This dependence of production on a variety of nitrogen sources means that nitrogen availability for a given year depends on the supply of nitrogen to the lake over several years rather than simply during the current year. Indeed, the residence time for dissolved inorganic nitrogen (DIN, NH_4-N+NO_3-N) in Pyramid Lake is approximately four years (Lebo et al., 1993a). Targeting representative years (as done in the Truckee River) is not appropriate for assessment of lake conditions because water quality characteristics in Pyramid Lake are affected by the total supply of water and DIN to the system over longer time scales (e.g. >4 yr). Thus, the evaluation of TROA flow scenarios on the lake requires information about both nitrogen loading and river inflow under the different management alternatives for decades rather than targeted individual years.

MODEL DESCRIPTION

The Davis Limnology Group developed a computer simulation modeling tool for the Pyramid Lake Tribe that predicts the water quality of Pyramid Lake (see Lebo et al., 1994; Lebo and Goldman, 1995, 1996). The eutrophication modeling Tool (PL-EUTR2) is a computer simulation tool that allows changes in the water quality of Pyramid Lake to be evaluated based on nitrogen availability. It also estimates changes in lake level and the approximate total dissolved solids (TDS) concentration of the lake. The program can be used to determine nitrogen concentrations, algal production, and hypolimnetic dissolved oxygen (DO) concentrations for a variety of simulated conditions.

PL-EUTR2 is a simple model in the sense that it computes single annual values for algal production and nitrogen concentrations based on changes in lake volume and the inventories of nitrogen fractions in the lake. All values reported by the Tool are annual averages for the lake (with the exception of DO) and do not account for seasonal or spatial variations in lake parameter concentrations. For oxygen concentrations, values are calculated by the model on October 1 of each year, consistent with the cooling of surface waters to temperatures adequate for coldwater fish habitat.

For nitrogen cycling in the lake, PL-EUTR2 maintains dissolved inorganic (DIN) and organic (DON) nitrogen inventories and tracks inputs, losses, and exchanges between nitrogen fractions for those inventories. The input sources to the lake are based on nitrogen budgets prepared as part of the final report series for the U.C. Davis project (see Lebo et al., 1993a). Included are precipitation, dry fallout, inflow through the Truckee River, streams, and groundwater, and four user specified sources. In addition, the Tool provides for the input of nitrogen through the internal sources of sediment release and N_2 fixation. The primary loss mechanisms for nitrogen from Pyramid Lake incorporated into the Tool are sedimentation of particulate matter (both algal cells and sediment loading) and denitrification in anoxic bottom waters and sediments. However, the Tool does export water and associated DIN and DON to the Winnemucca Lake basin when lake surface rises to an elevation >3863 feet. Within lake waters, PL-EUTR2 provides for the exchange of nitrogen between the DIN and DON pools through the hydrolysis of organic nitrogen and excretion of DON from algal cells.

The productivity of Pyramid Lake is integral to the ecological integrity of the system and the Pyramid Lake Paiute Tribe's efforts to further develop and maintain a natural thriving fishery. PL-EUTR2 provides a tool that allows nutrients, algal production, and coldwater fish habitat to be integrated in an assessment of the lake. To utilize the model for the report to the negotiators on TROA alternatives, the original version of PL-EUTR2 was modified slightly to output information on the volume of hypolimnetic waters in Pyramid Lake which are well-oxygenated (both >5 and >6 mg/l). With inclusion of hypolimnetic habitat, the Tool provides information on the DIN concentration of lake waters, annual algal production, bottom water anoxia, and hypolimnetic habitat for the coldwater fishery of the lake. These parameters form the basis for this assessment study of the impacts of the TROA alternative on the Pyramid Lake fishery.

STUDY DESIGN

The EUTR2 model was run for the full 100-yr simulation period identified for the EIS/EIR analysis (October 1900 to September 2000). Truckee River inflow data sets were obtained from Merlynn Bender of the Bureau of Reclamation for each of the four simulations run as part of this study. Precipitation data for Reno during the study period were obtained from the Western Regional Climate Center (Reno, Nevada) or the Pyramid Lake Paiute Tribe. The other source of data required to conduct the modeling study was predicted nitrogen loadings from the Truckee River to Pyramid Lake for the water years used to evaluate Truckee River water quality effects. These were obtained from Jim Brock at the University of Nevada at Reno Desert Research Institute (UNR DRI) who conducted the modeling work for the Truckee River water quality (using DSSAMIII) component of the TROA EIS/EIR. Other components of the water balance for the EUTR2 model are as described in Lebo et al. (1994) and Lebo and Goldman (1995).

For nitrogen loading to Pyramid Lake under the different alternatives, all sources were identical among runs except for Truckee River inflow. This includes N_2 fixed during summer-fall blooms of the blue-green alga *Nodularia spumigena* (300 Mg N/yr). Truckee River nitrogen loadings to the lake for the different alternatives were determined from rating curves of dissolved inorganic (DIN) and organic (DON) nitrogen versus discharge (see Appendix). Curves for both fractions were based on monthly points from the water years examined for the Truckee River portions of the EIS/EIR studies.

Truckee River nitrogen loading relationships were developed using log transformed data. Loadings for each year of the 100-yr simulation period were predicted from monthly inflow data, accounting for the seasonal increase in DIN removal efficiency during the growing season; separate equations to predict monthly DIN loading were developed for the winter (October to February) and growing season (March to September) periods. Rating curves are shown in the appendix.

The initial conditions for the simulations were based on values selected for the EIS/EIR study by the U.S. Fish and Wildlife Service and typical values for Pyramid Lake. For initial lake level, simulations were begun at a level of 3806.55 ft (December 1900, Current Conditions Simulation) consistent with modeling by the Bureau of Reclamation for current conditions. The initial value for lake TDS concentration was 5297 mg/l. Initial values for DIN and DON concentrations in Pyramid Lake were 0.09 and 0.70 mg/l, respectively, based on typical values reported for lake waters during the 1970's and 1980's. It is important to note that nitrogen concentrations observed in the lake during the recent 1989-1993 study were not used because of the nitrogen deficient state of the lake during that period (see Lebo et al., 1993c). In the mid-1980's, meromictic conditions (no winter overturn) prevailed in the lake, and when deep mixing resumed in January 1988, there was a tremendous stripping of DIN from lake waters. There was also minimal Truckee River nitrogen loading to the lake during the 1988-1992 period due to a regional drought. Thus, it is our belief that the conditions prior to the mid-1980's better represent typical conditions for Pyramid Lake DIN and DON concentrations.

All input parameters used in this modeling study are listed in the Appendix and are based on calibration of the model for the U.C. Davis study. One exception from prior analysis of Pyramid Lake Productivity in 1995-1996 is the return of the organic N hydrolysis rate to the 1994 calibration value of 0.01 (from 0.015 in the TROA DEIS/EIR). The improved technique to estimate river nitrogen loads from monthly rather than annual inflow allowed the fraction of algal production lost to the sediment to be returned to the original calibration value of 0.10; the fraction of algal production removed to the sediment was increased in the 1995 report to the negotiators to allow for a greater removal of DIN from lake waters. An accumulation of DIN in the lake under the original calibration required some modification of removal processes. Changes in these parameters both in the 1995 study, the 1996 study, and model runs reported here were based on achieving DIN (0.09 to 0.11 mg/l) and DON (0.67∀0.03 mg/l) concentrations under current conditions that are consistent with past observations. Other input parameters are identical to the previous study for TROA conducted in 1995 and 1996.

The parameters used here to evaluate how the different water management alternatives affect the productivity of Pyramid Lake include the lake DIN concentration, annual algal production (PPr), hypolimnetic fish habitat and years not achieving the lake DO water quality standard. These parameters form a basic analysis of the amount of food available to support fish production (algal production) and well-oxygenated coldwater fish habitat. Several measures of dissolved oxygen are reported by the Tool. These include the duration of anoxia at one meter from the sediment surface in the center of the lake, the hypolimnetic volume of water with oxygen >5 and >6 mg/l. Two DO criteria are used for hypolimnetic volume to better characterize coldwater fish habitat. For comparisons of the different alternatives in the discussion, only data for hypolimnetic habitat with DO >6 mg/l are used.

Trends in the "current conditions" and "No Action" scenarios are presented in the following two sections for the 100-yr simulation period. Following those sections, variations in the key parameters listed above for the TROA and LWS Alternatives are evaluated by comparing values for each year of the simulations with the No Action Alternative. In the analysis, data from the first 12 years of the simulations are excluded to allow the lake to equilibrate to the loading levels for the different water management alternatives. Data from the remaining 87 years are then compared with values from the No Action Alternative. A 12-year equilibration period was selected to be three times the approximate residence time for DIN in Pyramid Lake (see Lebo et al., 1993a). Comparisons are evaluated based on mean deviations (∀ standard deviation) from the No Action Alternative values.

CURRENT CONDITIONS

The level of Pyramid Lake increases under the simulated river inflow record for current conditions for the past 99 years (Fig. 1). During the initial 15 years of the simulation, lake elevation rose rapidly to a relative maximum in 1918 due to several years of extremely high inflow and then declined again until the late 1930's. Following this initial rise and fall in lake elevation, there was a general increase in level predicted for 1940-1990, with alternating periods of low and high river inflow. Highest water level in Pyramid Lake was 3856.5 ft predicted at the end of 1986

Water quality predicted for the lake under current conditions is similar to conditions reported during the 1970's and 1980's (see Lebo et al., 1993c). Mean values for DIN and DON during the final 87 years of the simulation were 0.091 and 0.69 mg/l, respectively, while average algal production was 173.4 g C/m^2Ayr (Table 1). Spikes in the simulated values for the DIN concentration in the lake and annual algal production (see Fig. 2) were associated with years of high river inflow (and nitrogen loading). Further, reduced dissolved oxygen concentrations in bottom waters as indicated by reduced well-oxygenated hypolimnetic volumes (DO >5 and >6 mg/l) and the duration of anoxia at the sediment surface (Fig. 3) were associated with these spikes in algal production. This linkage between nitrogen, algal production, and low dissolved oxygen demonstrates how excessive annual nitrogen loadings can have a detrimental effect on water quality conditions in the lake and potential habitat for the coldwater fishery. However, the predicted DO concentration at 70 m remained above 6 mg/l for all years of the simulation.

The patterns in hypolimnetic DO for current conditions need to be interpreted in the context of the overall needs of the coldwater fish population of Pyramid Lake. The predicted hypolimnetic volume available for coldwater fish (DO >6 mg/l) was typically around 1.8×10^{10} m^3, which is far greater than the approximate total hypolimnetic volume for the lake at its current (1989-1993) level of approximately 3800 feet. For values $>1.7 \times 10^{10}$ m^3, the volume of well-oxygenated hypolimnetic waters is greater than the total hypolimnion for the lake at an elevation

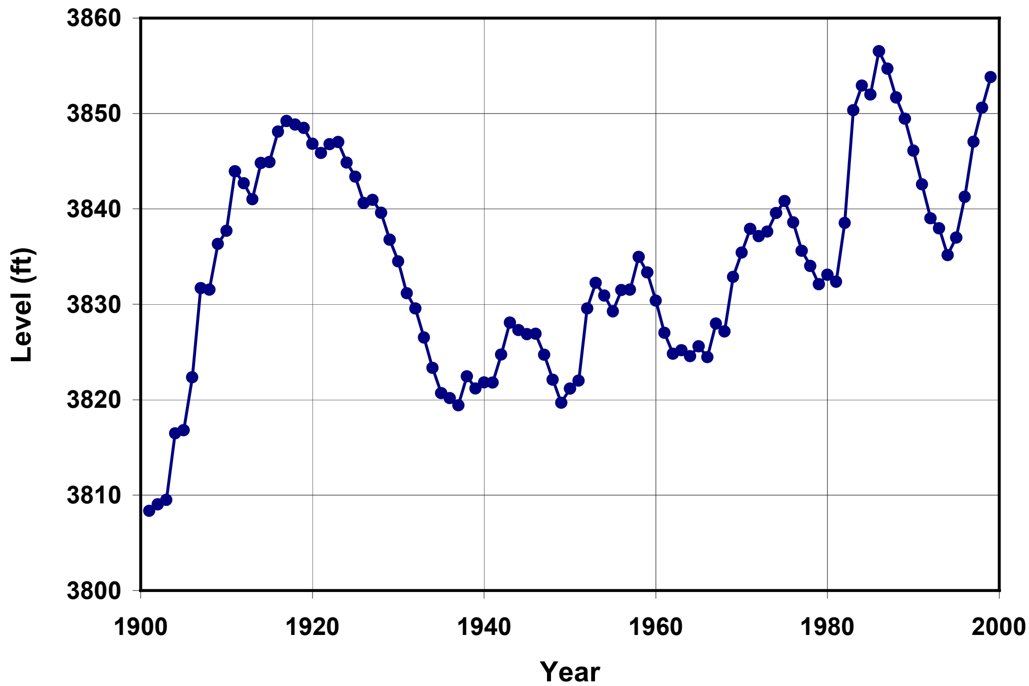


Figure 1. Pyramid Lake level for current conditions

Table 1. Comparison of No Action Alternative with Current Conditions. All values are for the 1913-1999 period. Deviations are defined as: Current Conditions – No Action. Positive values indicate the values for Current Conditions are larger. Parameters for which the mean deviation for the 87-year period are significantly different ($P<0.05$, Student's t-test) from zero are underlined. Deviations were calculated by year and then averaged.

Parameter	Unit	Current Conditions		No Action		Deviation
		mean	s.d.	mean	s.d	mean
Truckee River						
Inflow	1000 AF/yr	457.3	351.7	452.6	342.8	***4.7***
DIN-load	Mg/yr	46.4	35.2	39.8	26.3	***6.6***
DON-load	Mg/yr	179.0	137.4	191.8	152.9	***-12.8***
Pyramid Lake						
Level	feet	3835.5	10.0	3833.8	10.0	***1.7***
DIN-Conc	mg/l	0.091	0.001	0.091	0.001	-0.0001
DON-Conc	mg/l	0.687	0.024	0.710	0.026	***-0.023***
Algal Prod.	$g\text{-}C/m^2/yr$	173.4	2.8	173.2	2.3	0.29
DO-70 m	mg/l	6.67	0.10	6.68	0.08	-0.007
Anoxia	days	72.5	4.4	72.1	3.6	0.4
Hypo >5 mg/l	10^{10} m^3	1.786	0.119	1.766	0.118	***0.020***
Hypo >6 mg/l	10^{10} m^3	1.766	0.119	1.746	0.118	***0.020***

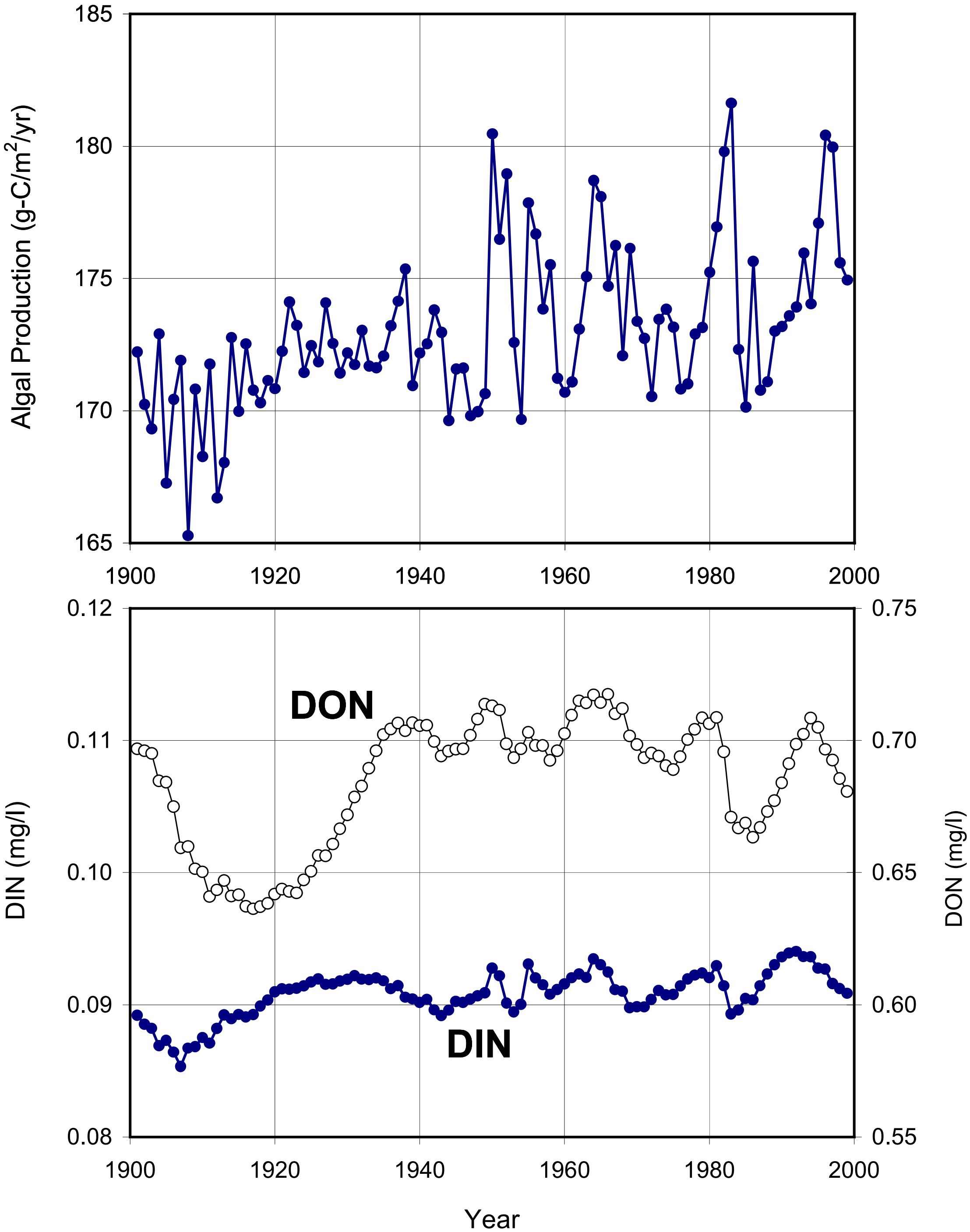


Figure 2. Algal production (top) and lake dissolved inorganic (DIN) and organic (DON) Nitrogen concentrations (bottom) for current conditions

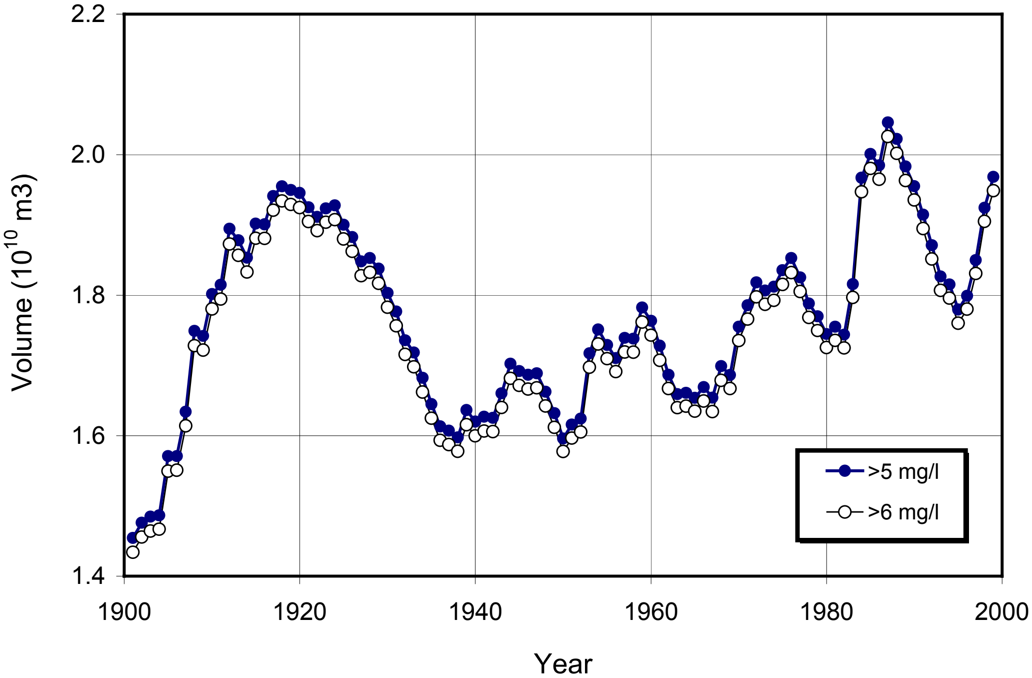


Figure 3. Hypolimnetic coldwater habitat for current conditions based on criteria of waters >5 mg/l and >6 mg/l.

of 3820 feet. This suggests that well-oxygenated habitat should not be limiting to fish under current conditions. It is important to note that for bottom water anoxia most of the period indicated for most years is after the initiation of surface water cooling in the late fall. Thus, values <100 days should have minimal impact on the coldwater fishery in the lake since seasonal overturn typically occurs in January of each year with cooling of surface waters during October-November.

NO ACTION ALTERNATIVE

The impact of the No Action Alternative on food availability and habitat for the coldwater fish population of Pyramid Lake is evaluated here by comparing predicted values for the alternative with values determined for current conditions. For each parameter, deviations in all key parameters were computed for each year during 1913-1999 (see study design) and the mean value was calculated for the 87-year test period. These average deviations were then compared with zero to determine if the mean differences are statistically significant (Student's t-test). Table 1 presents the results from these comparisons and the mean values for both the current conditions and No Action simulations. Under the No Action Alternative, Truckee River inflow to Pyramid

Lake was higher by 4,700 acreAft/yr (1%) causing mean lake level for 1913 to 1999 to be 2.0 ft higher for current conditions than the No Action Alternative.

The higher river inflow to Pyramid Lake under Current Conditions contributed to higher DIN loading but lower Organic N loading (Table 1). Despite a predicted decrease in annual algal production for No Action, compared with current conditions, hypolimnetic coldwater fishery habitat was lower for the No Action. However, the DO concentration at 70 m depth in the center of Pyramid Lake increased by 0.007 mg/l for the No Action Alternative. In conclusion, the No Action Alternative caused lake water quality conditions for the coldwater fish population of Pyramid Lake to be generally not as good as Current Conditions due to lower lake level and lower algal production.

TROA ALTERNATIVE

The impact of the TROA Alternative on food availability and habitat for the coldwater fish population of Pyramid Lake was evaluated by comparing values for the alternative with values from No Action. For model output parameters, deviations in predicted values between the two runs were computed for each year during 1913-1999 (see study design) and the mean value was calculated for the 87-year test period. These average deviations were then compared with zero to determine if the mean differences were statistically significant (Student's t test). Table 2 presents the results from these comparisons and the mean values for both the TROA Alternative and No Action simulations. As with the previous section, values from the No Action Alternative were subtracted from the corresponding ones from the TROA Alternative, with positive values indicating higher values for the TROA Alternative.

Under the TROA Alternative (see Table 2), Truckee River inflow to Pyramid Lake increased by 11,500 acreAft/yr (~2%) causing mean lake level for 1913-1999 to be 3.2 ft higher than under the No Action Alternative. This increase in river inflow for the TROA Alternative corresponded with higher predicted DIN loading (3.9 Mg N/yr) and DON loading (13.1 Mg N/yr). Differences in lake characteristics for the two simulations were small with significant increases in DIN concentration (0.0008 mg/l), DON concentration (0.006 mg/l), and algal productivity (1.28 g-C/m^2·yr). Hypolimnetic volume with DO >5 mg/l (0.037 x 10^{10} m^3) and >6 mg/l (0.037 x 10^{10} m^3) also increased under the TROA Alternative. In conclusion, the TROA Alternative improved lake water quality conditions for the fish population of Pyramid Lake through both higher algal production and greater coldwater habitat.

Table 2. Comparison of TROA with No Action Alternative. All values are for the 1913-1999 period. Deviations are defined as: TROA – No Action. Positive values indicate the values for TROA simulation are larger. Parameters for which the mean deviation for the 87-year period are significantly different (P<0.05, Student's t-test) from zero are underlined. Deviations were calculated by year and then averaged.

Parameter	Unit	TROA		No Action		Deviation
		mean	s.d.	mean	s.d	mean
Truckee River						
Inflow	1000 AF/yr	464.1	354.1	452.6	342.8	***11.5***
DIN-load	Mg/yr	43.7	28.8	39.8	26.3	***3.9***
DON-load	Mg/yr	204.9	157.3	191.8	152.9	***13.1***
Pyramid Lake						
Level	feet	3837.0	10.0	3833.8	10.0	***3.2***
DIN-Conc	mg/l	0.092	0.001	0.091	0.001	***0.0008***
DON-Conc	mg/l	0.717	0.028	0.710	0.026	***0.006***
Algal Prod.	g-C/m^2/yr	174.4	2.6	173.2	2.3	***1.28***
DO-70 m	mg/l	6.64	0.08	6.68	0.08	***-0.04***
Anoxia	days	74.0	3.9	72.1	3.6	***1.9***
Hypo >5 mg/l	10^{10} m^3	1.803	0.118	1.766	0.118	***0.037***
Hypo >6 mg/l	10^{10} m^3	1.783	0.118	1.746	0.118	***0.037***

LWS ALTERNATIVE

The impact of the LWS Alternative on food availability and habitat for the coldwater fish population of Pyramid Lake was evaluated by comparing values for the alternative with values from No Action. For model output parameters, deviations in predicted values between the two runs were computed for each year during 1913-1999 (see study design) and the mean value was calculated for the 87-year test period. These average deviations were then compared with zero to determine if the mean differences were statistically significant (Student's t test). Table 2 presents the results from these comparisons and the mean values for both the LWS Alternative and No Action simulations. As with the previous section, values from the No Action Alternative were subtracted from the corresponding ones from the LWS Alternative, with positive values indicating higher values for the LWS Alternative.

Under the LWS Alternative (see Table 3), Truckee River inflow to Pyramid Lake decreased by 926 acreAft/yr (<<1%) causing mean lake level for 1913-1999 to be 0.16 ft lower than under the No Action Alternative. This decrease in river inflow for the LWS Alternative corresponded with similar predicted DIN loading (0.14 Mg N/yr higher) but lower DON loading (3.1 Mg N/yr) than the No Action Alternative. Differences in lake characteristics for the two simulations were small, although many were significant. In conclusion, the LWS Alternative provided similar lake water quality conditions for the fish population of Pyramid Lake to the No Action Alternative.

Table 3. Comparison of LWS Alternative with No Action Alternative. All values are for the 1913-1999 period. Deviations are defined as: LWS – No Action. Positive values indicate the values for LWS simulation are larger. Parameters for which the mean deviation for the 87-year period are significantly different (P<0.05, Student's t-test) from zero are underlined. Deviations were calculated by year and then averaged.

Parameter	Unit	LWS Alternative		No Action		Deviation
		mean	s.d.	mean	s.d	mean
Truckee River						
Inflow	1000 AF/yr	451.7	342.5	452.6	342.8	***-926***
DIN-load	Mg/yr	40.0	26.6	39.8	26.3	0.14
DON-load	Mg/yr	188.7	147.5	191.8	152.9	-3.12
Pyramid Lake						
Level	feet	3833.6	10.0	3833.8	10.0	***-0.16***
DIN-Conc	mg/l	0.091	0.001	0.091	0.001	***-0.0001***
DON-Conc	mg/l	0.706	0.026	0.710	0.026	-0.004
Algal Prod.	g-C/m^2/yr	173.0	2.3	173.2	2.3	***-0.17***
DO-70 m	mg/l	6.68	0.08	6.68	0.08	***0.005***
Anoxia	days	71.8	3.6	72.1	3.6	***-0.3***
Hypo >5 mg/l	10^{10} m^3	1.764	0.118	1.766	0.118	***-0.002***
Hypo >6 mg/l	10^{10} m^3	1.744	0.118	1.746	0.118	***-0.002***

DISCUSSION

The results of this modeling study and prior simulations (see Lebo and Goldman, 1995, 1996) demonstrate the competition between providing a strong food base for the entire fishery of Pyramid Lake and maintaining well-oxygenated coldwater habitat. Both factors are important but can be in opposition when increased algal production to support the food base of the lake causes lower bottom water DO concentrations. Higher river inflow can partially offset potential negative impacts of increased algal production by increasing lake level, which increases total hypolimnetic volume to distribute the oxygen consuming demand of settling algae cells. For the model runs conducted in this study, Current Conditions showed slightly better conditions in Pyramid Lake for the coldwater fishery than the No Action Alternative (see Table 1). Differences between the TROA Alternative and No Action, however, showed clear benefits to the coldwater fishery. The LWS Alternative was similar to the No Action Alternative.

Lebo and Goldman (1995) used a set of seven output parameters from model runs to compare the five initial alternatives developed for the report to the negotiators. These were river inflow, lake level, lake DIN concentration, algal production, DO at 70 m, duration of anoxia, and hypolimnetic volume with DO >6 mg/l. Parameters from this set that were significantly different between the TROA Alternative and No Action were lake level and hypolimnetic volume with DO >6 mg/l, which were higher under TROA. River inflow was also higher under TROA. Based on this simple ranking procedure, the TROA Alternative provides the best conditions for the lake coldwater fishery.

The evaluations made here for the coldwater fishery of the lake are also true for the benthic invertebrate population, although the duration of bottom water anoxia becomes more important than cold well-oxygenated hypolimnetic volume. Provided bottom waters in the shallower portions of the lake (<40 m) remain well-oxygenated, higher DIN concentrations and hence higher algal production should benefit the benthic invertebrates as well as the fish. The key for Pyramid Lake is to provide a balance between habitat and food base. For the current study, the TROA alternative provided higher algal production but slightly lower DO concentration at 70 m than the No Action indicating the scenario did not provide optimal conditions for Pyramid Lake benthic invertebrates.

Predictions of nitrogen loadings and resulting nitrogen and dissolved oxygen concentrations in Pyramid Lake used in the current modeling study should be interpreted cautiously due to limited data available for higher flows to generate the rating curves. The relative comparisons among model runs are meaningful, but absolute values should be interpreted cautiously. To test the impacts of different river management alternatives on the lake, other nitrogen and water inputs to the lake were held constant across all model runs, including annual levels of nitrogen fixation. The lack of estimated river nitrogen loading to the lake from several years with moderate to high flows is also a limitation of the study; the rating curves are primarily based on 1986 predicted loadings. Additional eutrophication modeling of Pyramid Lake would be substantially improved by inclusion of data from at least one and preferably two more years with annual inflows of 200,000 to 600,000 acreAft/yr to provide better estimates of the DIN and DON loadings to the lake for all years. This is particularly important in determining if conditions under different alternatives substantially affect available DIN to support algal production and ultimately the fishery of the lake.

LITERATURE CITED

Lebo, M.E., and C.R. Goldman. 1995. Evaluating the Impact of Truckee River Operating Agreement (TROA) Alternatives on Pyramid Lake Algal Production and Hypolimnetic Oxygen. Submitted to U.S. Fish and Wildlife Service, Reno, Nevada.

Lebo, M.E., and C.R. Goldman. 1996. Evaluating the Impact of Truckee River Operating Agreement (TROA) Alternatives on Pyramid Lake Algal Production and Hypolimnetic Oxygen. Submitted to U.S. Fish and Wildlife Service, Reno, Nevada.

Lebo, M.E., J.E. Reuter, and C.R. Goldman. 1993a. Pyramid Lake, Nevada, Water Quality Study 1989-1993. Vol. III. Nutrient Budgets. Univ. California, Davis. 278 p.

Lebo, M.E., J.E. Reuter, C.L. Rhodes, and C.R. Goldman. 1993b. Pyramid Lake, Nevada, Water Quality Study 1989-1993. Vol. I. Limnological Data. Univ. California, Davis. 145 p.

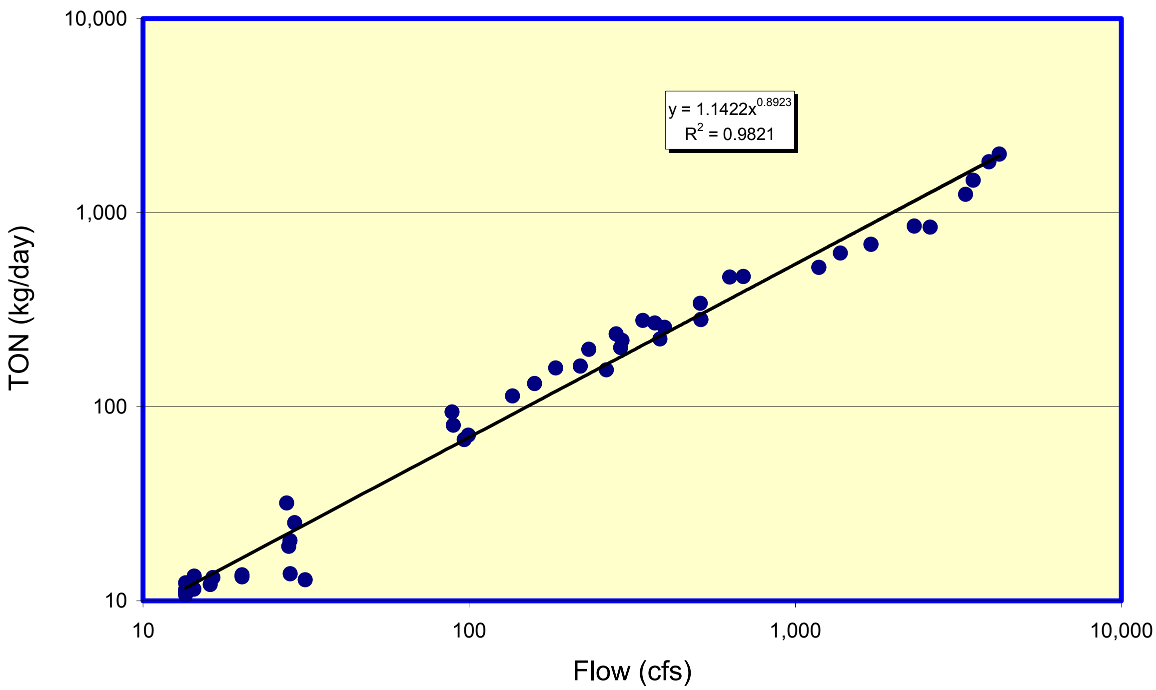
Lebo, M.E., J.E. Reuter, C.L. Rhodes, and C.R. Goldman. 1993c. Pyramid Lake, Nevada, Water Quality Study 1989-1993. Vol. II. Limnological Description. Univ. California, Davis. 280 p.

Lebo, M.E., J.E. Reuter, and C.R. Goldman. 1994. Pyramid Lake, Nevada, Water Quality Study 1989-1993. Vol. IV. Modeling Studies. Univ. California, Davis. 243 p.

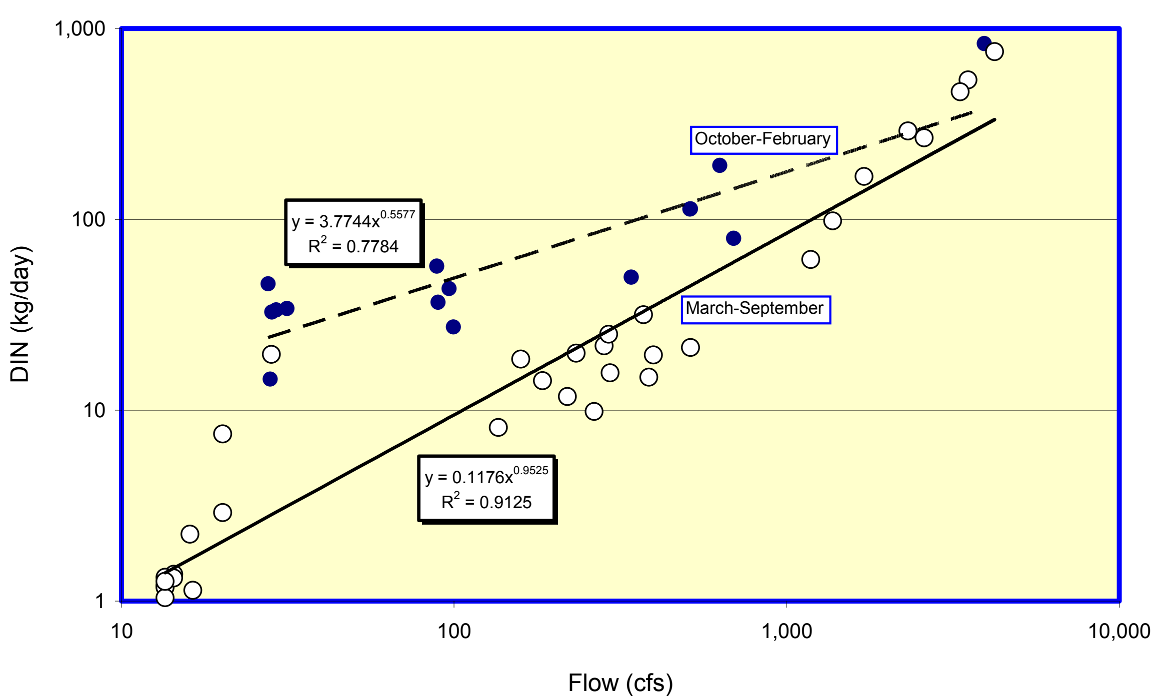
APPENDIX

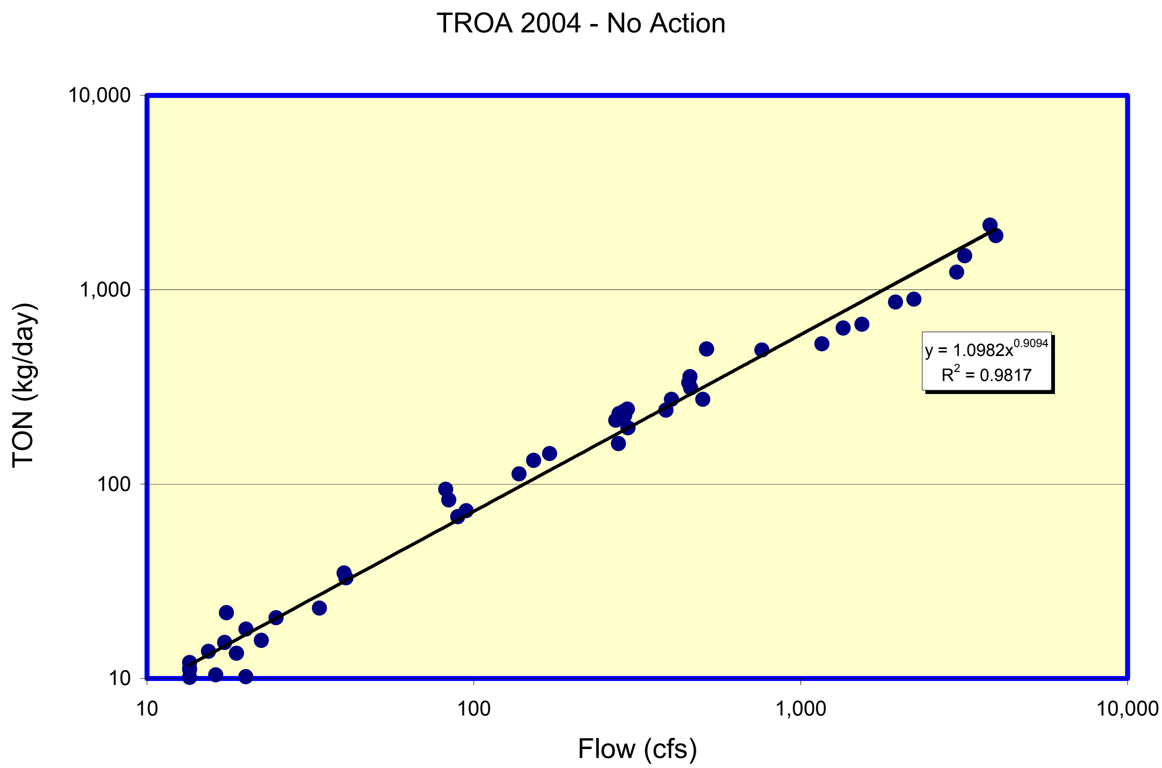
MODEL INPUTS AND RATING CURVES

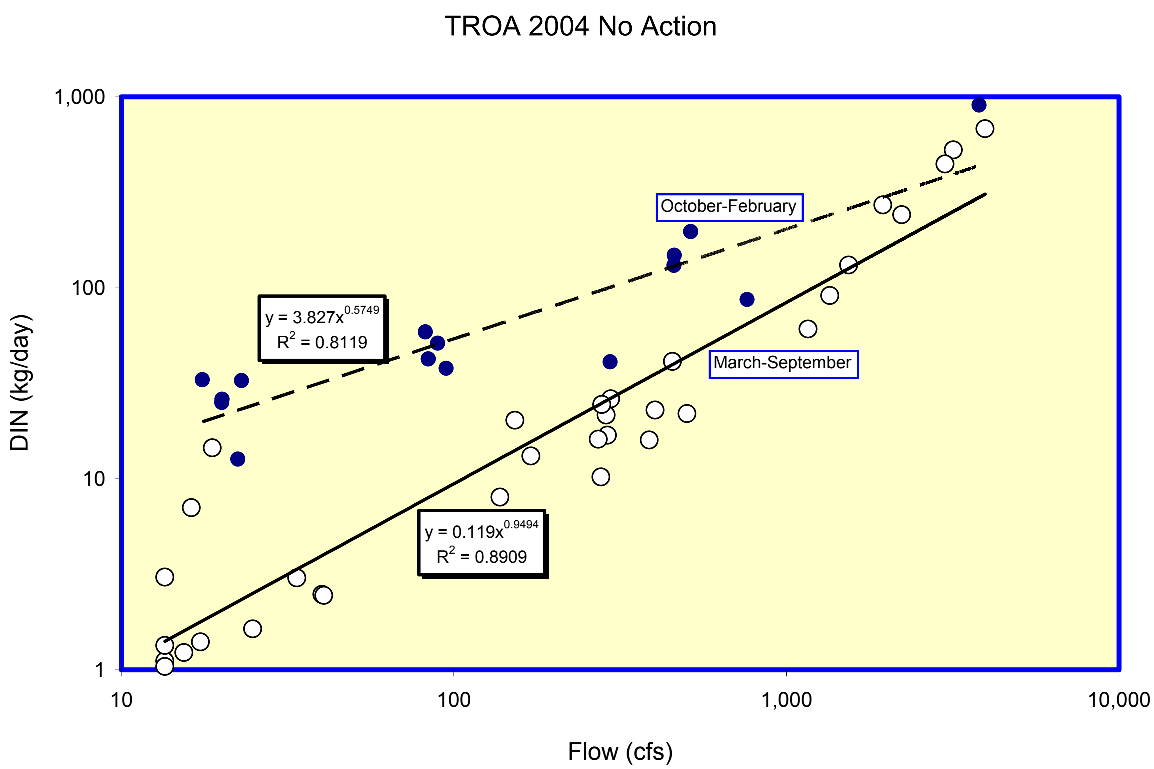
TROA 2004 - Current Conditions

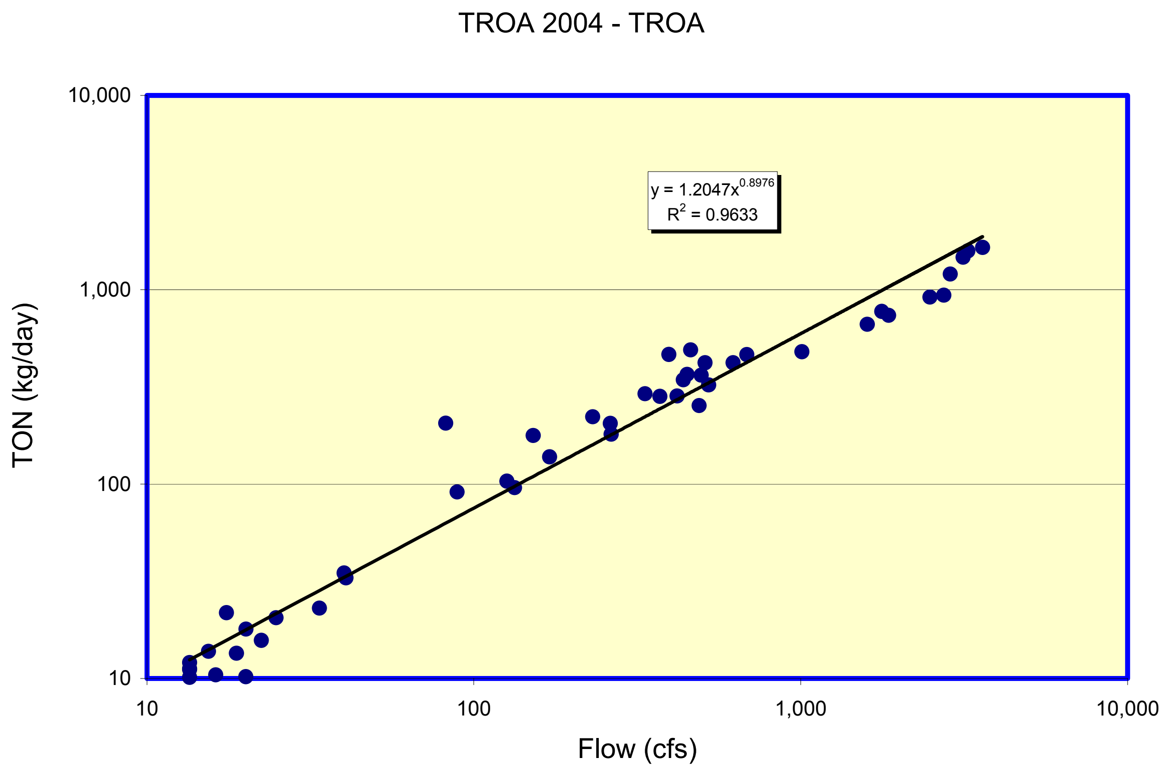


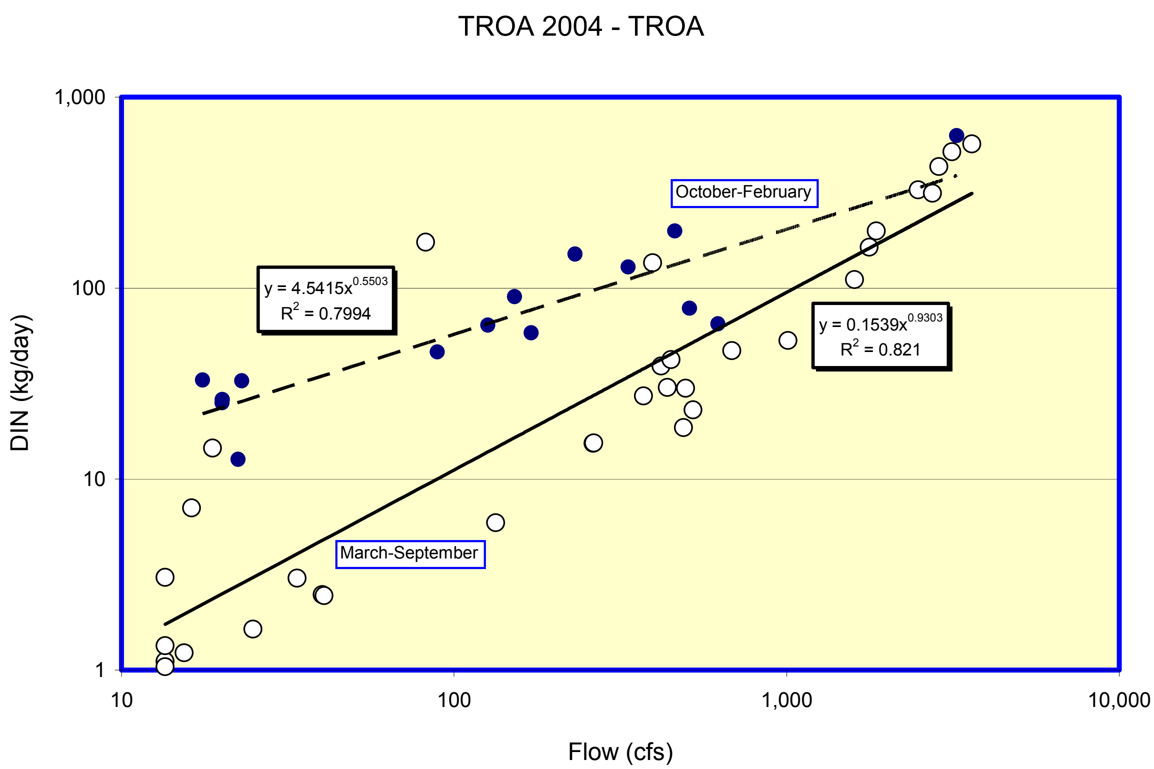
TROA 2004 Current Conditions

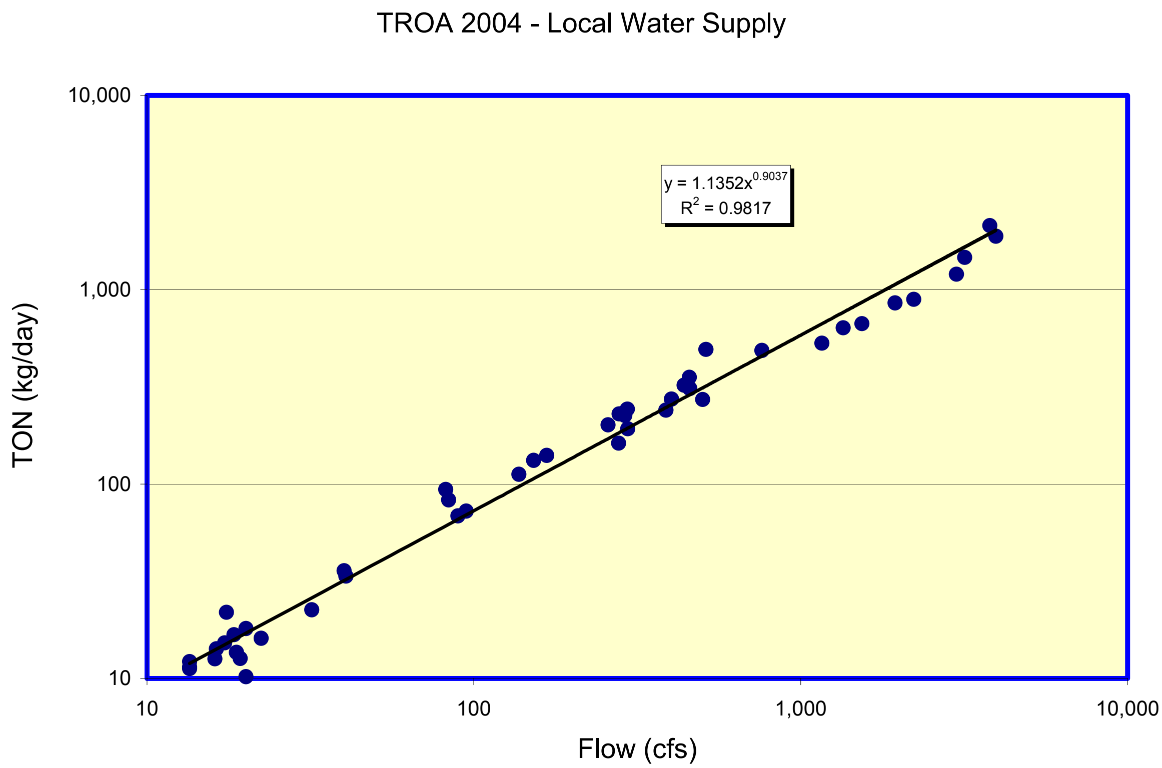


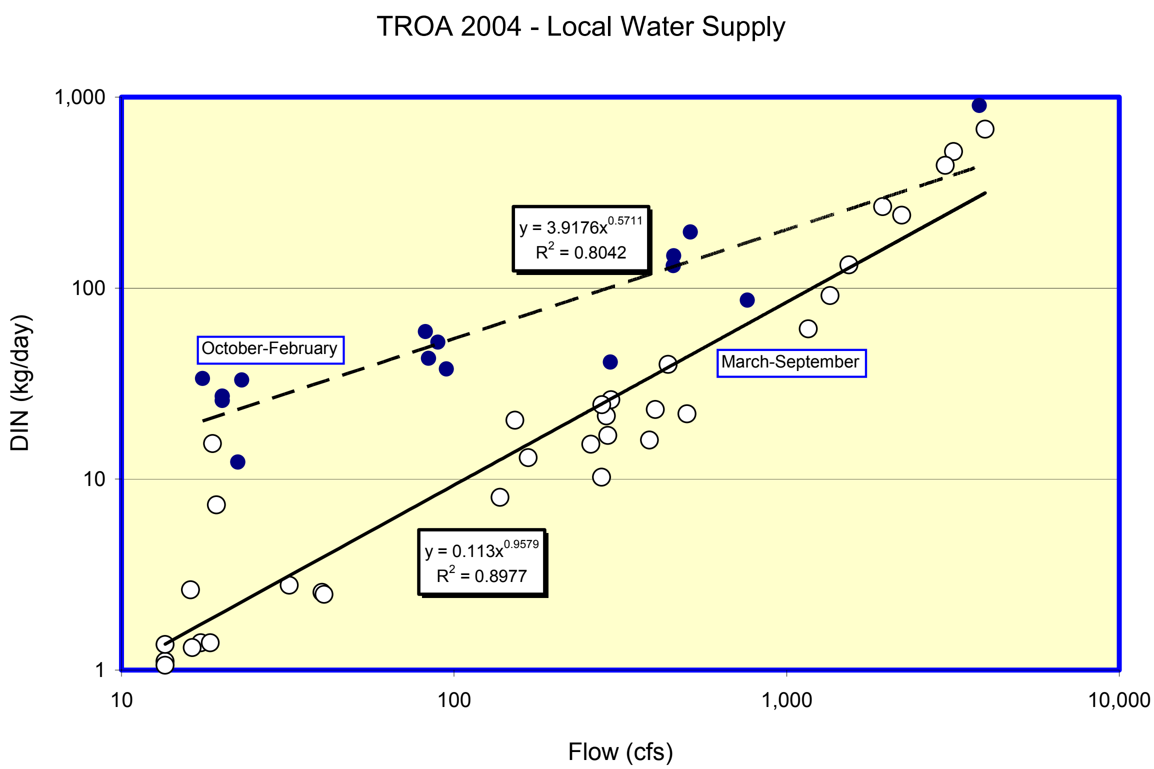

TROA 2004 - No Action
10,000
1,000
100
10
TON (kg/day)
10
100
1,000
10,000
Flow (cfs)
y = 1.0982x^0.9094
R^2 = 0.9817


TROA 2004 No Action
1,000
100
10
1
DIN (kg/day)
10
100
1,000
10,000
Flow (cfs)
October-February
March-September
y = 3.827x^0.5749
R^2 = 0.8119
y = 0.119x^0.9494
R^2 = 0.8909


TROA 2004 - TROA
y = 1.2047x^0.8976
R^2 = 0.9633
10,000
1,000
100
10
TON (kg/day)
10
100
1,000
10,000
Flow (cfs)


TROA 2004 - TROA
October-February
y = 4.5415x^0.5503
R^2 = 0.7994
y = 0.1539x^0.9303
R^2 = 0.821
March-September
1,000
100
10
1
DIN (kg/day)
10
100
1,000
10,000
Flow (cfs)


TROA 2004 - Local Water Supply
y = 1.1352x^0.9037
R^2 = 0.9817
TON (kg/day)
10,000
1,000
100
10
10
100
1,000
10,000
Flow (cfs)


TROA 2004 - Local Water Supply
y = 3.9176x^0.5711
R^2 = 0.8042
October-February
March-September
y = 0.113x^0.9579
R^2 = 0.8977
DIN (kg/day)
1,000
100
10
1
10
100
1,000
10,000
Flow (cfs)

Pyramid Lake Simulation Models: TDS and Eutrophication

Date	3/6/04	Time	11:55 PM

Model Control Parameters	Value	Units
Begin Year	1901	N/A
End Year	1999	N/A
Save Data Interval	1	Years

Time Series Input	Input Controls
☑ Precipitation	☐ Complex TDS
☑ River Inflow	☑ Eutrophication
☑ N2 Fixation	☑ Monthly River

Initial Lake Conditions	Value	Units
Lake Level	3806.55	feet
Lake Volume	2.770	10^10 m3
Lake Area	459.18	km^2
DIN Concentration	0.090	mg/L
DON Concentration	0.700	mg/L
TDS Concentration	5297	mg/L
Lake pH	9.2	NBS Scale
Lake Alkalinity	1372.2	mg HCO3/L
Lake Calcium	9.3	mg/L

Transfer Coefficients	Value	Units
Stream Sediment Load	1443	mg/L
Sediment DIN Release	0.77	gN/m2/d
Stream Flow Yield	478.8	Acre-ft/in
Algal Loss to Sediment	10.0%	Percent
Particle Settling	2.0	m/day
Anoxic Denitrification	50	See Notes
Sediment Denitrification	10	See Notes
Algal Loss to DON	1.0%	Percent
Organic N Hydrolysis	1.0%	1 / yr
N2 Fixation to DON	4.0%	1 / yr
Evaporation	4.228	ft / yr
Critical CaCO3 IAP	5.76	10 E-8
Lower CaCO3 IAP	2.75	10 E-8

Main Inputs to Lake	Inflow	Units	DIN mg/L	DON mg/L	PN mg-N/g	TDS mg/L
Truckee River Inflow	382790	Acre-ft/yr	0.100	0.222	5.5	
Precipitation	7.56	in/yr	0.194	0.037		0.0
Groundwater Inflow	23267	Acre-ft/yr	0.320	0.038		0.0
Ephemeral Streams	3620	Acre-ft/yr	0.640	0.222	1.8	217.0

Other Sources	Inflow	Units	DIN Mg-N/yr	DON Mg-N/yr	PN Mg-N/yr	TDS mg/L
Dry Deposition		N/A			9.3	
N2 Fixation		N/A	300			
Misc. External Sources	0	Acre-ft/yr	4.3	4.3	4.5	0
Undefined - User 1	0	Acre-ft/yr	0	0	0	0
Undefined - User 2	0	Acre-ft/yr	0	0	0	0
Undefined - User 3	0	Acre-ft/yr	0	0	0	0

Truckee River TDS Characteristics		
TDS - maximum	600	mg/L
TDS - high flows	87	mg/L
High flow definition	1863	cfs
TDS coefficient	2132.5	See Notes
TDS exponent	-0.4256	See Notes
River TDS as silicate	6.7%	(%)
River TDS as calcium	10.4%	(%)
River TDS as Alkalinity	61.4%	(%)

Truckee River Monthly Flows			
Jan	Feb	Mar	Apr
8.5%	10.6%	12.2%	12.3%
May	Jun	Jul	Aug
17.8%	11.8%	4.9%	2.4%
Sep	Oct	Nov	Dec
2.7%	2.6%	6.0%	8.2%

Select Output	Model Description	Run Model
Select Graphs	View Run Log	
Define Ranges	View Results	
Enter Data Series	View Graphs	Restore Defaults

Simulation Status	
Year	1999
Errors	☐ Yes
View Log	☐ Yes
Graphs	☑ Yes
Run Name	CC 2004
Run Date	3/2/04
Run Time	11:08 PM