EXECUTIVE SUMMARY

Peck's Lake, an oxbow of the Verde River near Clarkdale, Arizona, was placed on the Water Quality Limited List (303d List) in 1998 for violations of the state's dissolved oxygen and pH standards. Verification monitoring was conducted in 1999 and a TMDL analysis was undertaken in the spring of 2000.

The TMDL analysis focused on nutrient loading to Peck's Lake, considering both ambient conditions and projected development. The analysis combined a watershed loading model (Generalized Watershed Loading Function) with a lake receiving water model (BATHTUB) for linkage of nutrient loading to algal and macrophyte productivity. This approach was justified based upon the large biomass of aquatic macrophytes in the lake. Algal and plant productivity were consequently tied to biological oxygen demand, availability of dissolved oxygen and pH.

The results of the TMDL analysis indicated that under current conditions, the largest nutrient load to Peck's Lake is from internal cycling. The second largest nutrient load comes from native vegetation in the immediate watershed. Based upon evaluation of upstream USGS gage data, the nutrient load from the Verde River has not changed significantly within the past several decades and will be considered natural background. Current lake water quality conditions may have been influenced by the presence of a 9-hole golf course adjacent to the lake from the 1920s to 1992 and a dairy just below the lake outlet.

Phelps Dodge Corp. (PD) owns the land around Peck's Lake and has plans to develop approximately 550 acres. The Verde Valley Ranch development will include a new 18-hole golf course, residential housing, and some commercial infrastructure. Future nutrient load projections were calculated based upon the Storm Water Pollution Prevention Plan (SWPPP) provided by PD and their contractor, URS Griner-Woodward Clyde. Modeling results demonstrated the need for implementing and maintaining all proposed best management practices to contain the 2-yr, 24 hr event.

The Margin of Safety for this TMDL consists of several conservative assumptions incorporated into the models:

1. Extreme hydrologic events were included in the watershed loading analyses and indicate the range of watershed nutrient loadings expected

2. Long-term average loading results were used, since lakes respond to nutrient loading slowly

3. BATHTUB predictions do not include the effects of macrophyte shading effects on phytoplankton, therefore eutrophication predictions are conservative

4. If macrophyte growth in the lake was reduced, calculations for nutrients would be conservative, since the actual internal nutrient fluxes from macrophyte decomposition would be reduced

5. The macrophyte densities and turnover rates used in the nutrient budget and dissolved oxygen calculations assumed the higher values from the literature rather than some of the lower estimates provided from the BATHTUB calibrations; and

6. The GWLF loading predictions did not include reductions that would be achieved by the sand filter BMPs because there is no way to directly include them in the model. However, these reductions are included in the SWPPP.

Taking into consideration the Margin of Safety based upon conservative assumptions, TMDL allocations will reflect no net gain in external nutrient loading to Peck's Lake. Internal nutrient loading of both total phosphorus and total nitrogen will be reduced 25% through harvesting of aquatic macrophytes and other methods. Flow through the lake will be maintained under the existing passive system. If passive flow does not prove sufficient over the first 5-yr phase of this TMDL, addition of aeration devices may be necessary. A detailed lake monitoring plan has been added to the SWPPP and will be supplemented with monitoring by ADEQ and the AZ Game & Fish Dept. The nutrient reduction is reflected in the TMDL equation below; the TMDL load expected to meet DO and pH standards is as follows:

LA1 (natural background) + LA2 (development) + LA3 (in-lake) + MOS = TMDL for N
LA1 (8.32 lbs/day + 2.32 lbs/day) + LA2 (4.56 lbs/day) + LA3 (59.20 lbs/day[1,2]) + MOS = **74.40 lbs/day Total N**

LA1 (natural background) + LA2 (development) + LA3 (in-lake) + MOS = TMDL for P
LA1 (0.84 lbs/day + 0.07 lbs/day) + LA2 (0.53 lbs/day) + LA3 (9.78 lbs/day[1,2]) + MOS = **11.15 lbs/day Total P**

[1] lake inflow + atmospheric deposition
[2] in-lake load represents a 25% reduction from current conditions

TMDL implementation will include various strategies to minimize input from runoff and reduce internal nutrient cycling in Peck's Lake. Measures include macrophyte harvesting, flushing, and interception and treatment of storm runoff from residential and commercial areas. Runoff from the golf course will be totally contained on-site, with the exception of the lower part around the oxbow, which will have lysimeters installed to monitor shallow groundwater. A comprehensive and detailed monitoring plan has been incorporated in the Storm Water Pollution Prevention Plan for the Verde Valley Ranch development. In addition to monitoring under this permit, ADEQ and AGFD will also participate in ongoing lake monitoring.

Synoptic Report, Peck's Lake TMDL

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Arizona Game & Fish Department
U.S. Environmental Protection Agency
U.S. Fish & Wildlife Service
Arizona Department of Environmental Quality

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APPENDIX 5: Response to Public Comments

1.0 TMDL PROCESS

The Clean Water Act (CWA) establishes a national goal of fishable, swimmable waters. In cases where waters do not meet this goal, Section 303(d) of CWA requires States to develop Total Maximum Daily Loads (TMDLs), with oversight from the Environmental Protection Agency (EPA). A TMDL allocates pollution control responsibilities among pollution sources in a watershed, and is the basis for taking the actions needed to restore a water body.

High quality water is an extremely valuable commodity in Arizona. Water quality standards are established to protect the designated uses of Arizona's waters. When States and local communities identify problems in meeting water quality standards a total maximum daily load (TMDL) can be part of a plan to address water quality problems. The purpose of this TMDL study is to provide the local community, land and resource managers, ADEQ, and U.S. EPA Region 9 with technical information that can be used to develop a water quality plan.

A TMDL represents the total load of a pollutant that can be discharged to a water body on a daily basis and still meet the applicable water quality standard [assumed to be the existing standard(s)]. The TMDL can be expressed as the total mass or quantity that can enter the water body within a unit of time. In most cases, the TMDL determines the allowable pounds per day of a constituent and divides it among the various contributors in the watershed as waste load (i.e., point source discharge) and load (i.e., nonpoint source) allocations. The TMDL must also account for natural background sources and provide a margin of safety. For nonpoint sources such as accelerated erosion or internal nutrient cycling, it may not be feasible or useful to derive a pounds per day figure. In such cases, a percent reduction in pollutant loading may be proposed.

A load analysis may take the form of a phased TMDL, if source reduction or remediation can be better accomplished through an iterative approach. The key will be to identify the management strategy necessary to minimize the water quality concerns in Peck's Lake, while acknowledging ecosystem limitations and maximizing support of the lake's designated uses. The Peck's TMDL will be phased to effectively build monitoring and management plans for the lake and watershed that address seasonal constraints to the ecosystem.
In Arizona, as in other states, changes in standards or the establishment of site-specific standards are the result of ongoing science-based investigations or changes in toxicity criteria from EPA. Changes in designated uses and standards are part of the surface water standards triennial review process and are subject to public review. Standards are not changed simply to bring the water body into compliance, but are based on existing uses and natural conditions.

This TMDL has met or exceeded the following EPA Region IX criteria for approval:

- Plan to meet State Water Quality Standards: TMDL includes a study and a plan for the specific pollutants that must be addressed to ensure that applicable water quality standards are attained.

- Describe quantified water quality goals, targets, or endpoints: The TMDL must establish numeric endpoints for the water quality standards, including beneficial uses to be protected, as a result of implementing the TMDL. This often requires an interpretation that clearly describes the linkage(s) between factors impacting water quality standards.

- Analyze/account for all sources of pollutants. All significant pollutant sources are described, including the magnitude and location of sources.

- Identify pollution reduction goals. The TMDL plan includes pollutant reduction targets for all point and nonpoint sources of pollution.

- Describe the linkage between water quality endpoints and pollutants of concern. The TMDL must explain the relationship between the numeric targets and the pollutants of concern. That is, do the recommended pollutant load allocations exceed the loading capacity of the receiving water?

- Develop margin of safety that considers uncertainties, seasonal variations, and critical conditions. The TMDL must describe how any uncertainties regarding the ability of the plan to meet water quality standards that have been addressed. The plan must consider these issues in its recommended pollution reduction targets.

- Provide implementation recommendations for pollutant reduction actions and a monitoring plan. The TMDL should provide a specific process and schedule for achieving pollutant reduction targets. A monitoring plan should also be included, especially where management actions will be phased in over time and to assess the validity of the pollutant reduction goals.

- Include an appropriate level of public involvement in the TMDL process. This is usually met by publishing public notice of the TMDL, circulating the TMDL for public comment, and holding public meetings in local communities. Public involvement must be documented in the state's TMDL submittal to EPA Region 9.

2.0 DETERMINATION of USE IMPAIRMENT

2.1. Listing of Peck's Lake

Pecks' Lake is an oxbow of the Verde River, located in the central Verde Valley near Clarkdale, Arizona. (Figure 2-1) Peck's Lake was included on Arizona's 1998 Water Quality Limited Waters List (303(d) List for two stressors: numeric pH and numeric dissolved oxygen. Though not listed for violation of narrative nutrient standards, the verification sampling has identified the presence of excess aquatic weed growth, presumed to be at least part of the reason for numeric standards violations. The lake was listed in 1998 based on data collected by the ADEQ Clean Lakes Program in 1996 and 1997. The growth of excess aquatic weeds, in association with low DO and high pH, is interpreted as impairment of the aquatic and wildlife designated use and possibly recreational uses. Peck's Lake is designated for the following uses under Title 18, Chapter 11 of the Arizona Administrative Code:

A&Wc: Aquatic and wildlife uses, *cold-water fishery;
FBC: Full body contact;
FC: Fish consumption;
AgI: Agricultural irrigation; and
AgL: Agricultural livestock watering

* The designation of Peck's Lake as a cold-water fishery has been determined to be erroneous. The 2001 TriennialReview proposed Rule includes a change from cold-water to warm-water fishery for Peck's Lake. The corresponding water quality standard for dissolved oxygen will be 6.0 mg/L rather than 7.0 mg/L.

Figure 2-1. Site Location Map

At the time of this TMDL, the standards that pertain to Peck's Lake include: pH in a range of 6.5 SU to 9.0 SU (all year, all portions of the water column), dissolved oxygen no lower than 7.0 mg/L or 90% saturation within the top 1 meter of the water column, and a narrative standard which reads in relevant part (A.A.C. 18-11-108 (A)(6):

> ...Surface waters shall be free from pollutants in amounts or combinations that cause the growth of algae or aquatic plants that inhibit or prohibit the habitation, growth, or propagation of other aquatic life or that impair recreational uses...

2.2 Public Participation

The public participation requirement of this TMDL has been met through notice and participation by stakeholders in several Focus Group sessions. Focus Group sessions were attended by local community members and other stakeholders, including Clarkdale, Cottonwood and Jerome, Yavapai County, the Phelps Dodge Corporation, a local chapter of the National Audubon Society, Arizona State Parks, and the Verde Watershed Association. Meetings were held in Clarkdale every three weeks over a six-month period. ADEQ staff were present at all meetings; the ADEQ contractor, Tetra Tech, Inc., was present at two meetings to explain the modeling approach and respond to questions. The Draft TMDL was released in June 2000. The Draft Final TMDL was first released in December 2000. The revised Draft Final TMDL will be public noticed in June 2001, and will follow the requirements of Arizona's new TMDL statute, A.R.S. Title 49, Chapter 2, Article 2.1.

2.3 Summary of Peck's Lake Data

The data that placed Peck's Lake on the 1998 303(d) is listed in Table 2-1 in bold; site sampling locations are depicted on Figure (2-2). There were 7 of 10 violations of the dissolved oxygen standard (within the top meter) and 7 of 16 violations of the pH standard (greater than 9.0 SU); this information is contained in the 1998 305(b) Assessment Report, page 117. For the 305(b) Assessment Report, a standards exceedances in excess of 10% or 25% of the number of samples taken, may qualify for 303(d) listing depending on the parameter(s) of concern, the frequency of monitoring, and whether corroborating data exists. In the case of Peck's Lake, low DO, high pH, and an abundance of aquatic macrophytes and algae is a classic aging pattern of highly productive shallow lakes.

Subsequent data collected by ADEQ Lake Program staff in 1999 corroborate the 1997 summer data for dissolved oxygen but not for pH. Data from 1999 did not capture pH values in excess of the standard, though it is likely the peak growing period was June and July. Die-off and decay appeared to be well under way by August. Although 1999 pH violations were down to 10% from 43%, pH will be considered in the TMDL analysis, as will the role and implications of the narrative nutrient standard for Peck's Lake. Table 2-2 shows the results from 1999 sampling.

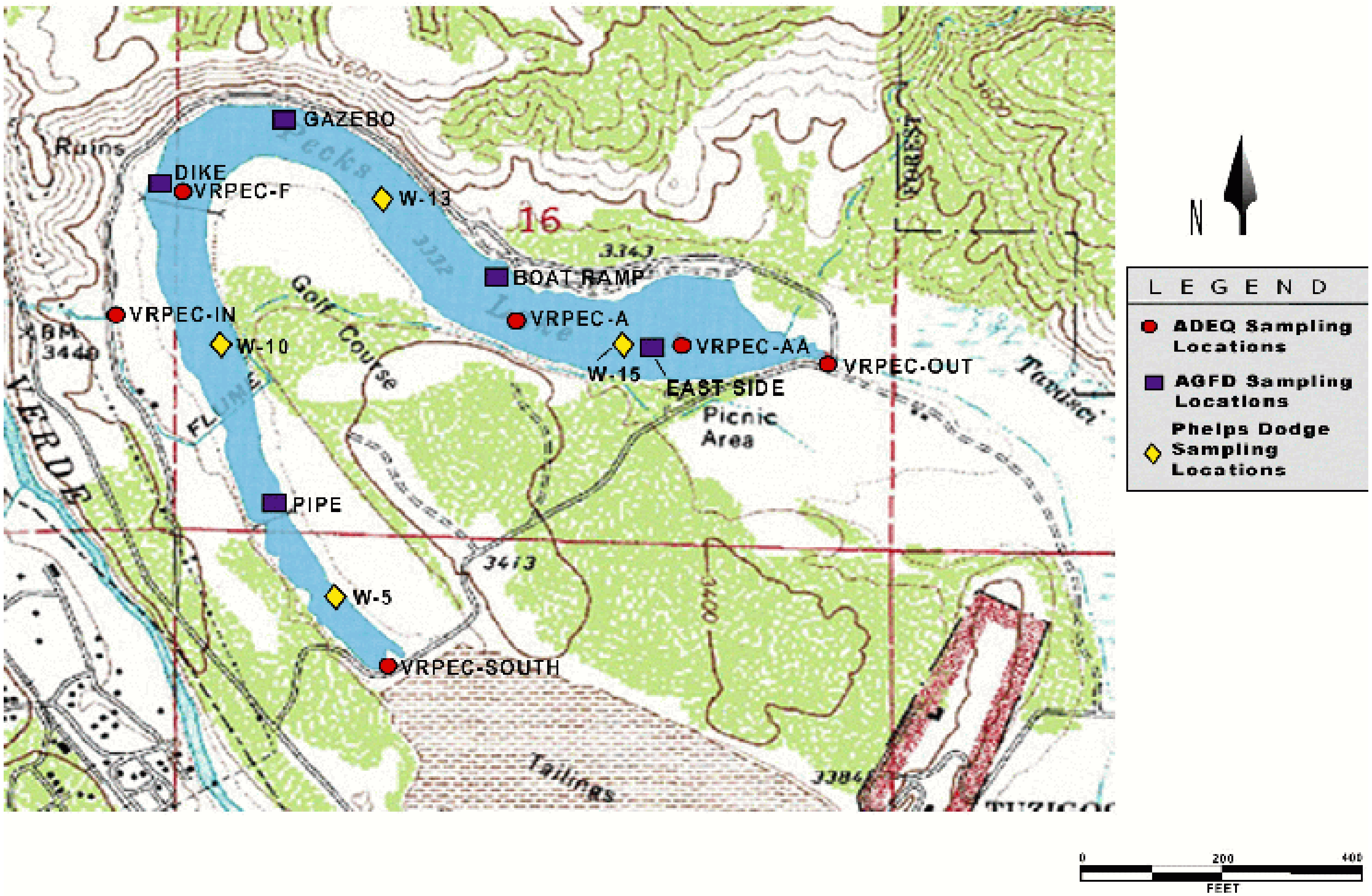


Figure 2-2. Water quality sample locations in Peck's Lake

Table 2-1. ADEQ data on Peck's Lake from 1996/1997

Lake Site	Date	Time	Depth (m)	Temp	pH	DO% sat	DO mg/L	Chlor-a	Secchi Depth	Comments
A	10/7/96	9:11	0.1	19.33	**9.26**	**71.8**	**5.93**			
A	10/7/96	9:13	0.9	19.34	**9.27**	**71.9**	**5.94**	<2	> 1.25	Weeds obscured SD at .5 m TKN=0.67; Total P=ND(.005)
A	10/7/96	9:14	1.9	19.53	7.22	12.4	1.02			at 2 m TKN=0.81; Total P=0.013
A	10/7/96	9:15	2.2	19.50	7.19	5.8	0.47			
A	1/22/97	8:52	0.1	5.24	8.52	97.2	11.01	2.65		at .5 m: TKN=0.76; Total P=0.014
A	1/22/97	8:53	1.0	5.36	8.52	96.7	10.93			
A	1/22/97	8:54	2.0	5.53	8.20	44.5	5.01		>2	at 2 m: TKN=0.81; Total P=0.024
A	4/23/97	8:07	.1	18.70	8.66	93.4	7.69			
A	4/23/97	8:08	1.0	18.73	8.64	**83.1**	**6.83**	<2		at 1 m: TKN=0.22 Total P=.027
A	4/23/97	8:10	1.8	18.51	8.53	77.1	6.37		>1.8	
A	7/23/97	8:26	.1	24.50	**9.60**	**53.9**	**4.01**			
A	7/23/97	8:27	.4	24.02	**9.63**	**64.1**	**4.81**			at .5m: TKN=1.03 Total P=0.022
A	7/23/97	8:28	.6	23.93	**9.67**	**72.7**	**5.46**			
A	7/23/97	8:28	.8	23.90	**9.66**	**72.9**	**5.49**	3.11		
A	7/23/97	8:29	1.1	23.88	**9.66**	67.8	5.10		1.5	SD "to bottom"
A	7/23/97	8:38	1.8	20.16	6.72	13.60	1.10			

Table 2-2. ADEQ data on Peck's Lake from 1999 (site codes on map)

Lake Site	Date	Time	Depth (m)	Temp	pH	DO% sat	DO mg/L	Chlor-a	Secchi Depth	Comments
F	2/24/99	10:15a	0.1	9.97	8.23	89.7	9.03			
			0.3	9.96	8.21	88.4	8.93			
			0.5	9.95	8.22	89.2	8.85			
			0.7	9.93	8.23	88.7	8.91			
			1.0	9.91	8.23	89.1	9.01	2.65	1.0	at 1m:TKN=0.88; Total P=0.037
			1.3	9.88	8.23	89.2	9.03			
			1.5	9.90	8.24	90.6	9.24			
A	2/24/99	11:25a	0.1	10.81	8.35	89.8	9.04			
			0.3	10.56	8.34	88.5	8.80			
			0.5	10.32	8.33	88.7	8.86	<2		at .5m:TKN=0.96; Total P=0.016
			1.0	10.19	8.33	88.9	8.89			
			1.3	10.11	8.33	89.0	8.93			
			1.6	10.10	8.33	88.7	8.90			
			2.0	10.12	8.33	88.3	8.87		2.0	
AA	2/24/99	12:40p	0.1	11.90	8.23	84.3	8.01			
			0.3	11.12	8.21	79.8	7.70			
			0.5	10.23	8.21	78.8	7.90	no chlor	.5	Turbid; TKN=0.80; Total P=0.054

Table 2-2. ADEQ data on Peck's Lake from 1999 (continued)

Lake Site	Date	Time	Depth (m)	Temp	pH	DO% sat	DO mg/L	Chlor-a	Secchi	Comments
AA	2/24/99	12:40	0.8	9.68	8.19	77.9	7.88			
			1.0	9.67	8.18	75.7	7.70			
			1.3	9.50	8.12	69.2	7.10			
F	5/13/99	10:15a	0.1	20.05	8.51	104.0	8.26			
			0.5	20.07	8.47	105.6	8.50	2.19		TKN=1.03; Ammonia=0.20; Total P=0.030
			1.0	19.92	8.47	102.4	8.34		1+	
			1.5	19.26	8.25	62.0	5.27			TKN=1.11; ammonia=0.19; Total P=0.014
A	5/13/99	11:00a	0.1	20.58	8.78	115.2	9.20			
			0.5	20.57	8.77	117.8	9.34	<2		TKN=0.99 Total P=0.011
			1.0	20.57	8.77	116.1	9.29			
			1.5	20.56	8.77	119.2	9.32			
			2.0	20.53	8.77	116.2	9.3		2+	TKN=1.09; Total P=0.028
			2.2	20.44	8.57	79.2	7.25			
A	5/17/99	5:15p	0.1	22.57	8.85	121.3	9.33			sediment/algae only
			0.5	22.56	8.85	122.6	9.42			
			1.0	21.69	8.88	148.5	11.73			
A	5/17/99	5:15p	1.5	21.08	8.90	143.8	11.34			
			2.0	20.93	8.88	102.1	8.53			

Table 2-2. ADEQ data on Peck's Lake from 1999 (continued)

Lake Site	Date	Time	Depth (m)	Temp	pH	DO% sat	DO mg/L	Chlor-a	Secchi	Comments
F	5/17/99	6:00p	0.1	24.13	8.63	127.4	9.51			sediment/algae only
			0.5	22.37	8.70	167.0	12.02			
			1.0	20.13	8.68	133.9	10.97			
			1.5	19.17	8.43	82.0	7.03			
A	8/19/99	8:25a	0.1	24.24	8.62	**62.7**	**4.68**			
			0.5	24.30	8.61	**61.4**	**4.60**	3.44		Pheophytin=5.56
			1.0	24.29	8.59	**58.2**	**4.38**			
			1.5	23.65	7.52	1.40	0.13			
			2.0	22.46	7.31	0.90	0.07		2	TKN=0.67; Total P=0.037
foul odor in sediment			2.4	21.91	7.16	1.00	0.07			
A	10/20/99	11:15a	0.1	15.84	7.88	**60.7**	**5.64**			
			0.5	15.34	7.80	**56.9**	**5.10**			
			1.0	15.12	7.78	**54.8**	**4.94**			
			1.5	15.06	7.77	56.9	5.20	<3		TKN=1.04; Total P=0.013
			2.0	15.01	7.77	60.8	5.52			
			2.3	14.99	7.75	60.1	5.46		2.5	

3.0 MODELING & ANALYSIS

3.1 Conceptual Approach, Model Selection

The TMDL analysis examined lake dynamics, modeling both external and internal nutrient loading, biomass production, death and decay, effects on lake water quality and biota, and possible management options. The initial step in developing a modeling approach for Peck's Lake was to compile and review existing data. Available data on land use, hydrology, geology, soils, climate, vegetation, and ecosystem biology in the Verde Basin revealed adequate information to utilize the mid-level watershed loading model, the Generalized Watershed Loading Function (GWLF, Haith, et. al, 1992). Tetra Tech also modeled the upper and middle Verde River for nutrient input and assimilation under separate contract using the Soil & Water Assessment Tool (SWAT). The results from GWLF were calibrated against the results from SWAT for the Upper Verde above the diversion to Peck's Lake.

For the lake, because data were insufficient to develop a dynamic model, the two-dimensional steady state model, BATHTUB (Walker, 1996), was chosen to predict lake response to nutrient loading. BATHTUB has often been applied to predict eutrophication responses in relatively small shallow lake systems. BATHTUB was used for the linkage analysis, calculating water quality variables such as nutrient concentrations, chlorophyll-a, turbidity based on the loadings, hydrology, lake geometry, and internal nutrient cycling processes within the lake.

Tetra Tech, Inc. (TT) contributed to data compilation and conducted the modeling and alternatives analysis for this project. Written reports submitted by TT were compiled and have been included in APPENDICES 2.0, 3.0, and 4.0 of this TMDL report. The reader is directed to these sections for more detailed explanation as needed.

3.2 Synopsis of Modeling Results

Modeling was constructed to evaluate the following: nutrient loads from the Verde River and upper watershed, nutrient loads from existing land uses within the local watershed, in-lake nutrient cycling, and nutrient loads from the proposed Verde Valley Ranch development. The Storm Water Pollution Prevention Plan (SWPPP, URS Greiner-Woodward Clyde, 1997) was used to inform the modeling effort with regard to effectiveness of proposed best management practices (BMPs). Model iterations were run to test the effects of changes in river flow/inflow, outflow/flushing, harvesting, and dredging on nutrient cycling, growth of algae and aquatic vegetation, and resulting water quality.

3.2.1 <u>General model findings</u> include the following:

- There was general model agreement between GWLF and SWAT for external loads from the upper Verde River watershed. Review of USGS data from the Clarkdale gage showed that Verde River water quality has not changed significantly over several decades. Thus, nutrient levels in Verde River inflow to Peck's Lake was considered to reflect historic background levels.

- For approximately the last decade, the immediate watershed above Peck's Lake has been relatively un-impacted. However, from the 1920s until 1992 there was a 9-hole golf-course along the inside of the oxbow, in addition to a dairy which was located just below the lake outlet for approximately a 40-year time period. Although the historic golf course was not modeled directly, the results of modeling the proposed Verde Valley Ranch golf course indicate the potential for significant nutrient loading in the past, and underscores the need to implement BMPs.

- The highest ambient external loading was found to be contributed by desert scrub vegetation. *With all* residential and golf course BMPs in place and fully functional, the projected future loading will not exceed ambient levels. Table 3-4 shows the potential increase in loading if BMPs are not functional. Under current conditions, growth and breakdown of aquatic vegetation contributes approximately 5 times greater nitrogen loading as external inputs; for phosphorus, the internal loading is 7 times greater than the external loading.

- Tables 3-1 through 3-3 summarize calculated nutrient loads and TMDL load calculations. Conservative assumptions, detailed in Section 3.2.3 of Tetra Tech's report, were made throughout the process to ensure a maximum margin of safety for the TMDL. This is particularly true for phosphorus, future projected loads are higher than those presented in the 1997 SWPPP, because the model assumed worse-case loading without retention or sand filters in place. Future projections will be used as a guideline, but because the lake is already impaired with respect to DO and pH, therefore implying the need for careful nutrient management from the start, the TMDL will use the current conditions to benchmark for nutrient allocation.

Table 3-1. Calculated nutrient loads for current conditions

	Total Nitrogen (lbs/year)	**Total Nitrogen (lbs/day)**	**Total Phosphorus (lbs/year)**	**Total Phosphorus (lbs/day)**
CURRENT CONDITIONS				
Inputs:				
Atmospheric loading	**848**	**2.32**	**25**	**.07**
Lake inflow (from Verde)	**3,036**	**8.32**	**307**	**.84**
Inflow (local watershed)	**1,664**	**4.56**	**192**	**.53**
Potential macrophyte release	**28,811**	**78.93**	**4,762**	**13.05**
Total Inputs:	**34,359**	**94.13**	**5,286**	**14.48**
Outputs:				
Lake outflow (w/seepage)	**- 9,781**	**- 26.80**	**- 226**	**-.62**
Net Load*:	**24,586**	**67.34**	**5,060**	**13.86**

*** Net load is retained in the lake sediments & plant biomass**

Table 3-2. Model Runs for Future Development Projections

FUTURE CONDITIONS	Total Nitrogen (lbs/year)		Total Phosphorus (lbs/year)	
Inputs:	**No BMPs**	**w/BMPs**	**No BMPs**	**w/BMPs**
Atmospheric loading	848	NA	25	NA
Lake inflow (Verde River)	3,036	NA	307	NA
Inflow (local watershed) Golf course Residential, Commercial & Natural land uses Increase over current =	 2,530 (Up 52%) 1,915 (Up 15%) 4,445 2,781 (Up 67%)	 0 0 0	 4,580 (up 2285%) 213 (Up 11%) 4,793 4,601 (up 2,296%)	 0 0 0
Potential macrophyte release	28,811	NA	4,762	NA
Total Inputs:	37,140	(same as current)	9,887	(same as current)
Lake outflow (w/seepage)	- 11,636	(same as current)	- 4,580*	(same as current)
Net Load:	25,504	24,586	5,307	5,060

*** seepage component for phosphorus reflects assumption that phosphorus as phosphate may infiltrate**

Table 3-3. TMDL Load Calculations in lbs/day

	*TMDL ALLOCATION**	Total Nitrogen (*lbs/day*)	Total Phosphorus (*lbs/day*)
LA3	Harvest macrophytes to reduce internal N & P loads by 25% (from macrophyte release) Increased aeration from harvesting & aerators	[(28,811 x .25) / 365 days] = reduction of 19.73 ALLOCATION = 59.2 Whole lake DO and pH meet water quality standards	[(4,762 x .25) / 365 days] = reduction of 3.26 ALLOCATION = 9.78 Whole lake DO and pH meet water quality standards
LA2	Containment & BMPs on golf course for N & P BMPs for residential/ commercial loads for N & P	[1,664 / 365 days] [1,664 / 365 days] conversion from desert scrub ALLOCATION = 4.56	[192 / 365 days] [192 / 365 days] conversion from desert scrub ALLOCATION = 0.53
LA1	No reduction in Verde River loads for N & P (natural background) No reduction in air deposition loads for N & P (natural background)	[3,036 / 365 days] ALLOCATION = 8.32 [848 / 365 days] ALLOCATION = 2.32	[307 / 365 days] ALLOCATION = 0.84 [25 /365 days] ALLOCATION = 0.07
	TOTAL LOAD	74.40 lbs/day Total N	11.22 lbs/day Total P

3.2.2 TMDL Equations:

LA1 (natural background) + LA2 (development) + LA3 (in lake) + MOS = TMDL for N
LA1 (8.32 lbs/day + 2.32 lbs/day) + LA2 (4.56 lbs/day) + LA3 (59.20 lbs/day) + MOS =
74.40 lbs/day Total N*

LA1 (natural background) + LA2 (development) + LA3 (in lake) + MOS = TMDL for P
LA1 (0.84 lbs/day + 0.07 lbs/day) + LA2 (0.53 lbs/day) + LA3 (9.78 lbs/day) + MOS =
11.15 lbs/day Total P*

*** NOTE: the TMDL allocations are based on the simulation of current loads, not on projected loads**

3.2.3 The Margin of Safety for this TMDL consists of several conservative assumptions incorporated into the models:

- Extreme hydrologic events were included in the watershed loading analyses and indicate the range of watershed nutrient loadings to be expected;
- Long-term average loading results were used since lakes respond to nutrient loading slowly;
- BATHTUB predictions do not include the effects of macrophyte shading effects on phytoplankton, therefore eutrophication predictions are conservative;
- If macrophyte growth in the lake was reduced, calculations for nutrients would be conservative, since the actual internal nutrient fluxes from macrophyte decomposition would be reduced;
- The macrophyte densities and turnover rates used in the nutrient budget and dissolved oxygen calculations assumed the higher values from the literature rather than some of the lower estimates provided from the BATHTUB calibrations; and
- The GWLF loading predictions did not include the sand filter BMPs because there is no way to directly include them in the model. GWLF results, without the BMPs, agree with reductions asserted in the SWPPP.

4.0 TMDL IMPLEMENTATION

All permits should recognize that Peck's Lake is an impaired water body for DO and pH. The explanation for these conditions is a combination of the physical, chemical, and biological character of the ecosystem: shallow depth/abundant light, nutrient cycling, build-up of biomass, increased oxygen demand, increase oxygen flux, less buffering capacity due to high plant productivity and its affects on carbon dioxide in the water. Careful management of nutrients and organic material is essential to avoid exacerbating the current condition. The TMDL will require a combination of best management practices, monitoring, and trophic evaluation to protect the ecosystem and attain water quality standards in Peck's Lake.

4.1 Synopsis of Options Considered for Lake Management:

4.1.1 Dredging:

- Based on the net nutrient load, the most obvious remedy for reduction of nutrients might be to dredge the lake. However, this remedy is not recommended, as metals concentrated as the result of past mining activities have accumulated in lake sediments (see Table 4-1). Several metals are elevated above background at levels that may potentially cause impairment to benthic organisms, when compared to Sediment Quality Guidelines from the Province of Ontario (1993); Arizona does not currently have sediment standards. A dredging project would have to be carefully planned to avoid mobilizing metals and causing potential harm to lake and marsh aquatic life and wildlife. Current soil remediation standards for metals in Arizona are well above levels found in Peck's Lake sediments, with the exception of regionally high arsenic.

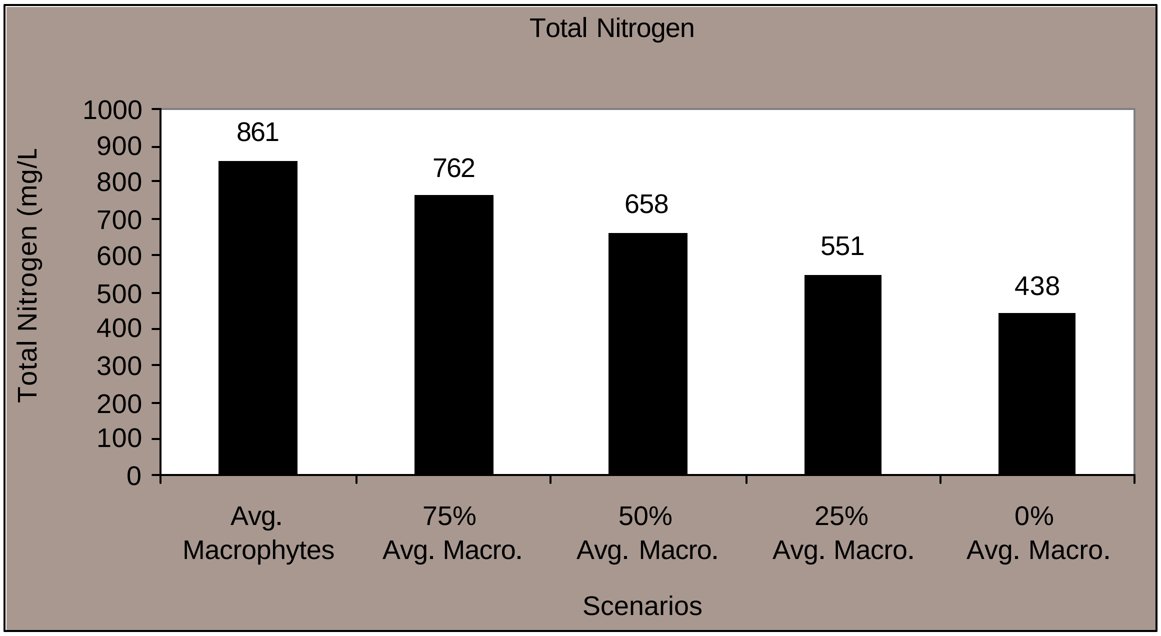
Table 4-1: Metals in Sediment (all values in mg/kg)

	As	Cd	Cr	Cu	Pb	Hg	Zn
USGS mean background (US)	5.2	NA	37	17	16	0.06	48
ADEQ mean background (Phx/Tucson)	9.4	0.4	17.5	16.6	7.7	0.05	38.9
Ecology & Environment, 1994							
~ below tailings (lake edge)	**623**	1.0U	NA	953	**512**	1.3J	625
~ out from ramadas (mid lake)	**65.3**	8.8U	NA	178	126	0.4U	228
~ mid-marsh (out from Shea Spring)	**69.8**	4.0	NA	200	97.7	0.40	251
ADEQ, 1999 ~ ramadas	**22**	3.1	8.9	150	48	0.53	100
AZ SRLs (1997)	10	38	2100	2800	400	6.7	23,000

Notes: "U" at detection limit "J" results estimated
Bold only = above SRL
SRLs = "Soil Remediation Levels" for residential soils

4.1.2 Macrophyte Harvest:

- The nutrient budget calculations show that macrophyte release (internal loads) appears to be a larger source of nitrogen than the Verde River and local watershed (external load). Oxygen budget calculations show that macrophyte release processes exert more oxygen demand than processes in the water column and external COD loads from the watershed. Figures 4-1 and 4-2 depict the significance of macrophyte growth and decomposition to internal nutrient loading and oxygen demand.



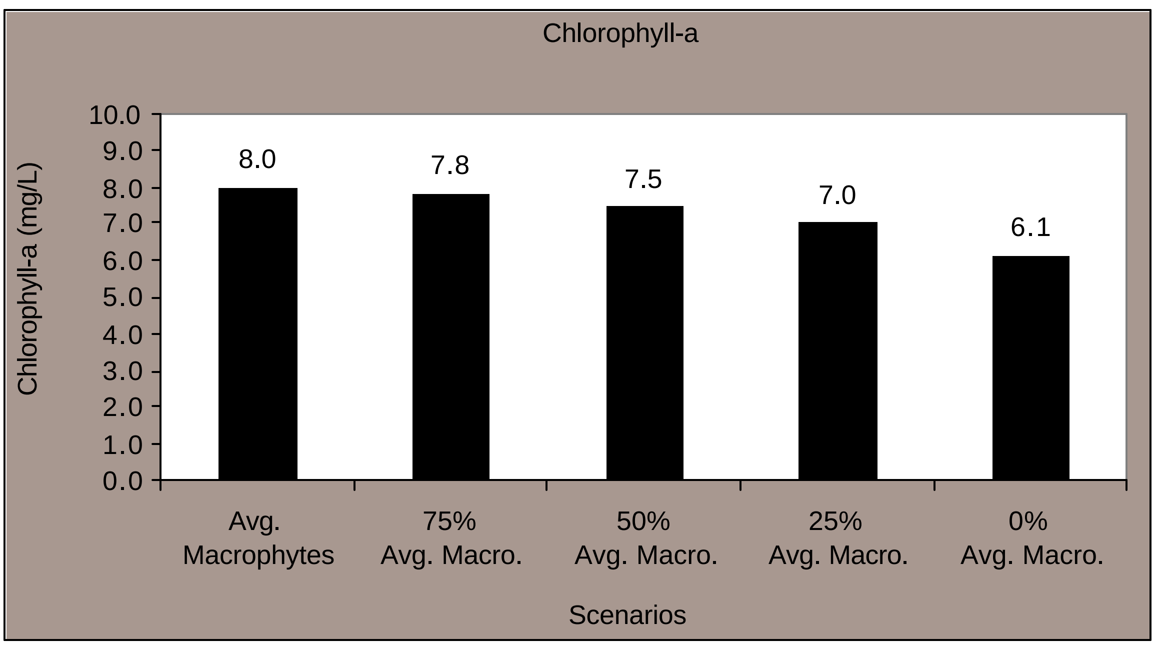


Figure 4-1. Effects of scaled reductions in macrophyte biomass on total nitrogen and chlorophyll-a concentrations in Peck's Lake for current conditions.

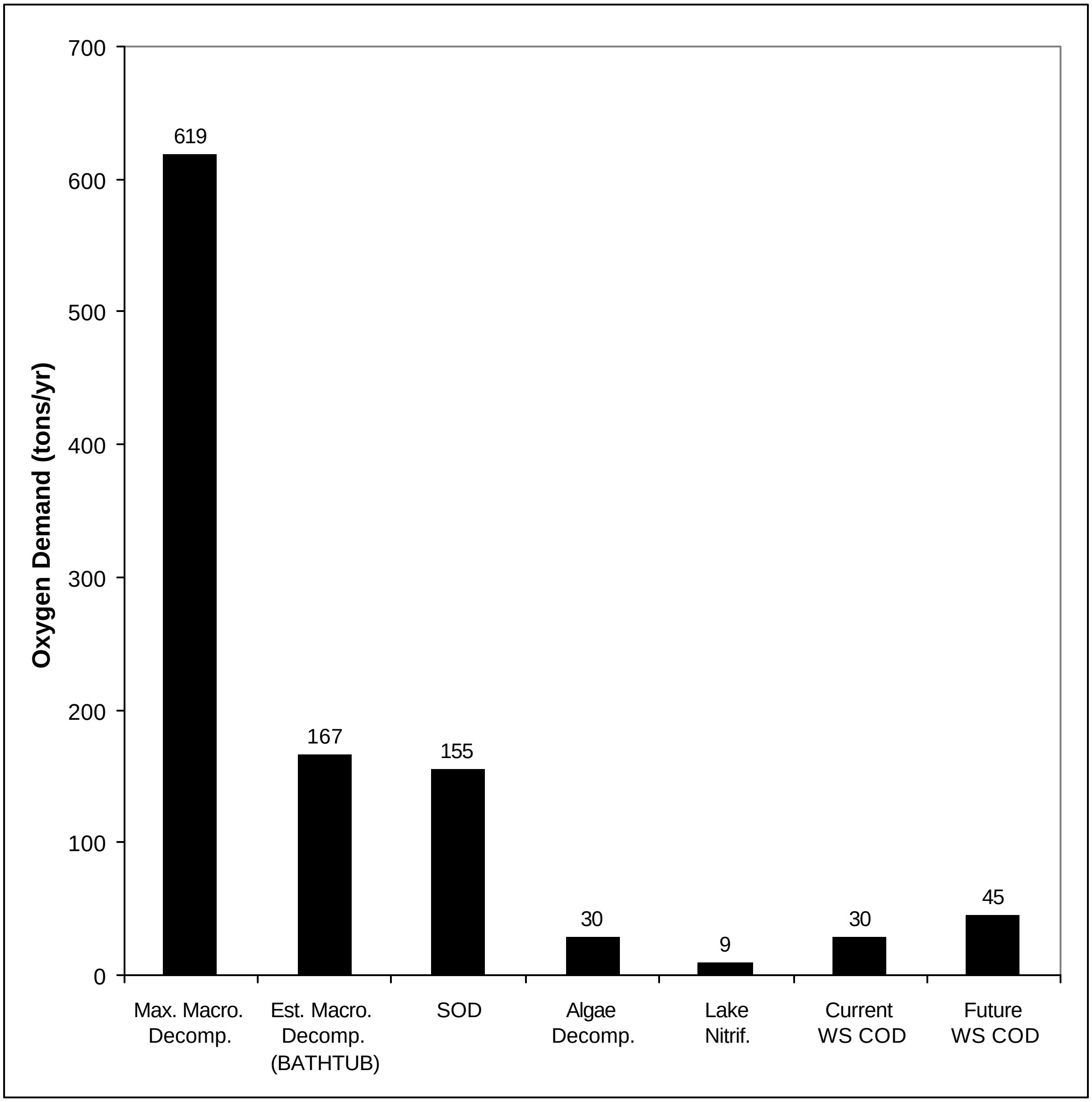
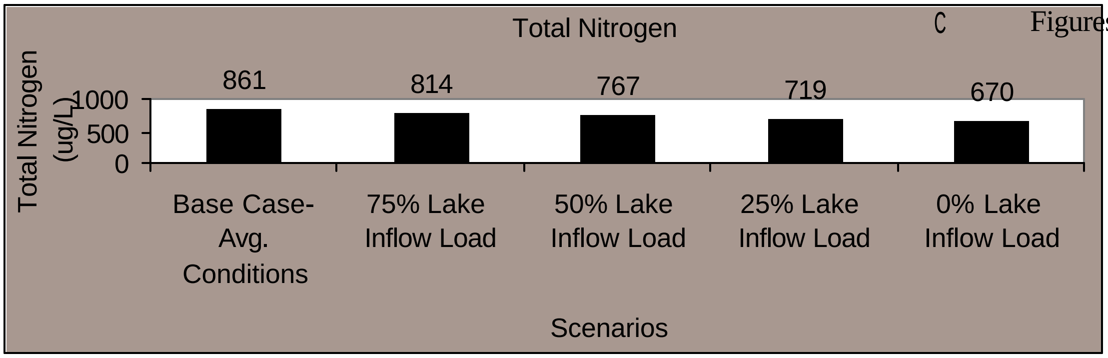
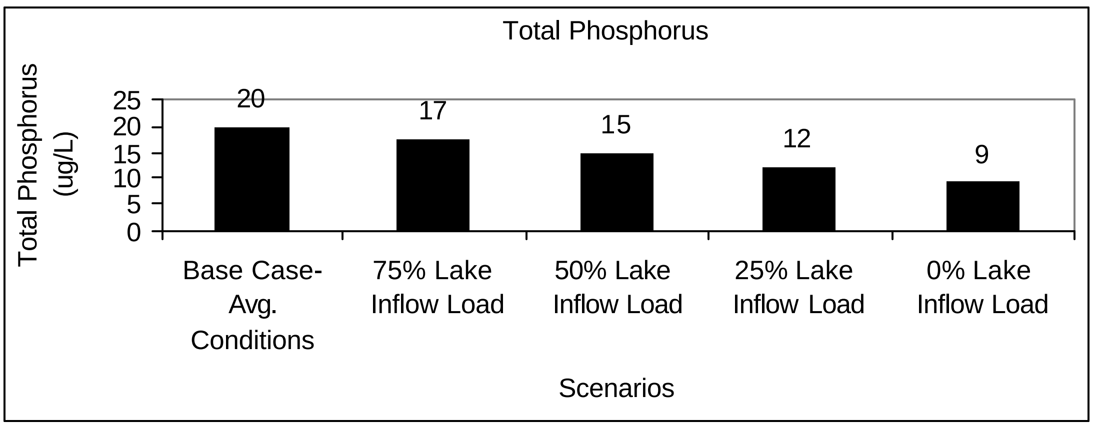


Figure 4-2. Comparison of oxygen demand fluxes in Peck's Lake (SOD=sediment oxygen demand; WS COD = watershed carbonaceous oxygen demand)

- Therefore, some harvesting is recommended, though aggressive removal of macrophytes is not advised, as it is likely to increase planktonic algal concentrations to unwanted levels. Harvesting should be approached incrementally as part of the management plan for the lake. The TMDL allocates a reduction of 25% in aquatic biomass; spot harvesting would open up low channels for additional circulation, which is anticipated to raise wholelake DO and lower wholelake pH. Use of shallow aeration devices may also assist with circulation. Use of herbicides or biological controls weighed within the context of meeting goals of both lake and marsh management.

4.1.3 <u>Manipulation of external factors such as river input, lake outflow and native vegetation:</u>





Figures 4-3, 4-4, 4-5 and 4-6 depict external factors such as river inputs, outflow, and native vegetation that could also be considered for further nutrient load reductions.

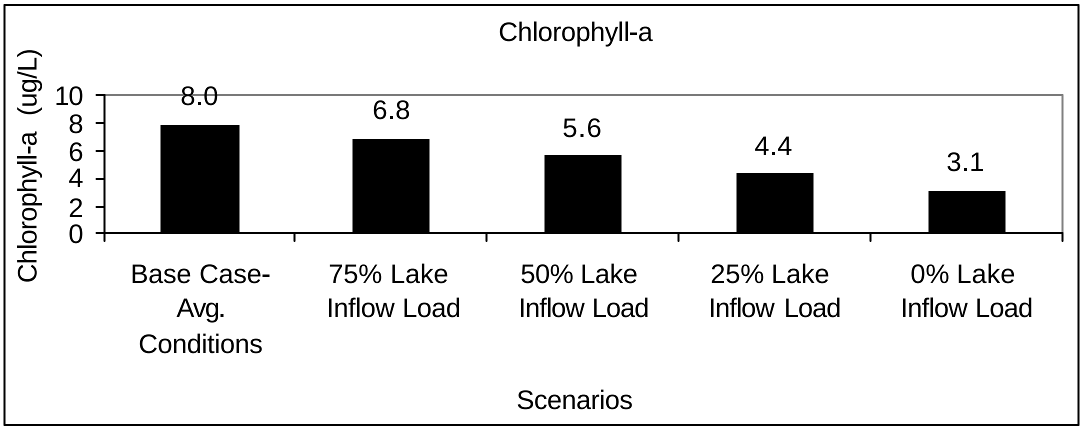


Figure 4-3 Effects of scaled reductions in Verde River inflow loadings on total nitrogen, total phosphorus, and chlorophyll-a concentrations in Peck's Lake for current conditions

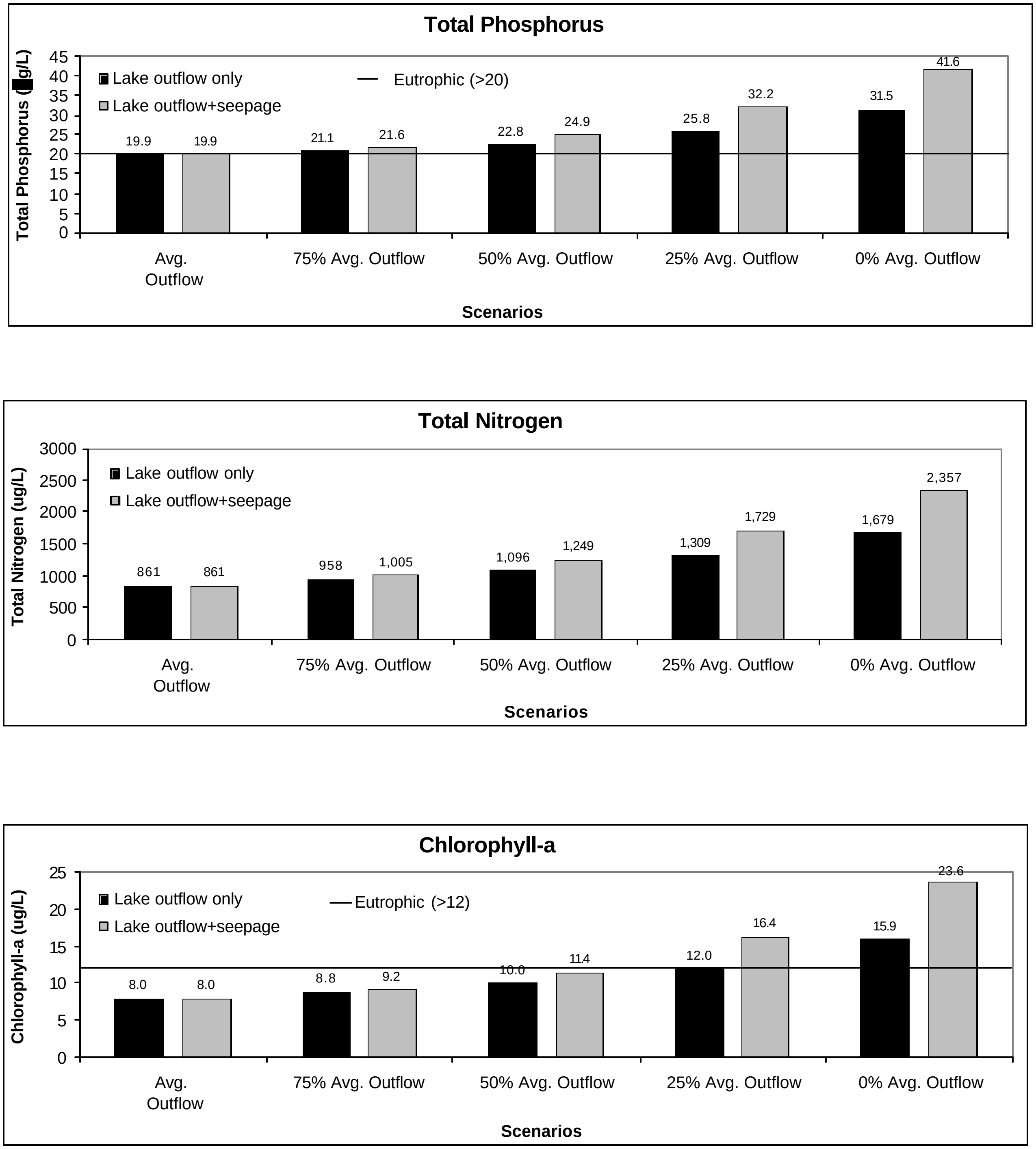
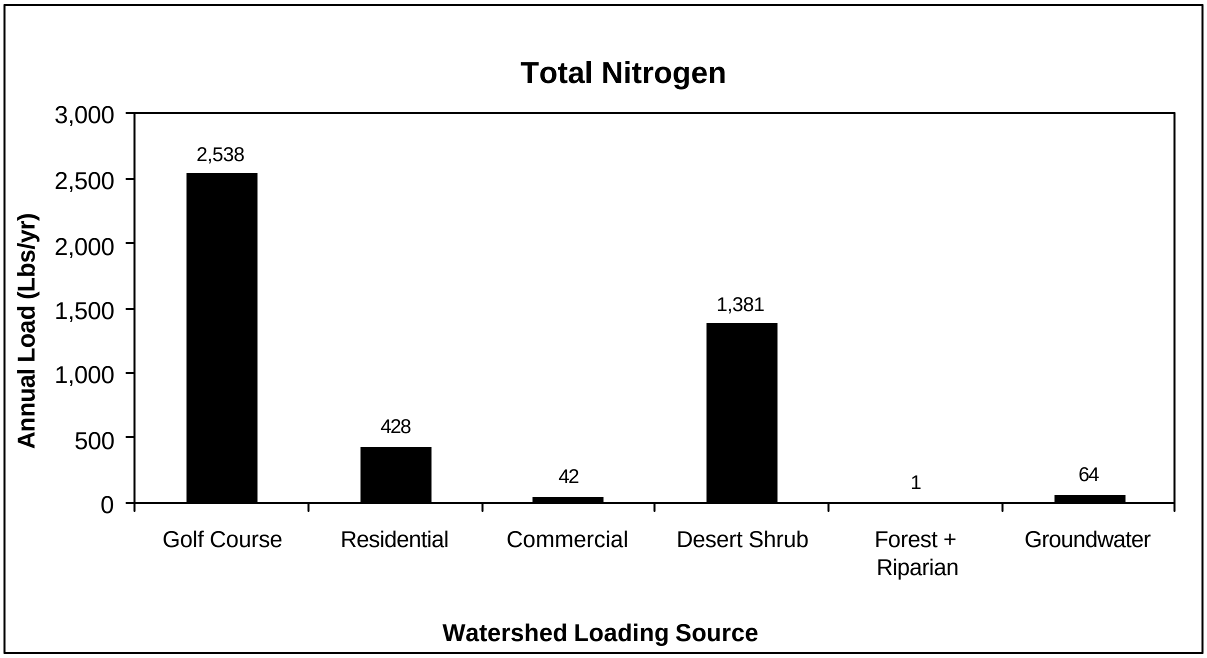


Figure 4-4. Effects of scaled reductions in lake outflow loadings on total phosphorus, total nitrogen, and chlorophyll-a concentrations in Peck's Lake for current conditions. <u>NOTE</u>: Line indicates level at which the concentration moves into the "eutrophic" range; for nitrogen, Arizona defers to the Brezonick Trophic State Index for Florida lakes (see Table 4-3).



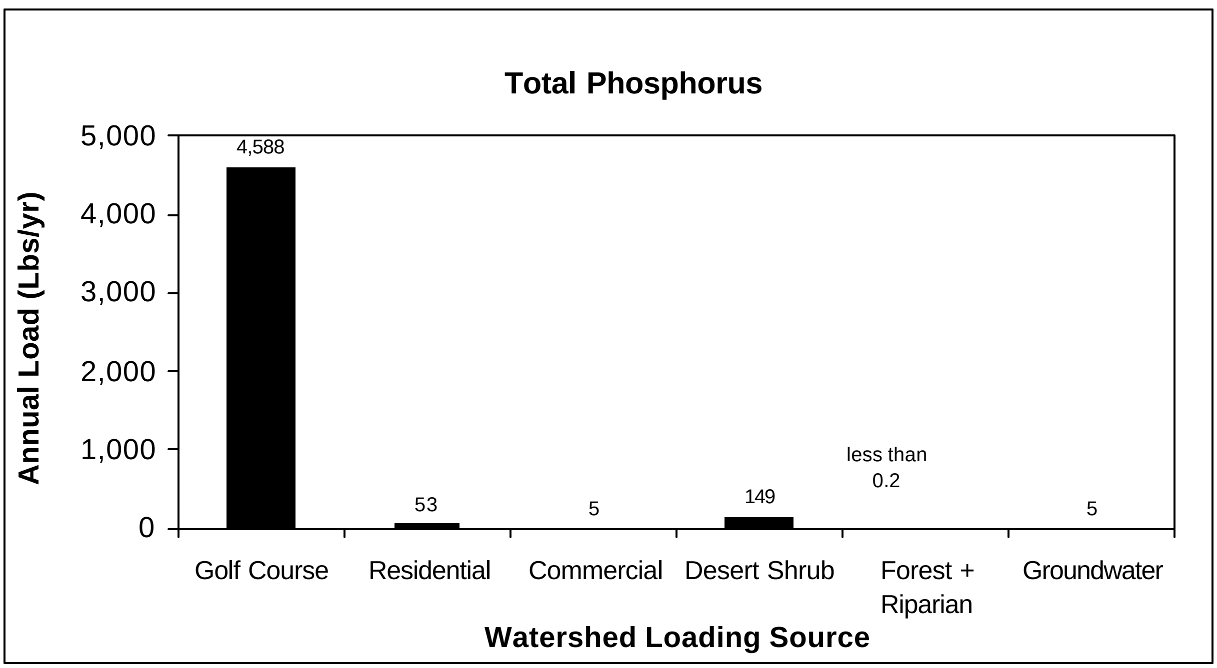


Figure 4-5. Long-term average of annual total nitrogen and total phosphorus contributions to Peck's Lake for future conditions.

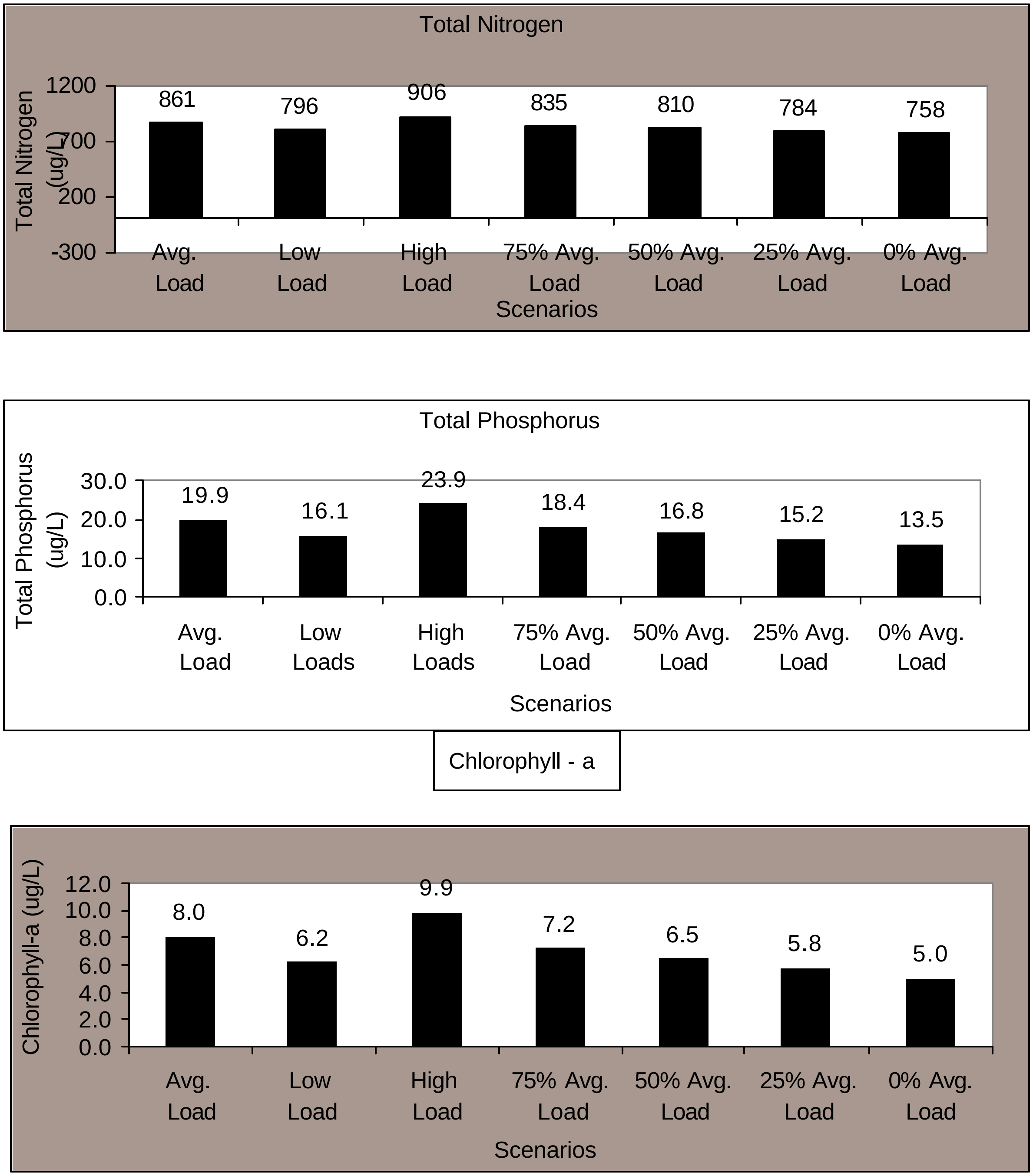


Figure 4-6. Effects of scaled reductions in watershed nutrient loadings on total nitrogen, total phosphorus, and chlorophyll-a concentrations in Peck's Lake for current conditions.

4.1.4 Lake Flushing:

- Sampling to date has revealed that outflow water quality is degraded below inflow water quality due to internal lake processes, particularly the build-up and breakdown of aquatic vegetation, the by-products of which tend to collect toward the outlet (Table 4-2). The processes themselves are natural; however, it may be a benefit to harvest this area prior to plant death and decay to avoid or minimize the situation. Conversely, increasing the flow through Peck's Lake would improve water quality due to increased flushing, even though the Verde River loads would be higher. However, downstream habitat and stream stability should not be compromised.

Table 4-2. Nutrient Concentrations (Inflow vs. Outflow) on 10/20/99, ADEQ

	Ammonia	TKN	NO3+NO2	Total N	Total P
VRPEC-In	0.22	0.88	0.17	1.05	0.009
VRPEC-Out	0.21	**1.44**	0.04	1.48	**0.064**

Notes: All Values in mg/L
Bold: indicates organic breakdown/release to water

- The loads from the Verde River are associated with groundwater flows and runoff from natural areas in the largely undeveloped watershed. Analysis of stream water quality over time does not indicate a downward trend. Therefore, current nutrient loads in the Verde River are considered natural background. However, nutrient loading from the river is important as a factor to monitor and track because it is related to 1) discharge rate, 2) storm runoff, and 3) lake flushing rate. Monitoring for TMDL implementation will include sampling from the river at the point of diversion into the lake (Brewer's Tunnel). Flows are variable (see Figure 4-9) with associated nutrient and sediment loads. The SWPPP should acknowledge a contingency plan, should inflow data show an upstream 'problem'.

C In general, the outflow reduction analyses showed that as outflow rates from Peck's Lake are reduced, water quality will deteriorate due to reduced flushing. Conversely, the model demonstrated that increased inflow improves water quality. This TMDL does not have jurisdiction over inflow/outflow, except as the retention time in the lake bears on water quality. As a result, the TMDL largely defaults to those entities responsible for health and maintenance of both the lake and the downstream water body, Tavasci Marsh (PD and AGFD). In general, a higher lake level and some flushing action are desirable in order to maximize water quality benefits. The model showed that with each drop in 1 cfs (from 4 down to 0), there would be a 10% increase in nutrient retention in the lake. These trends were similar for both the current and future scenarios.

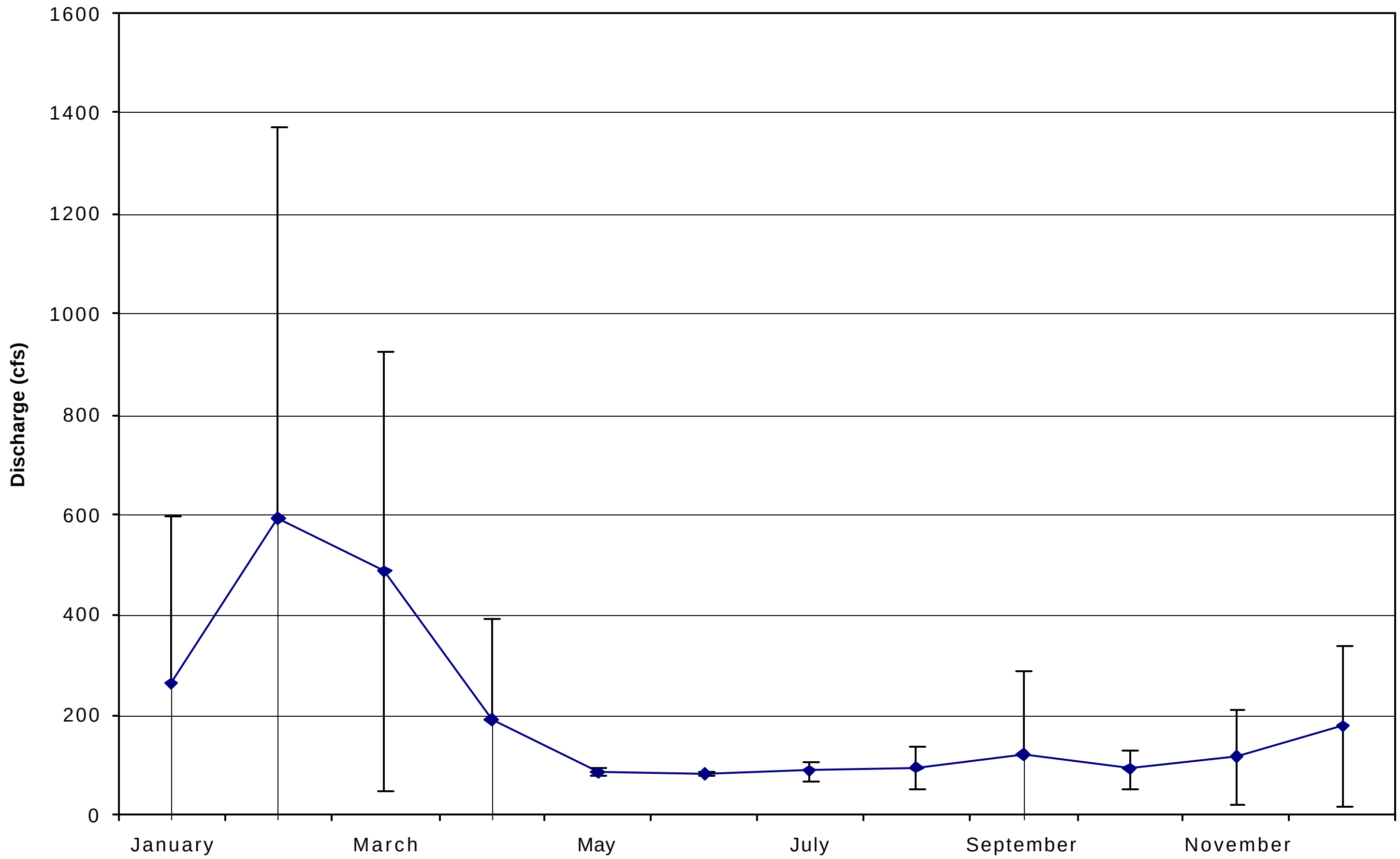


Figure 4-7 Station 0950400 (near Clarkdale). Average Daily Discharge w/standard deviations by month, 1978-1998.

4.1.5 Golf Course BMPs:

- Data suggest that Peck's Lake is currently phosphorus-limited. Therefore, the fertilizer and irrigation application practices in the Golf Course Management Plan (Woodward & Clyde, 1997 SWPPP) should result in consumptive use/uptake by turf with no excess nutrients reaching the lake. The Verde Valley Ranch Project proposes to use effluent for golf course irrigation that contains about 4 times as much nitrogen as phosphorus (40 mg/L N; 10 mg/L P).

- The TMDL model dramatically shows the importance of strict controls on irrigation and fertilization. Particularly for phosphate, but also for nitrate/ammonia, it will be important to curtail leaching and runoff from the golf course. NOTE: the golf course model predictions were high as a result of assumptions of no runoff or infiltration controls. The SWPPP references a "Nutrient Management Plan", which will be incorporated as an appendix to the SWPPP when sufficient data are evaluated to make the determination.

- Grass typically requires about 4 or 5 times as much nitrogen as phosphorus. In the event that excess nutrients were released to the lake, this would likely create a co-limitation that may spur unwanted algal scums in the late summer and fall. The irrigation and fertilizer management plan should reflect consumptive use only, based on soil testing, turf-specific uptake rates, effluent nutrient concentrations, seasonality, and growth cycles. The following information was provided to PD and its contractor as reference material for development of the Nutrient Management Plan for the golf course (a requirement of the SWPPP). NOTE: The TMDL model used Kentucky Bluegrass; specific information for bentgrass and Bermuda grass has been subsequently obtained by ADEQ (Green, 2000):

Turf variety	*Seeds/lb*	*lbs*	*seed/1000 sqft*	*germination*[1]
Creeping bentgrass	*6,500,000*	*.5 - 1*	*4 - 12*	*6 - 10 wks*
Bermuda grass	*1,750,000*	*1 - 2*	*10 - 30*	*"*

[1] *depends on local environmental conditions*

For established Bermuda grass (which is the majority of the golf course (tees, fairways, roughs)[2]
N: 3.3-9.8 lb/ac/wk
P: 2.2-6.5 lb/ac/wk
For established bentgrass (for greens)
N: 5.4-7.6 lb/ac/wk
P: 3.6-5.1 lb/ac/wk

Fertilization Rates From SWPPP for establishing grass:
N: 0.5 lb/ac/wk
P: 1.0 lb/ac/wk

Plant Consumption Rates From Reed et al (Kentucky Bluegrass):
N: 3.43 lb/ac/wk
P: 0.77 lb/ac/wk

[2] Dr. Green's fertilizer rates for established grass are much higher than the SWPPP values for establishing grass. There wasn't much difference between Bermuda grass and bentgrass rates. So it may be reasonable to assume that the plant consumption rates for bluegrass are likely to be good ball park numbers for Bermuda grass and bentgrass. The main point is to ensure the proper fertilizer ratio and to include that load with the effluent concentration

4.1.6 Lysimeters to monitor shallow groundwater:

- Nested lysimeters will be installed at 4-5 locations (including a background location) to characterize the vadose zone (unsaturated soil) and the shallow groundwater zone for possible nutrient migration from irrigation of the lower golf course. These locations will be sampled semi-annually (see revised SWPPP, 2000).

- The TMDL analysis calculated external nutrient loading on the basis of average annual precipitation and runoff rather than by event, as was done in the SWPPP. As proposed in the SWPPP, on-site retention for the lower golf course will be adequate to capture the 2yr/24hr event, calculated to be 1.78 inches of rain. Storm water discharge above the 2yr/24 hour event must be monitored (both discharge and lake water). Installation of a rain gage to track actual precipitation is suggested. The Storm water NPDES will specify these conditions and reporting requirements; should results indicate the need for additional nutrient controls, the permit may be reopened and further mitigation measures negotiated.

4.1.7 Residential BMPs:

- The TMDL model also assumed no retention or filtration in estimating nutrient loads from the residential and commercial areas of the proposed development. With this assumption, the model-projected loads were about 30 to 50 percent higher than existing loads from the undeveloped desert shrub areas on a per unit area basis. The residential area is approximately 65% of the total developed acreage (540 acres). The proposed SWPPP BMPs (sand filters and retention basins), if implemented and maintained correctly, should be sufficient to mitigate these loads at the level of the 2-yr/24 hour event.

- This TMDL benchmarks pre-development nutrient loads; therefore, loading from commercial and residential areas must reflect ambient background, except for storm events greater than the 2-yr/24-hr event. The Storm Water NPDES will specify monitoring and reporting requirements; should results indicate the need for additional nutrient controls, the permit may be reopened and further mitigation measures negotiated.

4.1.8 Lake Monitoring:

- The lake monitoring plan is to be included in Section 6 of the revised SWPPP and become part of the Arizona's CWA Section 401 conditions for certification of the NPDES Storm Water permit. It will include the following elements:
  - Clear definition of data objectives
  - Water, trophic parameters, sediment, and shallow subsurface (under lower golf course)
  - Citation of methods used, holding times, detection limits; the sample collection and analysis methods, as well as detection and reporting limits should be EPA-approved and identical to those utilized by ADEQ.
  - QA/QC protocols
  - Periodicity (quarterly for water, annually for sediment and tissue) NOTE: ADEQ will pick up the winter quarter of monitoring at the lake (full suite, including sediment sampling for nutrients)
  - Inflow and outflow rate
  - Map of sites, to include: 1 at river inflow (Brewer's Tunnel), and 4 in-lake locations, as specified in the SWPPP
  - Reporting requirements
  - Addition of total phosphate as phosphorus, total organic carbon and dissolved organic carbon, and chlorophyll-a, to the suite of analytes for the river and the lake.

- ADEQ has prepared simple graphs to depict water quality trends to date in Peck's Lake. It will be important to continue to collect quarterly samples from the lake and lake inflow (Brewer's Tunnel) as a foundation for "ambient"/pre-development conditions in the lake. ADEQ will supplement this data with collection of annual outflow chemistry and sediment nutrient chemistry.

- Figures 4-8 and 4-9 represent DO and pH values in the lake, before and after outflow modification in 1997. This data set is limited, but it is interesting to note that low DO concentrations may be persistent in the lake. DO appears to decline in the fall, presumably due to breakdown in macrophytes and corresponding increases in BOD. Since the flow-through modifications, pH has apparently improved, regardless of season.

- Figures 4-10 and 4-11 represent DO and pH values by sampling station within the lake. DO in particular shows a longitudinal trend; DO concentration depresses moving from Site F by the inflow down to Site AA by the outflow (refer back to Figure 2-2). This apparent trend is not surprising given the tendency to build up biomass toward the terminal end of the lake, thus generating a higher biological oxygen demand. pH values have not changed appreciably by station or depth over the period of 1995 to 1999.

- Figures 4-12 and 4-13 represent DO and pH values by season. Looking at the data by season, it is obvious that summer is the most critical season; the graph shows an elevation in pH, also the result of peak productivity. Background pH appears to be around 7.8-8.0 S.U. Shallow dissolved oxygen is clearly depressed in the summer and fall when plants are at their peak productivity. Because the water quality standard for DO pertains to the top meter of the water column, a management strategy must be developed to address this condition.

Figures 4-8 through 4-13 Spatial and Temporal Trends in Peck's Lake Water Quality

4.1.9 Trophic Indicators:

C The most critical goal of the lake monitoring program will be to identify and agree upon a set of water quality and/or biological indicators. Indicators can be used to identify different objectives, so it will be necessary to set strict interpretations for each indicator chosen. This TMDL has used nutrient values as an indicator for 1) productivity/plant biomass, and 2) indirectly, for changes in DO and pH. The monitoring program should lay out a flow chart for chemical and biological interpretation of measured values, whether that be one threshold value or a range of values, or even a temporal or spatial interpretation.

C The 'classic' Trophic State Index (TSI) was developed by Carlson (1977); the index includes total phosphorus, chlorophyll, and secchi depth. Subsequently, several other trophic indices have also become popular. ADEQ suggests using the Brezonick TSI (Table 4-3); this index differs from Carlson in that it also includes nitrogen. It would also be desirable for the indicator to include a way to score macrophyte biomass. ADEQ has provided PD with several professional articles related to trophic indices, two of which include a way to incorporate macrophytes in the TSI. ADEQ will work with PD and AGFD in estimating macrophyte biomass and choosing a trophic scoring method.

TMDL goals for the first Storm Water Permit cycle will be to maintain a chlorophyll-a value at or below 5 *u*g/L and to reduce the aquatic plant biomass by roughly 25%. At least one monitoring site should be located in a regularly harvested area to assess improvements to DO and pH.

Table 4-3 Trophic Classification Thresholds (Brezonick multi-parameter TSI, 1982)

*TSI	Trophic State	Chlor-a (*u*g/L)	SD(m)	Total P (*u*g/L)		Total N (mg/L)	
				P-lim	N&P-lim	N-lim	N&P-lim
<30	Oligotrophic	<5	>3	<10	<13	<.25	<.28
30-45	Mesotrophic	5-12	1.2-3	10-20	13-35	.25-.65	.28-.75
45-65	Eutrophic	12-20	.6-1.2	20-35	35-65	.65-1.1	.75-1.2
>65	+Hypereutrophic	>20	<.6	>35	>65	>1.1	>1.2

* TSI stands for "Trophic State Index" (relative score along a continuum of productivity)
+ Hypereutrophic: algae growth limited by light rather than nutrients (self-shading); particulate matter may also contribute

5.0 REFERENCES (Tetra Tech Inc. and ADEQ)

Aiken, S. A., P. R. Newroth, and I. Wile. 1979. The biology of Canadian weeds. 34. *Myriophyllum spicatum* L. Can. J. Plant Sci. 59:201-215.

Arizona Department of Economic Security, 2000. Arizona sub-county population projections for Yavapai County (unpublished).

Arizona Department of Environmental Quality (ADEQ), 2000. Data and information sent by Lake Program staff March , 2000.

Arizona Department of Economic Security, 1994. Population estimates and projections for Arizona's counties and incorporated places (unpublished).

Arizona Department of Water Resources. 1994. Arizona riparian protection program legislative report. Arizona Department of Water Resources. 459 pages.

Arizona Game and Fish Department (AGFD). 1979. Peck's Lake Restoration Project. Arizona Game and Fish Department.

Baker, M. United States Forest Service. 2000. Personal communication.

Baker, L. and L. Farnsworth. 1995. Feasibility of Management Options to Improve Water Quality in Rainbow Lake, Arizona. Arizona State University. Department of Civil and Environmental Engineering. Prepared for the Arizona Department of Environmental Quality.

Blaney, H.F., and Criddle, W.D. 1962. Determining consumptive use and irrigation water requirements. USDA Technical Bulletin Number 1275, 59 pp.

Butcher, J. 2000. Tetra Tech. Personal communication

Ecology and Environment, Inc. (E&E), 1994. Expanded Site Inspection Summary Report (Analysis of ESI Results). Prepared for U.S. Environmental Protection Agency Region IX.

Haith, D.A., R. Mandel, and R.S. Wu. 1992. GWLF Generalized Watershed Loading Functions. Version 2.0 (User's Manual). Department of Agricultural & Biological Engineering. Cornell University. Riley-Robb Hall. Ithaca, NY.

Hammer, M., and Hammer, Jr., M. 1986. Water and Wastewater Technology. Prentice Hall, Inc. Englewood Cliffs, New Jersey.

Hydro Geo Chem, Inc. 1983. Letter to Arizona Game and Fish Department dated June 22, 1983 regarding Hydro Geo Chem's water level contour map, recommendations for further study, and comments on implementing the study.

Jewell, W.J. 1971. Aquatic weed decay. Dissolved oxygen utilization and nitrogen and phosphorus regeneration. J. Water Poll. Control Fed. 43:1457-1467.

LULC, 1972. USGS. Land Use Land Coverage based on Andersons Level 2 classifications.

Madsen, J. D. 1997. Methods for Management of Nonindigenous Aquatic Plants. Ch 13 in *Assessment and Management of Plant Invasions*, Luken, J. O. and J. W. Thieret (eds). Springer-Verlag, New York.

Mike Haneman, U.S. Forest Service, Flagstaff, Arizona. March 2000. Personal communication.

Nichols, D.S., and D.R. Keeney. 1973. Nitrogen and Phosphorus Release from Decaying Water Milfoil. Hydrobiologia. 42(4):509-525.

Owen-Joyce, S. J. and C. K. Bell. 1983. Appraisal of Water Resources in the Upper Verde River Area, Yavapai and Coconino Counties. Arizona Department of Water Resources, Bulletin 2. Tucson, Az.

Pennwalt, 1979. Aquatic herbicides get results in Arizona's "Crooked Water". *press release*, Pennwalt Chemicals, Equipment, Health Products. Philadelphia Pennsylvania.

Reed, S.C., Middlebrooks, E.J., Crites, R.W. 1988. Natural Systems for Waste Management and Treatment. McGraw-Hill, New York.

Russ Radden, Coordinator for Natural Resources, Yavapai County Cooperative Extension Office. March 24, 2000. Personal communication.

Smith, C. S. and J. W. Barko. 1990. Ecology of Eurasian water milfoil. J. Aquat. Plant Manage. 28:55-64.

Tetra Tech. 2000a. Peck's Lake Data Summary Report, Total Maximum Daily Load (TMDL) Development. Prepared for Arizona Department of Water Quality.

Twenter, F.R., 1928. Geology and ground water in Verde Valley – the Mogollon Rim region, Arizona. Washington, U.S. Govt. Print. Off., 1963

USDA, 1996. Verde Cooperative River Basin Study. US Department of Agriculture.

United States Forest Service (USFS), 1995. Terrestrial Ecosystems Survey (TES) of the Coconino National Forest. USDA Forest Service Southwestern Region.

USGS, 2000. USGS Water data web page http://waterdata.usgs.gov/nwis-w/AZ/index.cgi?statnum=09504000

VRCP, 1991. Arizona State Parks. Verde river corridor project final report and plan of action. Verde Valley Arizona.

Water Resources Associates, 1992. Ground-Water Flow System Characterization, Clarkdale Tailings Area, Clarkdale, Arizona. Prepared for Phelps Dodge Development Corporation.

WRCC, 2000. Western Regional Climate Center web page, http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?azcott

Woodward-Clyde, 1997. Storm Water Pollution Prevention Plan (SWPPP) Verde Valley Ranch Clarkdale, Arizona. Prepared for Phelps Dodge Corporation, Phoenix, Arizona.

United States Department of Agriculture (USDA). 1976. Soil Survey of Yavapai County, Western Part. USDA. Soil Conservation Service and Forest Service in cooperation with Arizona Agricultural Experiment Station.

Walker, W.W. 1996. Simplified Procedures for Eutrophication Assessment and Prediction: User Manual. U.S. Army Corps of Engineers. Water Operations Technical Support Program. Instruction report W-96-2. September 1996.