Total Maximum Daily Load For: Rainbow Lake

Parameters: Nutrients

June 1999

Open File Report 09-02

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Rainbow Lake: Total Maximum Daily Load Study

Prepared for: ADEQ

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June 1999

EXECUTIVE SUMMARY

Description of TMDL Process

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 fix water quality problems. The purpose of this TMDL study is to provide the local community, ADEQ, and U.S. EPA Region 9 with technical information that can be used to develop a water quality plan.

Watershed Overview

Rainbow Lake is a man-made impoundment on Walnut Creek in the Pinetop-Lakeside area of Navajo County, Arizona. The lake, which is classified as eutrophic, and Walnut Creek are part of the Silver Creek subwatershed which is located in the Little Colorado watershed. The Rainbow Lake watershed has an area of 5,357 acres. Rainbow Lake has a surface area of 116 acres and a storage volume of 800.2 acre-feet. The lake has a mean depth of 6.9 feet and a maximum depth of 14 feet. The lake has a residence time of approximately 139 days.

Rainbow Lake is designated for the following uses under Title 18, Chapter 11 of the Arizona Administrative Code:

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

GIS coverages for land use, land ownership, and vegetation types were obtained from the Arizona Department of Environmental Quality (Ms. L. Gerrith), and from BASINS2 (US EPA, 1998). Land usage is based on Anderson Level 2 land classification system.

Topographic information was obtained from BASINS2 (1:250,000 scale DEM) and from USGS 1:24,000 scale topographic maps and DEMs for the area.

Identification of Violated Water Quality Standards and Impaired Designated Uses

Water quality standards are commonly expressed as either numeric (a specific concentration which cannot be exceeded) or narrative (used to describe a condition that is not desired). Arizona uses both types of water quality standards for Rainbow Lake. Rainbow Lake is listed on Arizona's 1998 303(d) list as impaired due to violations of narrative nutrient standards and numeric pH standards. Dissolved oxygen is not currently a major problem in Rainbow Lake. Its shallow depth prevents significant stratification, although low DO concentrations have been measured near the bottom during some periods.

pH and dissolved oxygen are stated as numeric standards, with nutrient concentrations having narrative standards. The water quality standards for these parameters (Title 18, Chapter 11 Arizona Administrative Code) are as follows:

- pH shall be between 4.5 and 9.0 SUs; The critical low pH for Aquatic and Wildlife is 6.5 SU;

- Dissolved oxygen shall not be lower than 7.0 mg/L between the surface and one meter depth, and the minimum dissolved oxygen saturation is 90%; and

- Nutrient concentrations shall not cause growth of algae or aquatic plants or settling of bottom deposits that inhibit or prohibit the habitation, growth, or propagation of other aquatic life or that impair recreational uses. Nutrient concentrations shall not change the color of the surface water from natural background levels of color.

Based on these water quality standards, pH standards for Rainbow Lake were violated in 82 out of 148 samples (55%) between 1983 and 1993. Dissolved oxygen concentration standards in the upper one meter water depth were violated in 4 out of 77 samples (5%) during the same time period. Rainbow Lake has been classified as slightly eutrophic and, as such, nutrient concentrations in Rainbow Lake may have been violated during this time period.

pH and dissolved oxygen are easily measurable water quality parameters and numeric water quality standards aid in determining whether violations are occurring. Rainbow Lake has been listed as impaired because of high pH concentrations in the water column. However, before pH can be remedied, the causes of the high pH, and associated water quality standards violations, must be addressed.

Numeric Targets

Possible water quality targets to control the noxious weed growth in Rainbow Lake could be expressed in terms of nutrient concentrations (e.g., mg/L of phosphorus and/or nitrogen) or macrophyte parameters (e.g., extent of growth, area of effect, biomass). The Water Quality Standards for these parameters in Title 18, Chapter 11 of the Arizona Administrative Code are as follows:

- pH, (A&Wc). The following water quality standards for pH, expressed in standard units (SUs) shall not be lower than 4.5 SU or greater than 9.0 SU (A.A.C. R18-11-109, paragraph D), the critical low pH for Aquatic and Wildlife is 6.5 SU;

- Dissolved oxygen, Aquatic and Wildlife, cold water fishery (A&Wc). The dissolved oxygen concentration in surface water shall not fall below 7.0 mg/L (A.A.C. r18-11-109, paragraph G), the minimum dissolved oxygen saturation is 90%. In the case of lakes, there is a further footnote in that: the dissolved oxygen water quality standard for a lake shall apply below the surface but not at a depth greater than 1 meter;

- Nutrients, (A.A.C. R18-11-109, paragraph A, Narrative Water quality Standards). This paragraph lists eight different impacts on surface waters that are considered the narrative standards for the state. The narrative water quality standards that are applicable to Rainbow Lake (R18-11-108-Narrative Water quality Standards):

A surface water shall be free from pollution 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;

- Change the color of the surface water from natural background levels of color.

The water quality standard for Walnut Creek and tributaries upstream of Lakeside Dam state that the waters shall not exceed 1.0 mg/L total phosphates as P (A.A.C. R18-11-109, Section H, Numeric Water Quality Standards).

The numeric targets recommended for the Luna Lake TMDL are compared to existing conditions in Table ES-1.

Table ES-1
Comparison of Existing Conditions to TMDL Endpoints

Parameter	Existing Value (Mean and range)	TMDL Endpoint	Comments
pH (SU)	8.91 (7.02 – 10.32)	Arizona Water Quality Standard: pH > 6.5 and < 9.0	This range ensures minimum concentrations of unionized ammonia and reduces toxicity to aquatic organisms & pH shock. Validated by monitoring.
Dissolved Oxygen (mg/L)	8.95 (0.12 – 17.43)	Arizona Water Quality Standard: DO > 7.0 mg/L or 90% saturation in upper 1 meter water depth	This range ensures that water column concentrations of dissolved oxygen will be adequate to sustain aquatic life. Validated by monitoring.
Phosphorus (mg/L)	0.14 (0.02 – 0.32)	Arizona Water Quality Standard: Best Professional Judgment for Lake, which is co-limited by phosphorus and nitrogen	ADEQ (1999): total phosphorus between 0.01 – 0.02 mg/L or ADEQ (2000): total phosphorus between 0.01 – 0.04 mg/L is classified “mesotrophic”; 0.04 – 0.07 is classified “eutrophic” Validated through Phased TMDL Monitoring.
Nitrogen (mg/L)	0.29 (<0.01 – 1.82)	Best Professional Judgment	ADEQ (2000): total nitrogen between 0.28 – 0.75 mg/L is classified “mesotrophic”; 0.75 – 1.2 mg/L is classified “eutrophic” Validated through Phased TMDL Monitoring.
Total Ammonia (mg/L)	0.13 (<0.03 – 0.35)	Protection of sensitive coldwater fish species (i.e., salmonids): Arizona Standard for Acute exposure: pH & temp dependent* Federal Criteria: Concentrations of unionized ammonia for Acute Exposure (< 1 hr): 0.35 mg/L; Chronic (4-days): 0.02 mg/L	Unionized ammonia is a strongly toxic aquatic pollutant whose concentration is driven by water column pH and temperature. *Concentrations measured to data are protective of the coldwater fishery in Rainbow Lake, but acute threshold for extreme high pH and temperature is 0.67 mg/L Validated through Phased TMDL Monitoring.
Aquatic Plants	The presence of excessive quantities that are causing impairment to the beneficial uses of the lake	Reduce quantities of nuisance aquatic plants	Reduce the quantities of nuisance aquatic plant biomass to levels that would not drive water column pH and dissolved oxygen levels to extremes or result in increasing the concentrations of unionized ammonia to toxic levels. Validated through Phased TMDL Monitoring.

Technical Approach

The technical approach to the Rainbow Lake TMDL Study included the following four primary elements: 1) conduct a source analysis for loadings, 2) develop a nutrient mass balance model for Rainbow Lake, 3) link the pollutant loads (stressors) to water quality endpoints, and 4) allocate loads to source categories that ensure water quality objectives are met. A watershed loading model (GWLF) and an in-lake processes model (BATHTUB) were used to perform the analysis for these elements of the TMDL.

Source Analysis of Loadings

Simulated loadings of total and dissolved nitrogen (Figure ES-1) and phosphorus (Figure ES-2) in Rainbow Lake from within the watershed varied with annual precipitation over the 16-year period (1980 to 1995). Nutrient loads during low flow years (e.g., 1989) were relatively low, while high flow years (e.g., 1992) resulted in substantially higher loadings of nutrients. The phosphorus loads during the high flow year were more than 3 times as high as the loads during the low flow year, and the nitrogen loads were more than twice as high as the low flow loads.

The long-term average annual loadings of total nitrogen and total phosphorus from the Rainbow Lake watershed source categories are illustrated in Figure E-3a & b. The following nutrient allocations and reductions will reduce the frequency, duration, and magnitude of water quality standard violations and significantly enhance the capability of Rainbow Lake to fulfill its designated uses. Occasional exceedances of the numeric pH standard may still occur in summer months at Rainbow Lake, exacerbated by the effects of high altitude. However, the lake will be managed as a whole to provide adequate refuge from pH impairment during these critical times. Rainbow Lake will remain a "eutrophic" lake, but the degree of eutrophication will be controlled. The nutrient reduction objectives expressed in the allocations are targeted on nonpoint sources and in-lake sources of nutrients.

ADEQ has assigned Scenario 2 allocations for this TMDL, summarized in Table ES-2 (nitrogen) and ES-3 (phosphorus).

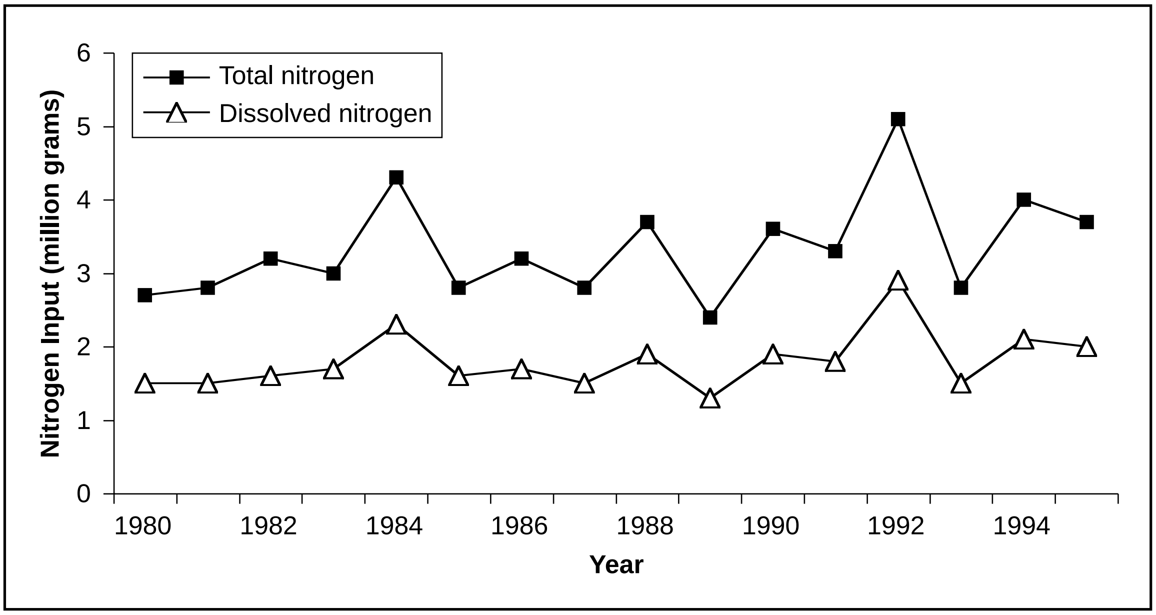


Figure ES-1. Annual total nitrogen and dissolved nitrogen inputs to Rainbow lake.

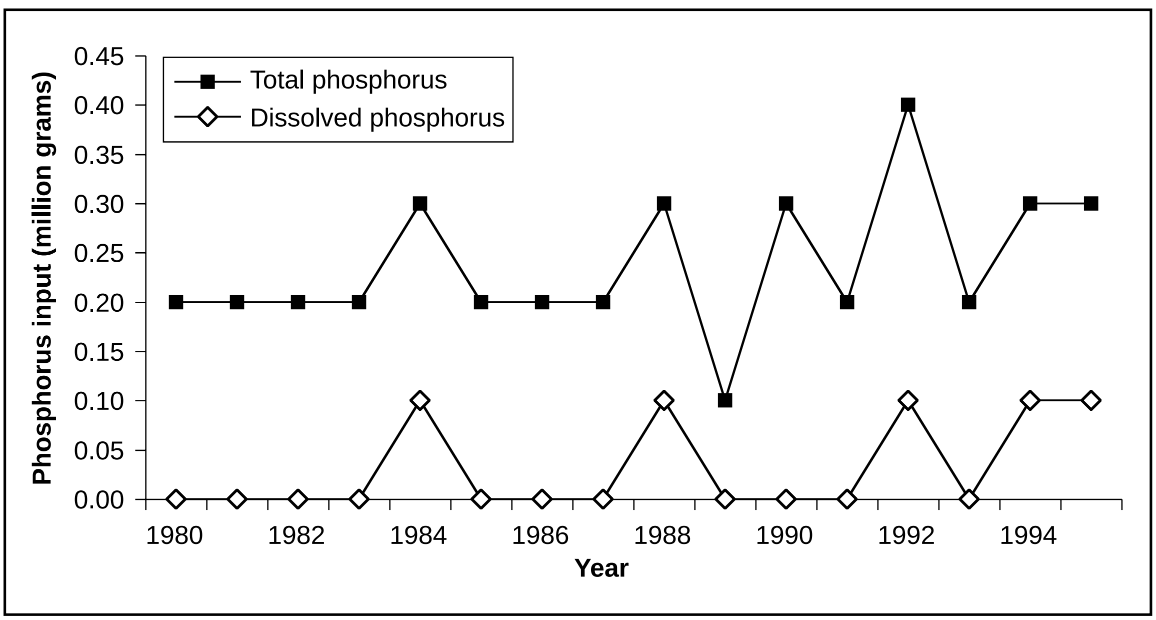
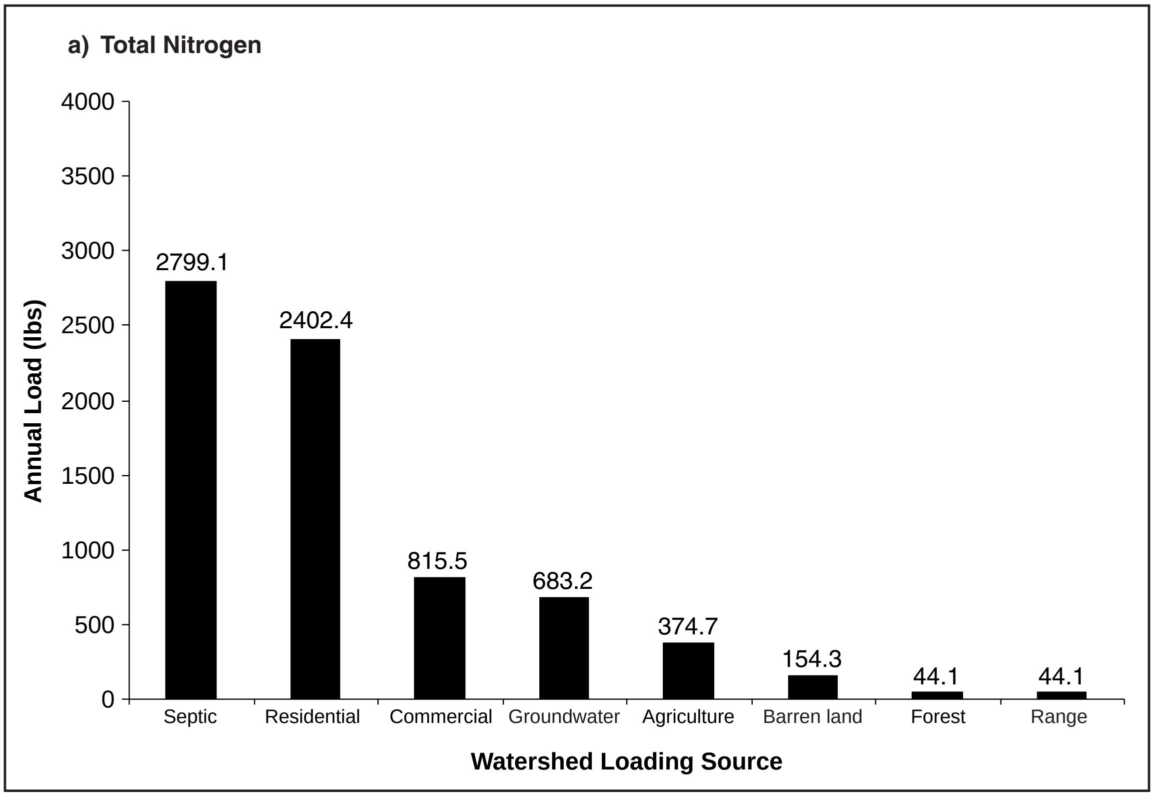


Figure ES-2. Annual total phosphorus and dissolved phosphorus inputs to Rainbow lake.



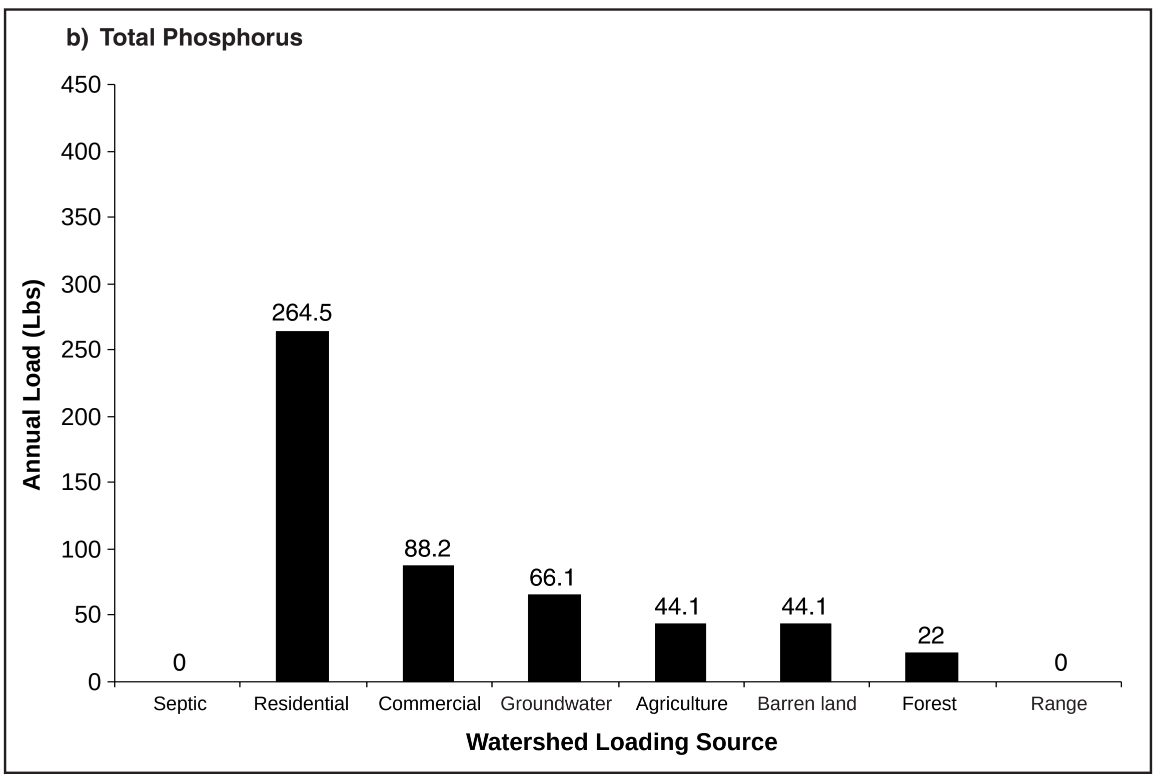


Figure ES-3a & b. Long-term averages of annual (a) total nitrogen and (b) total phosphorus contributions to Rainbow Lake.

Table ES-2
Rainbow Lake Recommended Allocations for Nitrogen (Scenario 2)

Source Category	Existing Nitrogen Total Loading (TL) (Lbs/yr)	% Existing Total Watershed/ Lake Loading	% Targeted Reduction of Category	Amount Nitrogen Reduced (Lbs/yr)	Remaining Load (RL) (Lbs/yr)
Septic	2800	35%	75%	2,100	700
Residential	2403	30%	50%	1,201.5	1,201.5
Commercial	816	10%	0%	0	816
Groundwater	683	8%	0%	0	683
Agriculture	375	5%	0%	0	375
Barren Land	154	2%	0%	0	154
Forest	44	0.5%	0%	0	44
Range	44	0.5%	0%	0	44
Macrophyte Decomposition	414	5%	50%	207	207
Sediment Release	339	4%	0%	0	339
(Dredging)			(50%)	(169.5)	(169.5)
Total	8,072	100%		3,508.5	4,563.5
(Dredging)				(3,678)	(4,394)

% of total existing nitrogen load remaining = 57%
= (54%)

% total watershed loadings of nitrogen reduced = 43%
= 46%

Note: Numbers in parentheses represent values associated with the dredging scenario.

Table ES-3
Rainbow Lake Recommended Allocations for Phosphorus (Scenario 1)

Source Category	Existing Phosphorus Total Loading (TL) (Lbs/yr)	% Existing Total Watershed/ Lake Loading	% Targeted Reduction of Category	Amount Phosphorus Reduced (Lbs/yr)	Remaining Load (RL) (Lbs/yr)
Septic	0	0%	100%	0	0
Residential	264	23%	50%	132	132
Commercial	88	8%	0%	0	88
Groundwater	66	6%	0%	0	66
Agriculture	44	4%	0%	0	44
Barren Land	44	4%	0%	0	44
Forest	22	2%	0%	0	22
Range	0	0%	0%	0	0
Macrophyte Decomposition	339	29%	50%	169.5	169.5
Sediment Release	280	24%	0%	0	280
(Dredging)			(50%)	(140)	(140)
Total	1,147	100%		301.5	845.5
(Dredging)				(441.5)	(705.5)

% of total existing phosphorus load remaining = 74%
= (62%)

% total watershed loadings of phosphorus reduced = 26%
= (38%)

Note: Numbers in parentheses represent values associated with the dredging scenario.

Linkage of Nutrient Loadings to In-Lake Water Quality Indicators

The BATHTUB model was used to predict the concentrations of total phosphorus, total nitrogen, and chlorophyll-a in Rainbow Lake in response to different nutrient loading scenarios. Three major sets of conditions were analyzed:

1. Effects of scaled reductions in watershed nutrient loads
2. Effects of scaled reductions in macrophytes
3. Effects of scaled reductions in watershed nutrient loads with different degrees of macrophyte removal

The concentrations of total phosphorus, total nitrogen, and chlorophyll-a that were predicted under the different environmental conditions and scenarios are compared to the ADEQ trophic classifications that are used for the 305 (b) statewide water quality assessment process. These comparisons are presented in Figures 3-6 to 3-11 and discussed in greater detail in the following sections. The results and discussions focus on nutrient and phytoplankton (chlorophyll-a) concentrations and trophic status as a surrogate for direct predictions of water quality variables such as pH and dissolved oxygen. Macrophyte productivity was simulated in BATHTUB as aerial biomass (chlorophyll-a) and will be tracked both directly and through planktonic productivity. The TMDL makes the assumption that a significant reduction in trophic parameters (nutrients and chlorophyll-a) loading to the lake will result in incremental but also significant reductions in lake trophic status, with corresponding improvements in maintaining acceptable pH and DO levels.

In other words, implementation measures which decrease nutrient loading will lower productivity in the lake, and thus reduce the frequency of water quality exceedances for dissolved oxygen and pH. Allocated reductions in external and internal nutrient loading are expected to result in substantial attainment of water quality standards. A focused monitoring plan will be developed to calibrate nutrient and chlorophyll concentrations to seasonal changes in plant biomass and diurnal fluctuations in DO and pH. This type of focused monitoring within the context of particular lake ecology, will allow development of a predictive model for minimizing pH and dissolved oxygen problems in Rainbow Lake, as well as develop a better understanding of actual vs. perceived impairments. Through periodic high pH and low dissolved oxygen are typical in lakes that are highly productive, their quantitative impact on attainment of lake designated uses is not fully understood.

If, after the required load reductions are achieved, exceedances continue and specific impairments are demonstrated, then will need to 1) revisit load reduction, and 2) collect more extensive diurnal and temporal data, to 3) set up and calibrate a more complex predictive ecosystem response model.

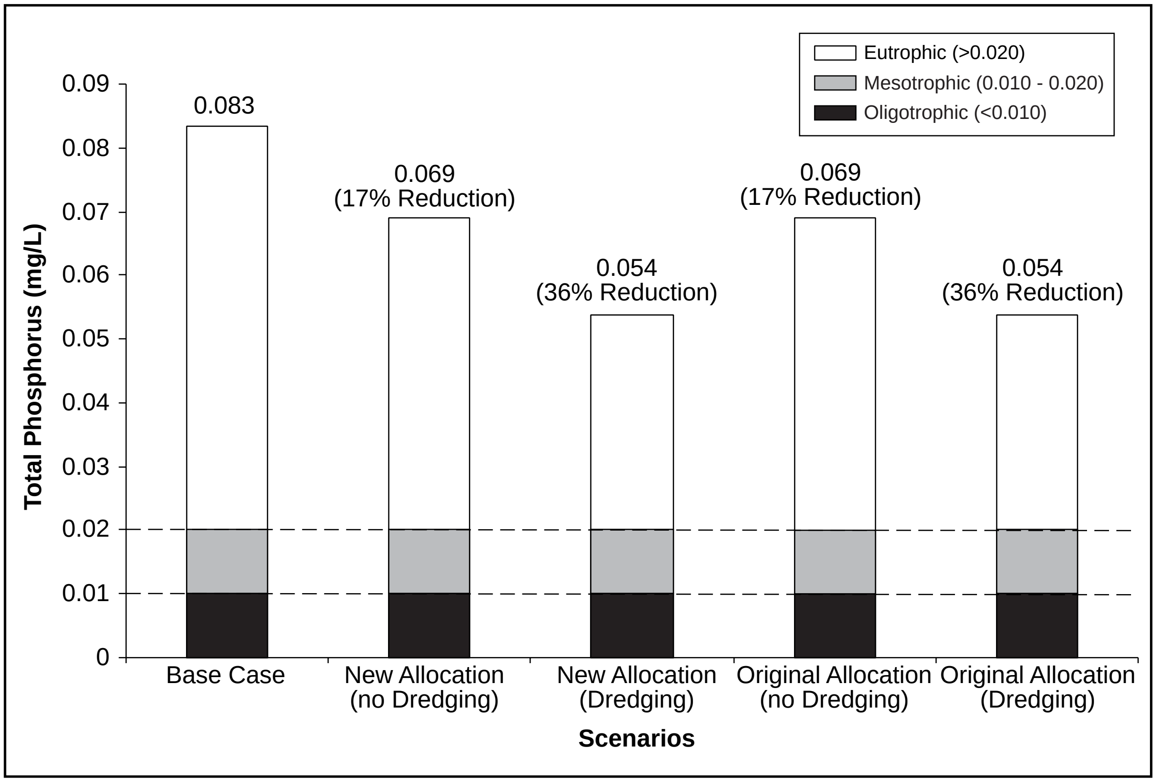


Figure ES-4. Effects scenarios of remedial actions on total phosphorus concentrations in Rainbow Lake.

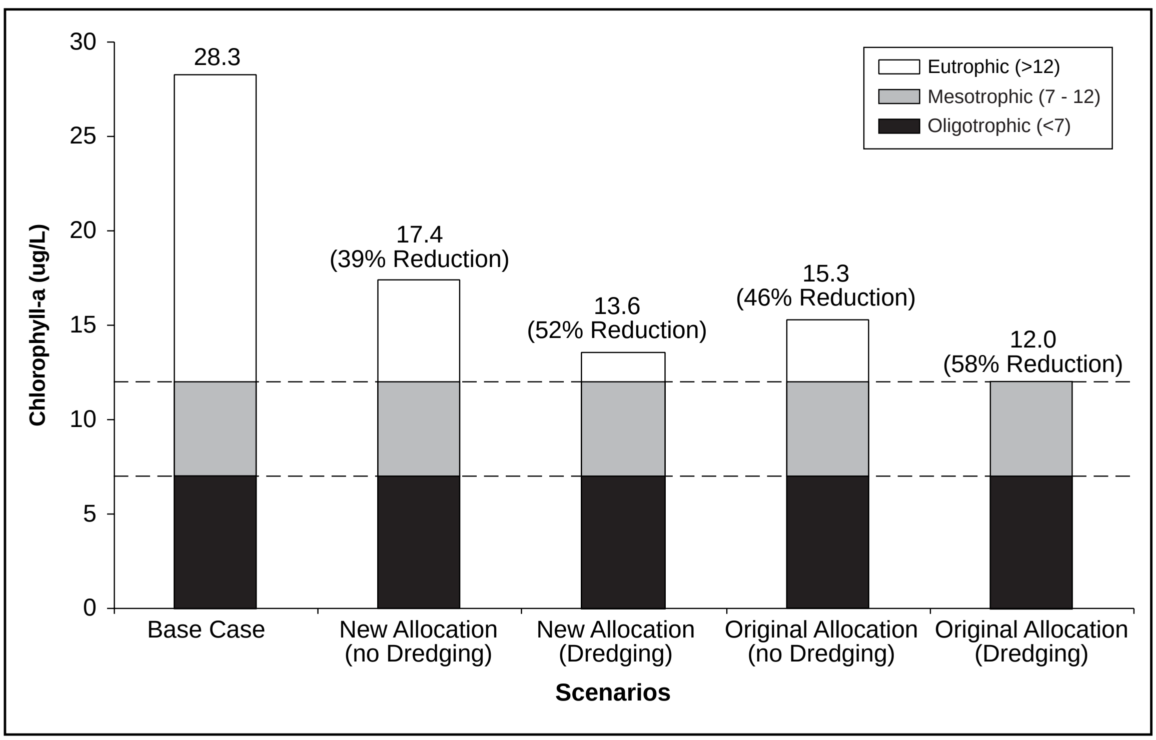


Figure ES-5. Existing scenarios of remedial actions on chlorophyll-a concentrations in Rainbow Lake.

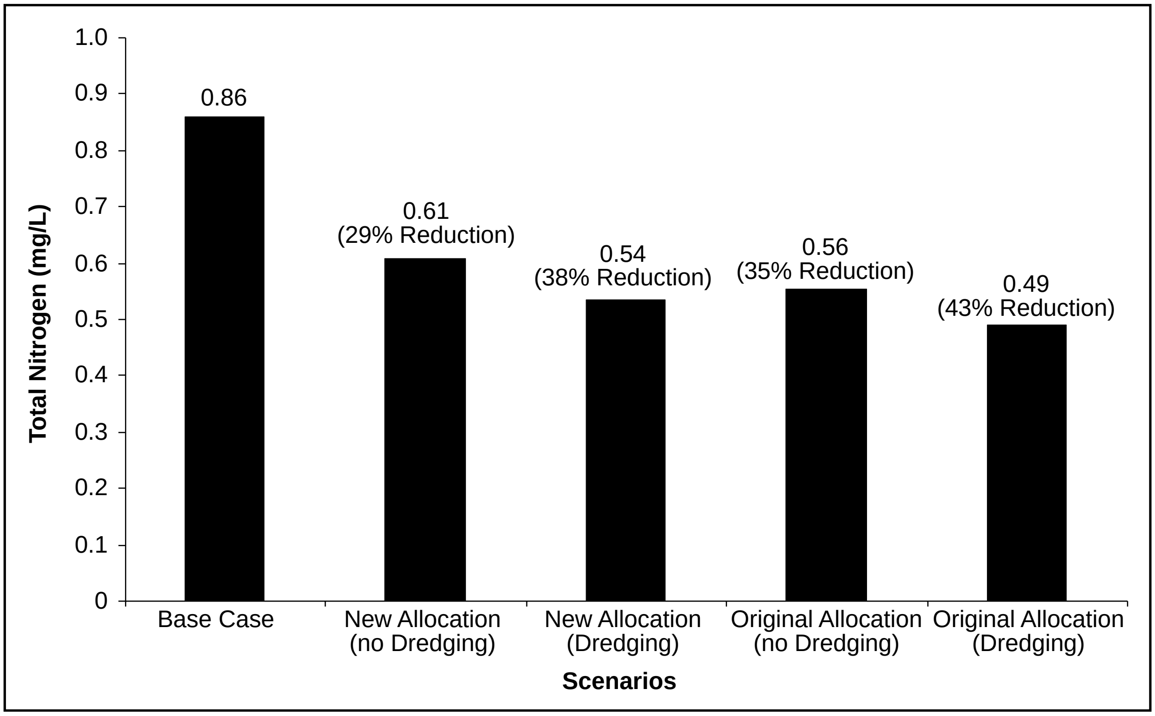


Figure ES-6. Effects scenarios of remedial actions on total nitrogen concentrations in Rainbow Lake. (NOTE: the lake is co-limited by nitrogen and phosphorus)

The Trophic Classification Thresholds below are based on Brezonick, (1982), a multivariate TSI using Florida data. Because this scheme incorporates nitrogen, ADEQ plans to develop state-specific regression formulas to refine this index for Arizona lakes; many lakes exhibit seasonal variations or regional patterns in nutrient limitation.

*TSI	Trophic State	Chlor-a (ug/L)	SD (m)	Total P (ug/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"

TMDL Margin of Safety

TMDLs must include a Margin of Safety that assures water quality standards will be met. The following list of factors that were included in the technical analysis comprise the Margin of Safety for the Rainbow Lake TMDL:

- The watershed loading model (GWLF) evaluated loadings over a long period of time that included a wide range of climatic, precipitation, and flow patterns. The analysis included extreme high and low flow events over the period of record providing boundaries for the assessment.

- The in-lake process analysis did not include the effect of shading by macrophytes on algal production in the lake.

In the nutrient budget calculations the project team assumed high macrophyte densities for the nutrient release flux from macrophyte decomposition.

Implementation Options

Septic: The septic allocation is confounded by inconsistent information on the number of septic systems remaining in use in the Rainbow Lake area. Therefore, the first step for implementation for the septic allocation is to conduct a survey to determine the number of remaining systems that are in use and the extent to which unused systems are continuing to leach. The community could then consider the benefits of mitigating unused systems and active systems that are not functioning properly. If there are a large number of active systems the community could consider extending sewer lines to unserviced areas near the lake.

Residential: Residential nutrients loads are a result of increased impervious surface and soil amendments (e.g., fertilizers for lawns) used by residents, among other materials associated with development. There are many voluntary BMPs that could be used to reduce runoff from residential areas and other development. ADEQ's Nonpoint Source program can be consulted for specific techniques and potential sources of funding for BMP implementation. The 50% reduction targeted by this allocation is not an unrealistic goal for a well conceived program of BMPs for the Pinetop community.

Dredging: Dredging addresses the sediment release source category by removing the nutrient rich layers of soil that have been deposited on the lake bottom. The dredging goal would remove the top meter of sediments that have accumulated most of the nutrients (Baker and Farnworth 1995). The soils below the accumulated sediments also contain nutrients. Therefore, it is not possible to remove 100% of the nutrients released from the sediments. Dredging would also improve water quality conditions by increasing the depth of the lake limiting the reemergence of macrophytes in certain portions of the lake. Dredging would also increase the storage capacity of the reservoir. The feasibility of dredging is discussed in detail Baker and Farnsworth 1995.

Macrophyte Harvest: Macrophyte decomposition is addressed both through dredging and macrophyte harvesting. Macrophytes would be largely eliminated by any dredging operation, but only temporarily. Macrophytes are known to thrive even in oligotrophic conditions. Macrophytes will re-colonize Rainbow Lake within a short period time after dredging has been completed. The well-established macrophyte harvest program should address this allocation requirement. There are other management options that can be considered other than mowing. Biological control of macrophytes is a potential alternative.

Other Best Management Practices: This implementation option does not directly address any of the source category allocations. However, Best Management Practices that would help maintain higher levels of water in the lake could significantly contribute to improved water quality. These BMPs would be directed to improving the efficiency of irrigation water that is drawn from the lake, possibly reducing the total amount of water that would need to be taken from the lake. In addition, lining irrigation canals from the lake would reduce seepage losses. The increased volume would serve to dilute the remaining nutrients thus reducing overall algal productivity. The emergence of macrophytes on exposed lakebed would also be slowed.

Watershed Forum: Rainbow Lake provides different beneficial uses to a wide range residents within the Pinetop community and surrounding areas. Many of the implementation recommendations will require local support and initiative. The local community may want to consider forming a watershed forum to build support for the nonpoint source BMPs that will be necessary to improve water quality in Rainbow Lake. A watershed forum would provide residents with a mechanism for coordinating activities to design, pursue funding for, and apply solutions to water quality problems within the Rainbow Lake watershed. ADEQ has a watershed approach program that could provide general assistance to the forum upon request from the local community.

Monitoring

ADEQ, the local community, and other cooperating agencies should consider initiating a monitoring program for Rainbow Lake to assess whether the overall objectives of this TMDL study are being met (i.e., no violations of narrative nutrient and numeric pH water quality standards).

Currently, Rainbow Lake is classified as being a eutrophic water body. Ideally, this TMDL would recommend methodologies that would improve the trophic status of the lake and result in Rainbow Lake being reclassified as mesotrophic. However, model predictions indicate that this level of improvement is most likely unattainable. This does not mean, however, that the water quality of the lake cannot be improved. As mentioned in section 3.5, Rainbow Lake's eutrophic status can be improved by degrees. This improvement can be achieved via the various management procedures that have been discussed above. With this in mind, the specific objective of this monitoring program is to assess whether the management procedures are achieving their stated objectives and improving the water quality of Rainbow Lake.

There is a crucial need for a monitoring program for the parameters that have are identified as water quality indicators within this TMDL study. ADEQ, the local community, and other cooperating agencies must have a monitoring program in place because of key uncertainties that could exist in estimating pollutant loading and in predicted lake response. The TMDL management activities that are undertaken to achieve allocations, guided by responses measured through a monitoring program

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1.0 BACKGROUND AND PROBLEM STATEMENT

1.1 Description of TMDL Process

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 fix water quality problems. The purpose of this TMDL study is to provide the local community, ADEQ, and U.S. EPA Region 9 with technical information that can be used to develop a water quality plan.

Section 303(d) of the Clean Water Act (CWA) requires states to identify the waters for which the effluent limitations required under the National Permit Discharge Elimination System (NPDES) or any other enforceable limits are not stringent enough to meet any water quality standard adopted for such waters. The states must also rank these impaired water bodies by priority, taking into account the severity of the pollution and the uses to be made of the waters. Lists of prioritized impaired water bodies are known as the "303(d) lists" and must be submitted to EPA every two years.

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. 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 also accounts for natural background sources and provides a margin of safety. For nonpoint sources such as accelerated erosion it may not be feasible or useful to derive a pounds per day figure. In such cases, a percent reduction in pollutant discharge may be proposed.

TMDLs must include specific information to be approved by U.S. EPA Region 9. This information can be summarized in the following 8 elements:

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

2. **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.

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

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

5. **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?

6. **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.

7. **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.

8. **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.

1.2 Arizona's 303(d) Process

ADEQ has recently developed a four-step approach to eliminating water quality impairment through its 303(d) Process. After a waterbody is listed, further monitoring is initiated to validate the original listing and determine probable sources of the stressors causing the listing. This monitoring step was added because waters have been listed based on nominal data and information. ADEQ has very limited resources for surface water monitoring, assessments, and completing TMDLs; therefore, every year two watersheds will be focused on in a cycle, so that within five years all 10 watersheds will have been included.

Steps in Arizona's Revised 303(d) Process

1. List waterbodies based on listing criteria.
2. If the waterbody is in an active watershed management unit, validate stressor.
3. If valid stressor:
   - Complete a TMDL (loading capacity model); or
   - Bring the waterbody into compliance with standards (i.e., utilize permit process; utilize enforcement/compliance process; utilize remediation process; change standards or designated uses).
4. Delist waters when waters are in compliance with standards or approved TMDL is completed.

If additional data or closer examinations of existing data show that the water quality is impaired, then the most appropriate action to bring this waterbody back into compliance with its standard is pursued. Normally, this action would include completing a Total Maximum Daily Load analysis for the drainage basin.

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 waterbody into compliance, but are based on existing uses and natural conditions.

Rainbow Lake is included on Arizona's 1998 Water Quality Limited Waters List (303(d) List) for two stressors: narrative nutrient and numeric pH water quality standards. Rainbow Lake was listed in 1994 as a result of 1992/93 sampling data collected by the ADEQ Clean Lakes Program.

1.3 Watershed

1.3.1 Overview

Rainbow Lake is a man-made impoundment on Walnut Creek in the Pinetop-Lakeside area of Navajo County, Arizona. The lake, which is classified as eutrophic, and Walnut Creek are part of the Silver Creek subwatershed which is located in the Little Colorado watershed. The Rainbow Lake watershed has an area of 5,357 acres (US EPA, 1977) (Figure 1-1). Rainbow Lake has a surface area of 116 acres and a storage volume of 800.2 acre-feet. The lake has a mean depth of 6.9 feet and a maximum depth of 14 feet. The lake has a residence time of approximately 139 days.

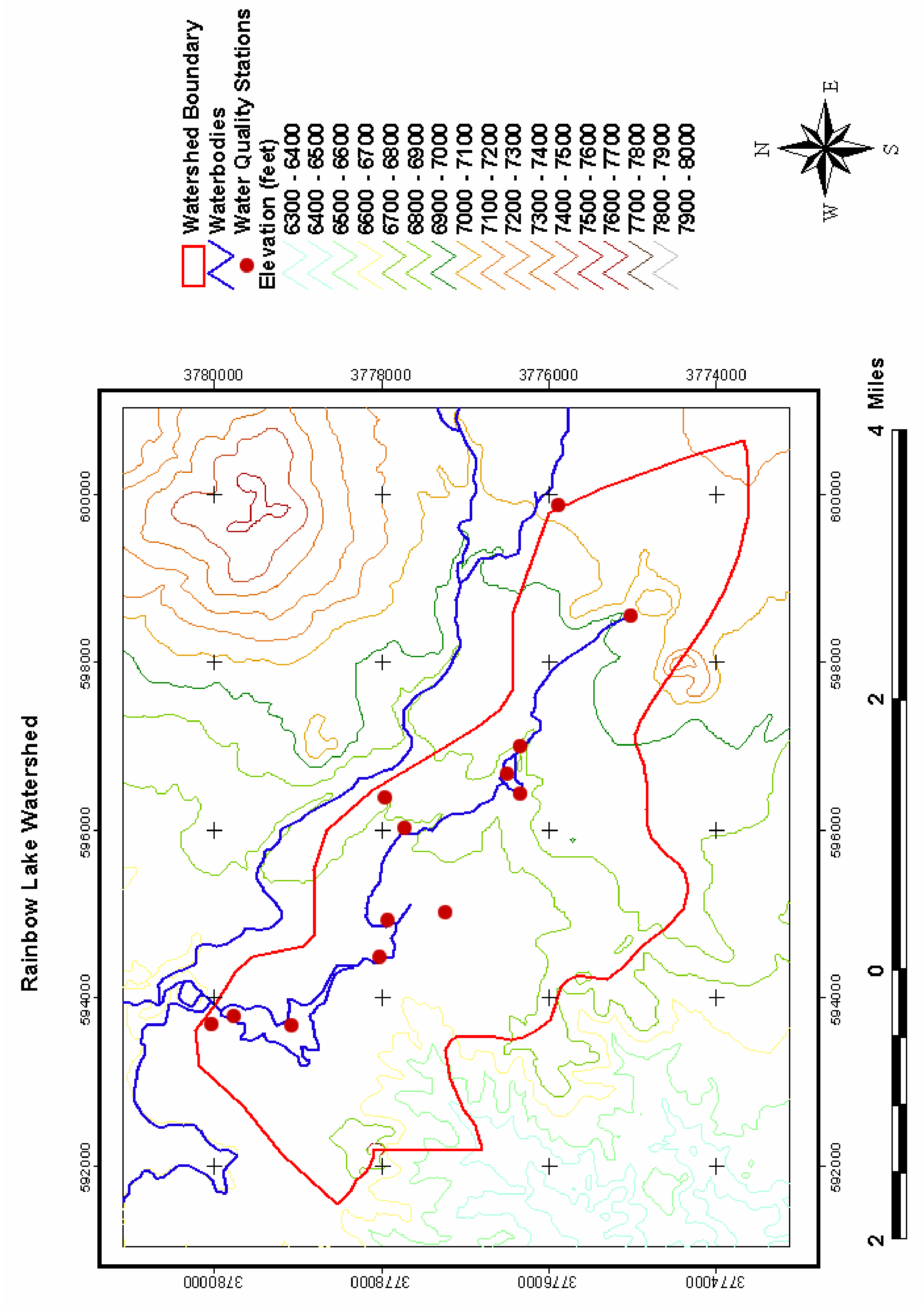

Figure 1-1. Rainbow Lake watershed.

Rainbow Lake is designated for the following uses under Title 18, Chapter 11 of the Arizona Administrative Code:

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1.3.2 Hydrology

The Little Colorado River Basin and the Walnut Creek Basins are the major and minor basins in which Rainbow Lake is found, respectively. The Walnut Creek Basin, which contains Rainbow Lake, has an area of about 5,357 acres (2,168 hectares). The major tributary to Rainbow Lake is Walnut Creek. Walnut Creek receives flows from two primary springs, Adair Spring and Big Spring, and a diversion from Billy Creek. Two other small impoundments, Woodland Reservoir and Pine Lake, are located upstream of Rainbow Lake on Walnut Creek. Rainbow Lake and Walnut Creek are part of the Silver Creek Sub-Watershed (Hydrologic Unit Code 15020005).

Precipitation in the vicinity of Rainbow Lake averages 22.56 inches per year, ranging from a low of 13.72 inches observed in 1996 to a high of 30.69 inches measured in 1992 (WRCC 1999). The highest precipitation occurs from July through August, while the driest months are April through June. The total annual evaporation at Rainbow Lake is approximately 45 inches (NOAA 1982).

The annual ambient air temperature is 49.2 ^{o}F (9.6 ^{o}C), varying from an average monthly temperature of 32.8 ^{o}F (0.4 ^{o}C) in January to an average of 67.2 ^{o}F (19.6 ^{o}C) in July (WRCC 1999). The maximum ambient air temperature does not exceed 32 ^{o}F (0 ^{o}C) an average of 6.6 days per year, while the minimum temperature reaches freezing an average of 171 days per year (WRCC 1999).

The water budget for Rainbow Lake was first established in1977 by the EPA. However, the evaporation rate that was calculated for this study was reported by Baker and Farnsworth (1995) to be greater than an order of magnitude larger than those reported by Linsley et al., 1982) for other lakes in the region. This prompted Baker and Farnsworth to recalculate the water budget for Rainbow Lake. Baker and Farnsworth (1995) reported the following for Rainbow Lake:

- Average of daily inflows of water provided to Rainbow Lake by Walnut Creek was approximately 2,351 acre-feet/year (based on average annual flow measurements);

- Average of daily of inflows of water provided to Rainbow Lake by Walnut Creek was approximately 2513 acre-feet/year (based on calculations);

- Mean annual precipitation at Rainbow Lake between 1944 and 1998 was 24”/year and ranged from 13.6 – 37.6”;

- Natural runoff was estimated to be 2108 acre-feet/year;

- Irrigation return flows (from three irrigation companies in the area: Lakeside Irrigation Co., Pinetop-Woodland Irrigation Co., and Woodland Irrigation Co.) were estimated to be 124 acre-feet/year;

- Irrigation withdrawals by the three local irrigation companies was estimated to be 300 acre-feet/year;

- Seepage from Rainbow Lake was estimated to be 396 acre-feet/year;

- Lake area and volume was estimated to be approximately 32 hectares and, based on an average depth of 13.5 feet, the lake volume was calculated to be 623 acre-feet;

- Lake evaporation rates of 3.8 feet/year, or a total of 300 acre-feet/year for the entire lake;

- Outflow from Rainbow Lake = 1,216 acre-feet/year; and

- The outflow residence time for Rainbow Lake was approximately 139 days

Baker and Farnsworth (1995) point out that the last point is significant because the “response time” of a lake to changes in nutrient inputs is directly related to the water loading rate. They point out that when compared to other lakes, Rainbow Lake is rapidly flushed and should recover fairly quickly from past contamination.

1.3.3 Physiographic Characteristics

Elevations in the Walnut Creek Basin range from 7,385 feet at Pinetop Mountain to 6,706 feet at Rainbow Lake (USGS, 1976). The entire basin upstream of Rainbow Lake lies within the Arizona/New Mexico Mountains ecoregion (Figure 1-2) (Omerick 1987, 1995).

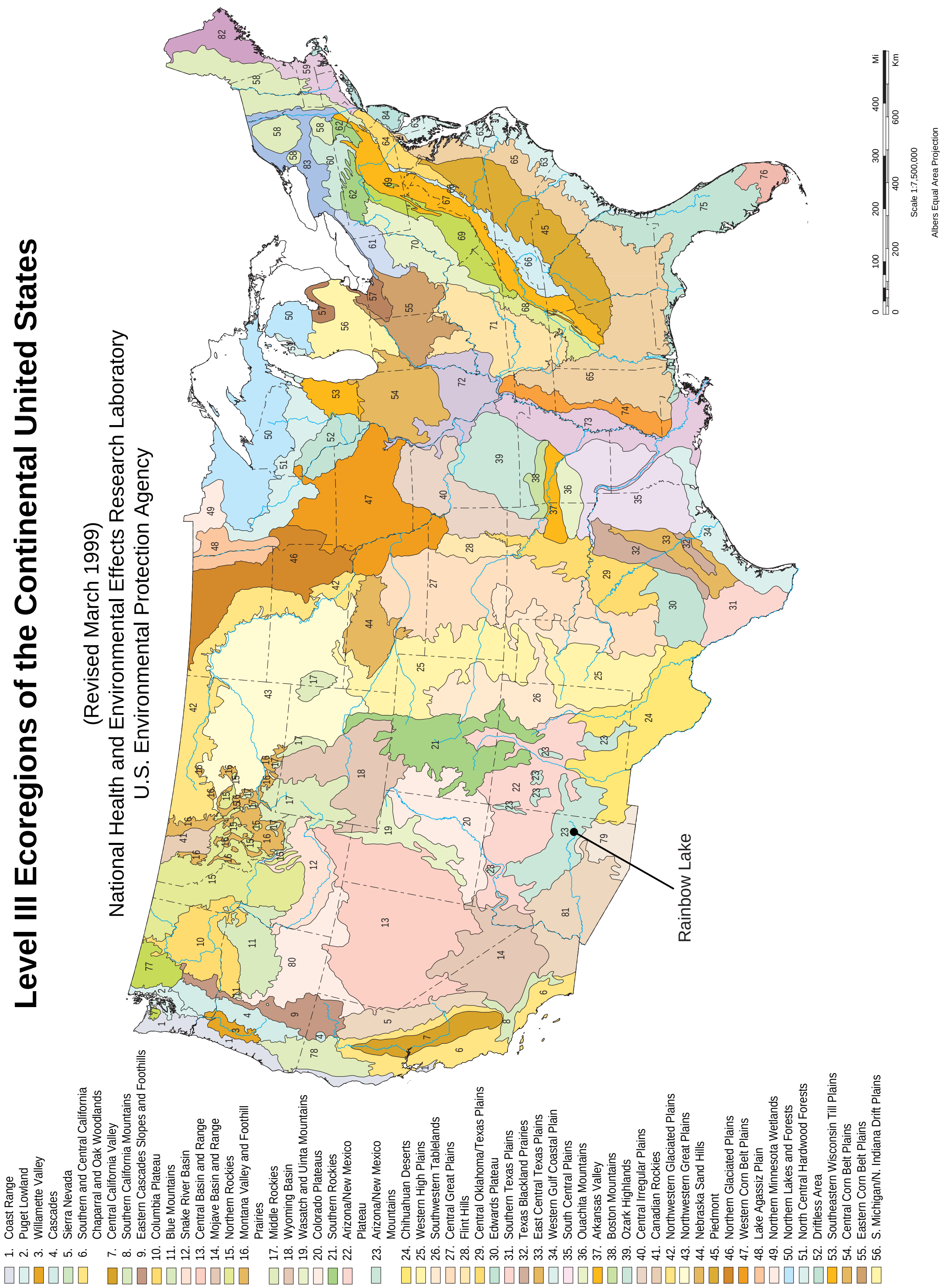


Figure 1-2. Level III Ecoregions of the Continental United States.

ECOREGIONS

The ecoregions shown here have been derived from Omernik (1987) and from refinements of Omernik's framework that have been made for other projects. These ongoing or recently completed projects, conducted in collaboration with the U.S. EPA regional offices, state resource management agencies, and with other federal agencies, involve refining ecoregions, defining subregions, and locating sets of reference sites. Designed to serve as a spatial framework for environmental resource management, ecoregions denote areas within which ecosystems (and the type, quality, and quantity of environmental resources) are generally similar. The most immediate needs are to develop regional biological criteria and water quality standards and to set management goals for nonpoint source pollution.

The approach used to compile this map is based on the premise that ecological regions can be identified through the analysis of the patterns and the composition of biotic and abiotic phenomena that affect or reflect differences in ecosystem quality and integrity (Wiken 1986; Omernik 1987, 1995). These phenomena include geology, physiography, vegetation, climate, soils, land use, wildlife, and hydrology. The relative importance of each characteristic varies from one ecological region to another regardless of the hierarchical level. Because of possible confusion with other meanings of terms for different levels of ecological regions, a Roman numeral classification scheme has been adopted for this effort. Level I is the coarsest level, dividing North America into 15 ecological regions, whereas at Level II the continent is subdivided into 52 classes (CEC 1997). Level III is the hierarchical level shown on this map. For portions of the United States (see map inset) the ecoregions have been further subdivided to Level IV. The applications of the ecoregions are explained in Gallant et al. (1989) and in reports and publications from the state and regional projects. For additional information, contact James M. Omernik, U.S. EPA National Health and Environmental Effects Laboratory (NHEERL), 200 SW 35th Street, Corvallis, OR 97333 (phone: 541-754-4458).

The exposed geologic formations of the Walnut Creek Basin upstream of Rainbow Lake are primarily composed of Quaternary and Tertiary volcanics. The oldest of the geologic formations is the Coconino Sandstone which is overlain by Kaibab Limestone. Sedimentary rocks of Upper Cretaceous age composed of sandstones, shales and limestones occur above the Kaibab Limestone. These Upper Cretaceous Sedimentary rocks are generally overlain by Quaternary basalt composed of fractured basalt flows, cinder cones, and beds (ADHS 1985).

The Coconino Sandstone and Kaibab Limestone form one aquifer which is the deepest source of water in the area. The Upper Cretaceous sedimentary rocks and Quaternary basalt form a second aquifer when they are separated from the Coconino Sandstone aquifer by the low permeability Moenkopi and Chinle Formations or the shale beds in the Upper Cretaceous sedimentary rocks. Where these low-permeable beds are absent, the Pinetop-Lakeside aquifer is generally dry (ADEQ, 1996). Eighty to ninety percent of the groundwater pumped from the Pinetop-Lakeside aquifer is from the basalt (Mann, 1976). Water infiltrates relatively quickly down through the cracks, fissures, and fractures in the basalts of this aquifer. Where this aquifer is underlain by the less permeable Moenkopi Formation, downward movement of infiltrating waters may be impeded. This water may then flow along the base of the aquifer until it either percolates further downward through the underlying strata or is discharged to the stream system as seeps and springs (ADWR, 1990). Depth to water in the Pinetop-Lakeside aquifer is generally from 49 to 151 feet.

Groundwater flow velocity may vary from no flow to many cubic feet per day, depending on the number of fractures, quantity of cinders, etc., in the basalt (ADHS, 1985).

The soils of the Rainbow Lake area have been generally typified by the U.S. Department of Agriculture (USDA) as Argiboralla-Cryoborolls-Ustorthents or moderately deep to deep, loamy sloping to steep soils of the mountains (USDA, 1981).

Soil erosion rates in the Rainbow Lake Basin have been classified as being less than 0.2 acre-feet per year (USDA, 1981). Additionally, the USDA reports that this watershed area is within an area of no external drainage and therefore contributes little or no stream flow to the Little Colorado River. Contribution of the Walnut Creek Basin to sedimentation and sediment loads downstream of the Lakeside Dam is considered minimal.

1.3.4 Vegetation

Forested lands comprise approximately 50 percent of the land cover of the Rainbow Lake watershed (Figure 1-3, Table 1-1). The forests are predominantly evergreen forests with some mixed deciduous/evergreen forests. Agricultural lands comprise approximately 3 percent of the watershed area and mixed rangelands comprise less than 1 percent. Approximately 2 percent of the watershed is comprised of barren land (BASINS2 U.S. EPA 1998).

1.3.5 Land Use

Urban or other built-up land comprise approximately 42 percent of the watershed and are found predominantly along the central portion of the watershed (Figure 1-3, Table 1-1 same as in Section 1.3.4). Land uses in the watershed include recreation, grazing and small plots of irrigated agriculture (ADEQ 1997). Grazing, residential areas, and irrigated agricultural are possible sources of nutrients.

1.4 Existing Conditions and Summary of Monitoring Data

Data from water quality sampling stations (Figure 1-1) within the Rainbow Lake watershed were obtained from various sources including, previously published reports (Baker and Farnsworth, 1995; U.S. EPA, 1977); unpublished data from the Arizona Department of Environmental Quality and the Arizona Department of Game and Fish; and from BASINS2 (U.S. EPA, 1998). These data are summarized in Tables 1-2, 1-3, and 1-4.

These data indicate that at all sites upstream of Rainbow Lake, in Rainbow Lake, and downstream of Rainbow Lake had measurable concentrations of nutrients (nitrogen and phosphorus) and chlorophyll-a. General water quality parameters are presented for those constituents that have been measured. These data are discussed in the following sections.

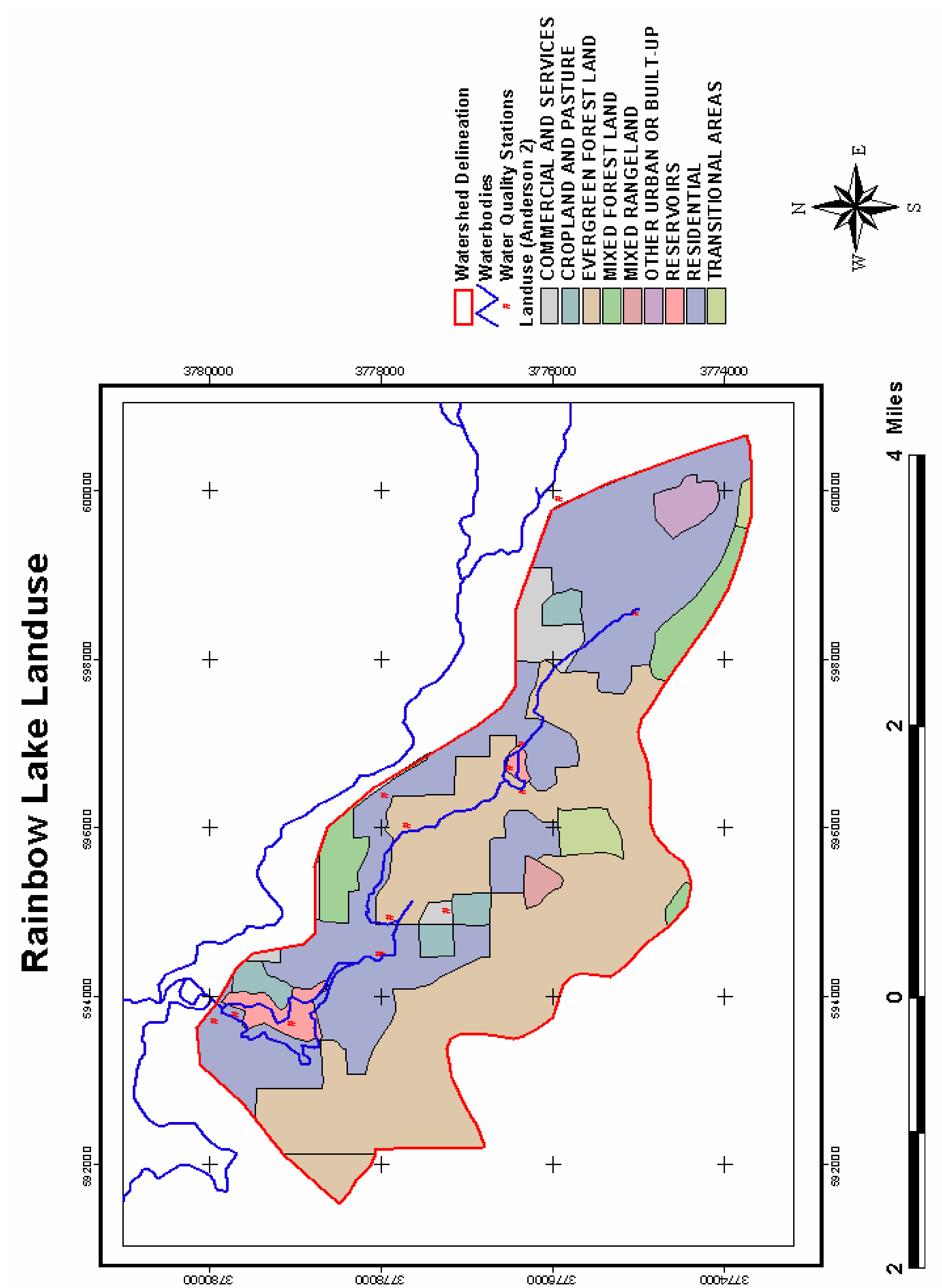


Figure 1-3. Rainbow Lake landuse.

Table 1-1
Rainbow Lake Detailed Land Use Distribution

Land Use Name and Code	Area (acres)	% of Total Area
Urban or Built-Up Land		
Residential	2,312	43.2%
Commercial and Services	281	5.3%
Subtotal	2,593	48.5%
Agricultural Land		
Subtotal	177	3.3%
Forest Land		
Subtotal	2,429	45.3%
Range Land		
Subtotal	44	0.8%
Barren Land		
Subtotal	114	2.1%
Total	5,357	100%

Nutrients - All of the sites within the Rainbow Lake watershed had detectable concentrations of nutrients (nitrogen and phosphorus). Nutrients are of particular concern in this and all watersheds and become problematic when their influence becomes detrimental. They can directly influence the health of a waterbody and can be responsible for other non-desired effects (e.g., algal and macrophyte blooms, odor, pH, dissolved oxygen concentrations, and fish kills).

Nutrient limitation (nitrogen or phosphorous) may be affected when large populations of heterocystis algae are present. These algae (blue-greens) can fix nitrogen from the atmosphere even when nitrogen is limited in the water column.

Concentrations of nitrogen and phosphorus measured in the watershed between 1992 and 1993 tended to be slightly higher in Rainbow Lake than in either the upstream or downstream sites (Table 1-2). Total ammonia, nitrate/nitrite, Kjeldahl nitrogen, and total phosphorus concentrations ranged from <0.03 to 0.36, <0.01 to 0.51, 0.13 to 1.82, and 0.012 to 0.202 mg/L, respectively. Rainbow Lake sediments contained the largest concentrations of nutrients, with total ammonia, nitrate/nitrite, Kjeldahl nitrogen, and total phosphorus concentrations ranging from 19 to 358, 2.7 to 230, 358 to 6820, and 68.7 to 487 mg/L, respectively.

Table 1-2
Nutrient Concentrations in the Rainbow Lake Watershed

Site	Parameter (Mean and Range)			
	NH_3-N (mg/L)	$NO_3 + NO_2$ (mg-N/L)	Total Kjeldahl N (mg-N/L)	Total Phosphorus (mg-P/L)
Pine Lake	0.10 (0.07 – 0.11)	<0.02 (<0.01 – 0.03)	0.74 (0.47 – 0.99)	0.10 (0.046 – 0.202)
Woodland Reservoir (inflow)	0.04 (n = 1)	0.17 (n = 1)	0.39 (n = 10)	0.12 (n = 1)
Woodland Reservoir	<0.05 (<0.03 – 0.1)	<0.02 (<0.01 – 0.03)	0.6 (0.32 – 0.86)	0.051 (0.012 – 0.143)
Walnut Creek above Adair Springs	<0.04 (<0.03 – 0.05)	0.16 (0.08 – 0.31)	0.51 (0.13 – 0.82)	0.07 (0.043 – 0.127)
Adair Springs	<0.06 (<0.03 – 0.16)	N/A	0.4 (0.2 – 0.76)	0.10 (0.083 – 0.13)
Big Springs	<0.09 (<0.03 – 0.25)	0.16 (0.06 – 0.38)	0.59 (0.43 – 0.81)	0.07 (0.049 – 0.086)
Walnut Creek upstream of Rainbow Lake	<0.14 (<0.03 – 0.36)	0.29 (0.15 – 0.51)	0.7 (0.24 – 1.44)	0.09 (0.055 – 0.125)
Rainbow Lake				
Dam	0.16 (n = 1)	0.07 (n = 1)	122 (n = 1)	0.32 (n = 1)
LCRAI-A	<0.13 (<0.03 – 0.2)	<0.05 (<0.01 – 0.11)	0.79 (0.58 – 1.22)	0.11 (0.03 – 0.32)
LCRAI-B	<0.14 (<0.03 – 0.35)	<0.05 (<0.01 – 0.16)	0.75 (0.51 – 0.89)	0.06 (0.032 – 0.151)
LCRAI-C	<0.08 (<0.03 – 0.16)	<0.04 (<0.01 – 0.08)	0.9 (0.46 – 1.82)	0.08 (0.02 – 0.18)
Outfall	0.28 (n = 1)	0.03 (n = 1)	0.94 (n = 1)	0.06 (n = 1)
Sediments (RL-S1)	86.4 (19 – 223)	20 (2.7 – 68)	2082 (358 – 4500)	214 (81.3 – 487)
Sediments (RL-S2)	223 (47 – 358)	62 (4.53 – 230)	4348 (3290 – 6820)	255 (68.7 – 453)
Walnut Creek downstream of Rainbow Lake	0.09 (<0.03 – 0.15)	0.05 (<0.01 – 0.11)	0.88 (0.61 – 1.2)	0.08 (0.033 – 0.123)
Pinetop Springs	<0.09 (<0.03 – 0.2)	0.13 (0.05 – 0.23)	0.3 (0.25 – 0.36)	0.08 (0.026 – 0.121)
Billy Creek (City Yard Pond)	0.12 (<0.03 – 0.33)	0.13 (0.05 – 0.23)	0.5 (0.38 – 0.56)	0.07 (0.033 – 0.135)
Billy Creek (Diversion)	0.2 (0.1 – 0.2)	0.08 (0.07 – 0.09)	0.46 (0.45 – 0.47)	0.04 (0.017 – 0.055)

N/A = Data not available.

Table 1-3
Chlorophyll-a Concentrations in the Rainbow Lake Watershed

Site	Secchi Depth (m) (Mean, Range)	Chlorophyll-a (μg/L) (Mean, Range)
Pine Lake	N/A	1.9 (0.92 – 2.88)
Woodland Reservoir (inflow)	N/A	N/A
Woodland Reservoir	3.2 (n = 1)	0.4 (0.19 – 0.53)
Walnut Creek above Adair Springs	N/A	1.5 (0.14 – 2.69)
Adair Springs	N/A	0.9 (0.47 – 1.25)
Big Springs	N/A	1.3 (1.07 – 1.5)
Walnut Creek upstream of Rainbow Lake	N/A	3.6 (2.37 – 4.41)
Rainbow Lake		
Dam	N/A	N/A
LCRAI-A	1.5 (0.45 – 2.1)	3.1 (1.04 – 5.91)
LCRAI-B	1.6 (0.45 – 2.3)	3.6 (1.22 – 5.98)
LCRAI-C	2.1 (0.45 – 3.1)	1.5 (1.13 – 2.28)
Outfall	N/A	N/A
Walnut Creek downstream of Rainbow Lake	N/A	5.9 (4.41 – 8.87)
Pinetop Springs	N/A	0.1 (0.06 – 0.15)
Billy Creek (City Yard Pond)	N/A	0.18 (n = 1)
Billy Creek (Diversion)	N/A	0.6 (0.54 – 0.75)

N/A = Data not available.

Chlorophyll-a - Chlorophyll-a is a direct measure of the concentration of algae in the water column. The algal concentration is directly affected by two primary water quality parameters (turbidity (clarity) and nutrient concentration). The data collected between 1992 and 1993 (Table 1-3) indicate that these two parameters were present in sufficient quantities to allow for measurable concentrations of chlorophyll-a to be present throughout the watershed. The greatest concentrations of chlorophyll-a were found in Rainbow Lake and in Walnut Creek directly downstream from the Lake and ranged from 1.04 to 5.98 and 4.41 to 8.87 ug/L, respectively. The secchi-depth, which measures water clarity, and thus the amount of sunlight that can penetrate the water column, averaged 5.7 feet (1.7 meters) and ranged from 1.5 feet (0.45 meters) to 10.2 feet (3.1 meters).

General Water Quality Parameters - The general water quality parameters provide a measure of the overall water quality. These parameters include pH, dissolved oxygen (DO), turbidity, alkalinity, total dissolved solids (TDS), total suspended solids (TSS), carbonate and bicarbonate. Many of these parameters are affected by the presence or absence of other water quality parameters (e.g., pH and DO are affected by the presence of algae). The data collected from the Rainbow Creek watershed between 1992 and 1993 (Table 1-4) indicate that the pH and dissolved oxygen concentrations have been problematic (i.e., pH values > 9.0 SU and DO values < 7.0 mg/L).

1.5 Identification of Violated Water Quality Standards and Impaired Designated Uses

Water quality standards are commonly expressed as either numeric (a specific concentration which cannot be exceeded) or narrative (used to describe a condition that is not desired). Arizona uses both types of water quality standards for Rainbow Lake. Rainbow Lake is listed on Arizona's 1998 303(d) list as impaired due to violations of narrative nutrient standards and numeric pH standards. Dissolved oxygen is not currently a major problem in Rainbow Lake. Its shallow depth prevents significant stratification, although low DO concentrations have been measured near the bottom during some periods.

pH and dissolved oxygen are stated as numeric standards, with nutrient concentrations having narrative standards. The water quality standards for these parameters (Title 18, Chapter 11 Arizona Administrative Code) are as follows:

- pH shall be between 4.5 and 9.0 SUs; The critical low pH for Aquatic and Wildlife is 6.5 SU;

- Dissolved oxygen shall not be lower than 7.0 mg/L between the surface and one meter depth, and the minimum dissolved oxygen saturation is 90%; and

- Nutrient concentrations shall not cause growth of algae or aquatic plants or settling of bottom deposits that inhibit or prohibit the habitation, growth, or propagation of other aquatic life or that impair recreational uses. Nutrient concentrations shall not change the color of the surface water from natural background levels of color.

Based on these water quality standards, pH standards for Rainbow Lake were violated in 82 out of 148 samples (55%) between 1983 and 1993. Dissolved oxygen concentration standards in the upper one meter water depth were violated in 4 out of 77 samples (5%) during the same time period. Rainbow Lake has been classified as slightly eutrophic and, as such, nutrient concentrations in Rainbow Lake may have been violated during this time period.

pH and dissolved oxygen are easily measurable water quality parameters and numeric water quality standards aid in determining whether violations are occurring. Rainbow Lake has been listed as impaired because of high pH concentrations in the water column. However, before pH can be remedied, the causes of the high pH, and associated water quality standards violations, must be addressed.

A conceptual model showing the relationships between aquatic plants (macrophytes and phytoplankton), nutrients, pH, dissolved oxygen, and fish kills is presented in Figure 1-4. This figure breaks the process down into 8 steps:

1. Nutrients (nitrogen and phosphorus) are added to the system and made available to the aquatic plants via point sources, non-point sources, and/or in-lake processes;

2. Excess nutrient concentrations and light stimulate growth;

3. Plant growth consumes CO_2 from the water. This causes the pH to rise. The slope and magnitude of the pH rise is dependant on the plant biomass;

4. Once maximum growth has occurred, the plants begin to fragment or die:

   - Phytoplankton are either consumed by zooplankton or die and settle to the lake bottom where they decompose and produce ammonia, carbon dioxide, and phosphorus or do not decompose and become part of the refractory fraction and slowly release nitrogen and phosphorus. Zooplankton eventually die and produce ammonia, carbon dioxide, and phosphorus.

   - Macrophytes begin to fragment and die back. Decomposition produces ammonia, carbon dioxide, and phosphorus. Those that do not readily decompose settle into the sediments and form the refractory fraction.

   - Decomposition is oxygen consumptive and can deplete dissolved oxygen from the water column.

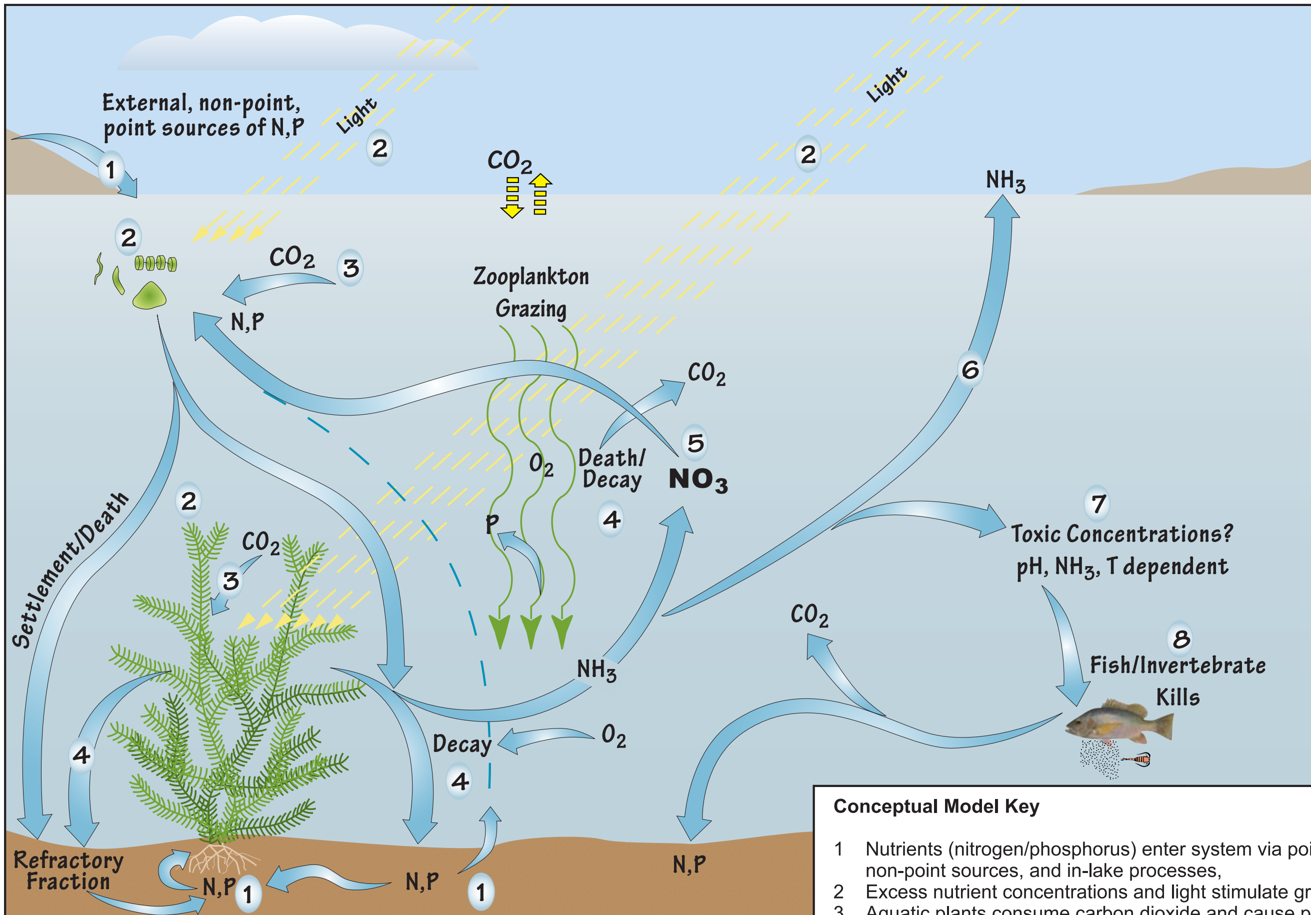


Figure 1-4. Conceptual model of the relationship between Macrophytes/Algae and nutrients, pH, and dissolved oxygen.

Conceptual Model Key

1. Nutrients (nitrogen/phosphorus) enter system via point sources, non-point sources, and in-lake processes,
2. Excess nutrient concentrations and light stimulate growth,
3. Aquatic plants consume carbon dioxide and cause pH to rise,
4. Aquatic plants fragment or die releasing ammonia, phosphorus, carbon dioxide, and consume oxygen into water column or sediments,
5. Ammonia undergoes nitrification to yield nitrate. Nitrate is recycled back into system,
6. Ammonia diffuses into atmosphere,
7. Ammonia can become toxic if pH and ammonia concentrations are high enough, and
8. High concentrations of unionized ammonia can cause fish and invertebrate kills and release ammonia into the water column and consume additional dissolved oxygen.

5. Ammonia undergoes nitrification to yield nitrate. This nitrate is recycled into the nutrient budget of the water column;

6. Some ammonia diffuses into the atmosphere;

7. Ammonia can become toxic if the pH and ammonia concentrations are high enough. As the pH increases, the concentration of toxic (unionized) ammonia increases logarithmically (Figure 1-5). Therefore, as the pH level rises, less total ammonia is required to produce the same amount of toxic unionized ammonia;

8. High concentrations of unionized ammonia can kill fish and invertebrates. Their decomposition adds ammonia, phosphorus, and carbon dioxide into the system dissolved oxygen and depletes dissolved oxygen concentrations.

This process can lead to impairment of beneficial uses by:

- Allowing for unrestricted algal and macrophyte growth;
- Increasing water column pH;
- Decreasing water column DO concentrations;
- Decreased DO and elevated pH concentrations can result in fish and invertebrate kills; and
- Producing foul odors.

1.6 Identification of Pollutants Being Addressed and Why

This TMDL addresses the nutrients phosphorus and nitrogen. Although nutrients are required for plant growth and a healthy ecosystem, excess nutrients can cause eutrophication, which is characterized by excessive plant growth (algal blooms), and in shallow lakes can result in the development of extensive macrophyte beds. This produces other water quality problems such as low dissolved oxygen, high turbidity, high pH values, and high concentrations of toxic unionized ammonia.

Excess nutrients in Rainbow Lake most likely account for excessive macrophyte growth and algal blooms in the Lake. Records from the Arizona Department of Game and Fish for the period 1987 to 1997 (J. Novy, ADG&F, personal communication) indicate that between 1982 and 1990, annual harvest of macrophytes from Rainbow Lake ranged between 174 and 789 tons (1.5 to 6.8 tons per acre). However, since 1991, no harvests have been conducted, with the exception of 1995 when 65 tons of macrophytes were removed.

High biomass in the lake and the in-lake effects that plants have on water chemistry may also contribute heavily to the adverse pH conditions which occur (USFWS, 1982). Fish kills have occurred in Rainbow Lake in recent decades, probably due more to the

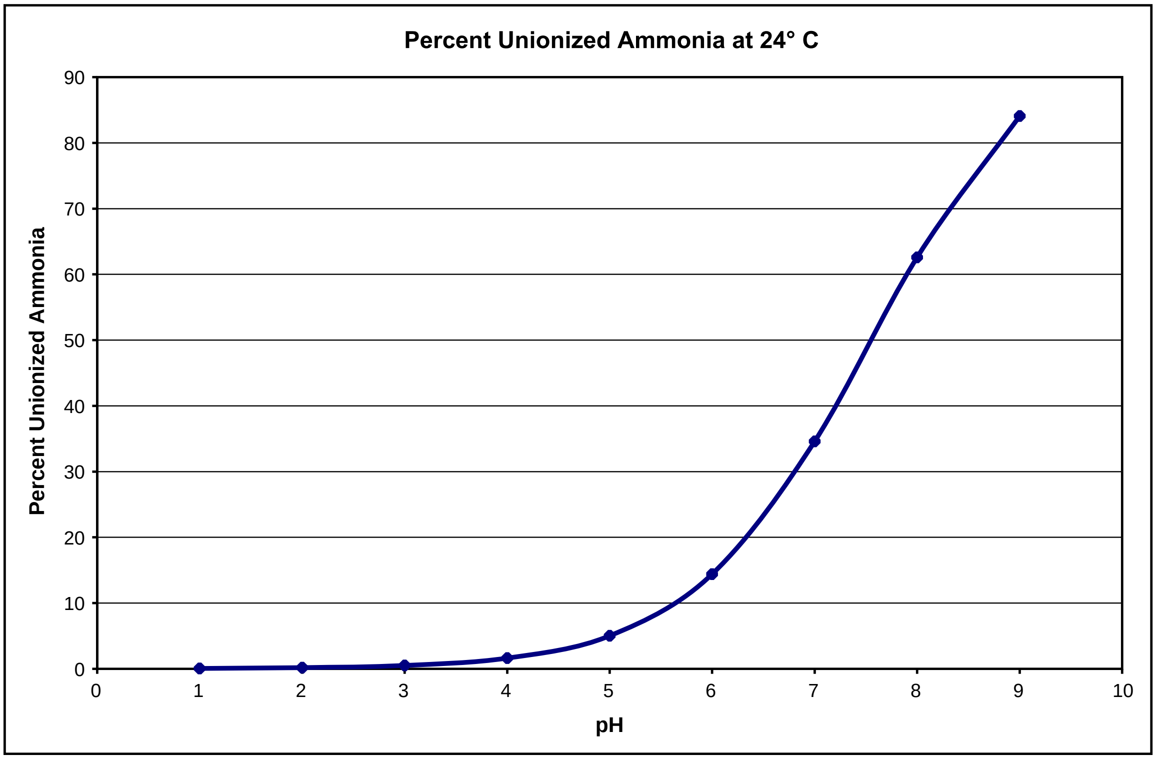


Figure 1-5. Relationship between pH and percent unionized ammonia at the maximum temperatures observed in Rainbow Lake.

presence of toxic concentrations of ammonia than to low dissolved oxygen (Baker and Farnsworth, 1995; Jim Novy (ADG&F) personal communication, 1999). The high pH and abundance of ammonia from decaying plant matter result in concentrations of unionized ammonia that are toxic to fish and invertebrates.

Previous studies (Baker and Farnsworth, 1995) indicate that lake sediments and decomposition of macrophytes are major sources of nutrients in Rainbow Lake, and are probably more important than external loadings. Therefore, this TMDL evaluates both nutrient inputs from sources within the watershed, and nutrient cycling within Rainbow Lake. Because macrophytes perpetuate the cycling of nutrients in the system, removal of plants to reach some target amount (e.g., biomass of plants) would directly reduce the impairment as well as remove nutrients from the system. In addition, because higher pH and lower dissolved oxygen values occur during periods of macrophyte and algal growth when they remove CO_2 from the water, controlling the growth of macrophytes and algae would result in lower pH and higher dissolved oxygen levels in the Lake.

2.0 NUMERIC TARGETS AND IN-LAKE INDICATORS

Previous sections have discussed the combined effects of the individual water quality parameters. This section will discuss the need to determine numeric targets and in-lake indicators that can be used to protect the beneficial uses of Rainbow Lake.

2.1 Numeric Targets

Possible water quality targets to control the noxious weed growth in Rainbow Lake could be expressed in terms of nutrient concentrations (e.g., mg/L of phosphorus and/or nitrogen) or macrophyte parameters (e.g., extent of growth, area of effect, biomass). The Water Quality Standards for these parameters in Title 18, Chapter 11 of the Arizona Administrative Code are as follows:

- pH, (A&Wc). The following water quality standards for pH, expressed in standard units (SUs) shall not be lower than 4.5 SU or greater than 9.0 SU (A.A.C. R18-11-109, paragraph D), the critical low pH for Aquatic and Wildlife is 6.5 SU;

- Dissolved oxygen, Aquatic and Wildlife, cold water fishery (A&Wc). The dissolved oxygen concentration in surface water shall not fall below 7.0 mg/L (A.A.C. r18-11-109, paragraph G), the minimum dissolved oxygen saturation is 90%. In the case of lakes, there is a further footnote in that: the dissolved oxygen water quality standard for a lake shall apply below the surface but not at a depth greater than 1 meter;

- Narrative Nutrients, (A.A.C. R18-11-109, paragraph A, Narrative Water quality Standards). This paragraph lists eight different impacts on surface waters that are considered the narrative standards for the state. The narrative water quality standards that are applicable to Rainbow Lake (R18-11-108-Narrative Water quality Standards):

A surface water shall be free from pollution 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;

- Change the color of the surface water from natural background levels of color.

2.2 Identification of In-lake Indicators

Indicators are parameters that can be easily measured and understood and that can be applied to a complex system to assess whether impairment is occurring. This section describes seven in-lake indicators that will be used to assess whether the beneficial uses of Rainbow Lake are being impaired. These indicators measure chemical, biological, and physical water quality parameters, each of which are described below.

pH: pH levels in Rainbow Lake have exceeded the stated water quality standards in 55% of the samples measured between 1983 and 1993. Elevated pH concentration is an indicator of eutrophic conditions with excessive aquatic plant growth. In addition, high pH levels increase the concentrations of toxic levels of ammonia in the water column causing toxic concentrations of ammonia to occur and lead to fish and invertebrate kills. This indicator will be used to assess whether the control measures have accomplished their stated goal of limiting the frequency and magnitude of high pH events that exceed the water quality standard for Rainbow Lake and lead to toxic concentrations of unionized ammonia.

The following is an important note regarding the pH standard for Rainbow Lake and its use as indicator for impairment. The high elevation of Rainbow Lake predisposes the lake to high pH events. The high elevation results in a low atmospheric partial pressure for carbon dioxide which leads to a low pCO_2 in the water column. Carbon dioxide is a key component of the carbonate / bicarbonate buffering system that controls the rate and magnitude of changes in aquatic pH. Even a normal level of plant photosynthesis (e.g., uptake of carbon dioxide) is likely to overwhelm the pH buffering capacity of the lake.

Dissolved Oxygen: Dissolved oxygen concentrations in Rainbow Lake provide an indication of whether the decomposition of plant matter is exceeding the oxygen capacity of the lake. Low dissolved oxygen concentrations, while not currently a problem in Rainbow Lake, can lead to anoxic conditions and subsequent fish and invertebrate kills.

Nutrient Concentrations: Concentrations of nitrogen and phosphorus are most likely the controlling factors of the in-lake processes that drive the pH exceedences and potential dissolved oxygen violations in Rainbow Lake. Elevated nutrient concentrations lead to excessive macrophyte and algal growth that result in increased pH and decreased dissolved oxygen.

Macrophytes: Since excessive levels of macrophytes have historically contributed to water quality impairment and interference with the designated beneficial uses of Rainbow Lake, and because they play an integral part of the process of recycling nutrients in the system, the water quality target for the TMDL could then be some appropriate measure of macrophyte growth (biomass, percent coverage, or another measure).

Phytoplankton (Free Floating Micro-algae): Macrophytes are not the only plant life that exists in Rainbow Lake. There are also free floating micro-algae (phytoplankton) present. Eutrophic conditions can lead to an overabundance of non-desirable phytoplankton species (cyanobacteria, or blue-green algae) that can cause foul odors and, in some cases, release substances in the water that are toxic to both aquatic life and humans. Phytoplankton can bloom uncontrollably resulting in elevated pH and ammonia levels, and decreased dissolved oxygen concentrations.

This indicator, like the macrophyte indicator, would provide information that would allow us to assess whether the narrative nutrient water quality standards are being met by the control measures. The measure of this indicator could be as simple as measuring the chlorophyll-a concentration in the water column and comparing the result to the standard used by ADEQ to assess the trophic level of the lake.

Ammonia Concentration: As mentioned previously, ammonia is produced during the decomposition of plant or organic matter. The concentration of unionized ammonia is pH and temperature sensitive and extremely toxic to aquatic organisms, especially the unionized form. Two by-products of unrestricted macrophyte and phytoplankton growth are increased pH and ammonia concentrations. These two conditions, when co-occurring, can be deadly to fish and aquatic invertebrates.

The sensitivity of aquatic organisms to unionized ammonia has been well covered in the toxicological literature and measured concentrations in Rainbow Lake can be used to assess whether toxic concentrations of ammonia are present.

Lake Depth: Lake depth plays an integral part in the quantity and quality of sunlight that reaches the lake bottom (where the macrophytes are growing). Light attenuates fairly rapidly in water and decreases in quality with depth. This indicator can be used to determine whether the lake is sufficiently deep enough to prohibit light from reaching the bottom and stimulating macrophyte growth. Barnes and Farnsworth (1995) state that a 1 meter increase in the depth of Rainbow Lake would double the volume of water in the lake. This increase in water depth would reduce the amount of lake bottom that is viable for macrophyte growth.

2.3 Identification of Target Levels to be Protective of Beneficial Uses

The system's response to nutrient inputs is especially variable because of the concentration of nutrients stored in the lake sediments. Ecoregional characteristics for reservoirs of similar type are unknown, eliminating the ability to establish reference conditions.

The relationship of pH, temperature, and dissolved oxygen to unionized ammonia suggest that these parameters must be maintained within the ranges that have been identified in Title 18, Chapter 11 of the Arizona Administrative Code for Water Quality Standards. These levels provide safe water quality levels for aquatic organisms residing within the lake and for the protection of the other listed beneficial uses of the lake.

The lake's response to nutrient reductions and subsequent phytoplankton and macrophyte levels will need to be monitored more closely than they have in previous monitoring efforts.

The TMDL study results indicate that nutrient concentrations in the water column and bedded sediments will have to be reduced to control phytoplankton and macrophyte growth. The target range for nutrients and possible strategies for attaining the desired levels of nutrients are provided in Section 3.0 *Watershed and Lake Modeling: Source Analysis for Loadings, Nutrient Mass Balance, and Linkage of Stressors to Water quality Endpoints* and 4.0 *Recommendations for Allocations, Implementation and Monitoring* of this report.

2.4 Comparison of Numeric Targets and Existing Conditions

This section assesses how far the water quality parameters of concern for Rainbow Lake have to go in order to be in compliance with the stated water quality standards for the lake. Table 2-1 illustrates the existing water quality conditions, the desired TMDL Endpoints, and commentary.

Table 2-2 (ADEQ 305(b) website 1999) provides the water quality parameters that the state of Arizona uses to determine the trophic level of a waterbody. This classification system relies on three water quality parameters to assess trophic level (1) chlorophyll-a, (2) total phosphorus, and (3) Secchi-depth. Using this classification system, Rainbow Lake ranges from oligotrophic (based on chlorophyll-a concentrations) to eutrophic (based on Secchi depth and total phosphorus). ADEQ has included a revised trophic classification system for the upcoming 305(b) Water Quality Assessment. ADEQ will develop regional regression relationship using Brezonick's (1982) classification to refine this index (Table 2-2a).

Table 2-1
Comparison of Existing Conditions to TMDL Endpoints

Parameter	Existing Value (Mean and range)	TMDL Endpoint	Comments
pH (SU)	8.91 (7.02 – 10.32)	Arizona Water Quality Standard: pH > 6.5 and < 9.0	This range ensures minimum concentrations of unionized ammonia and reduces toxicity to aquatic organisms & pH shock. Validated by monitoring.
Dissolved Oxygen (mg/L)	8.95 (0.12 – 17.43)	Arizona Water Quality Standard: DO > 7.0 mg/L or 90% saturation in upper 1 meter water depth	This range ensures that water column concentrations of dissolved oxygen will be adequate to sustain aquatic life. Validated by monitoring.
Phosphorus (mg/L)	0.14 (0.02 – 0.32)	Arizona Water Quality Standard: Best Professional Judgment for Lake, which is co-limited by phosphorus and nitrogen	ADEQ (1999): total phosphorus between 0.01 – 0.02 mg/L or ADEQ (2000): total phosphorus between 0.01 – 0.04 mg/L is classified “mesotrophic”; 0.04 – 0.07 is classified “eutrophic” Validated through Phased TMDL Monitoring.
Nitrogen (mg/L)	0.29 (<0.01 – 1.82)	Best Professional Judgment	ADEQ (2000): total nitrogen between 0.28 – 0.75 mg/L is classified “mesotrophic”; 0.75 – 1.2 mg/L is classified “eutrophic” Validated through Phased TMDL Monitoring.
Total Ammonia (mg/L)	0.13 (<0.03 – 0.35)	Protection of sensitive coldwater fish species (i.e., salmonids): Arizona Standard for Acute exposure: pH & temp dependent* Federal Criteria: Concentrations of unionized ammonia for Acute Exposure (< 1 hr): 0.35 mg/L; Chronic (4-days): 0.02 mg/L	Unionized ammonia is a strongly toxic aquatic pollutant whose concentration is driven by water column pH and temperature. *Concentrations measured to data are protective of the coldwater fishery in Rainbow Lake, but acute threshold for extreme high pH and temperature is 0.67 mg/L Validated through Phased TMDL Monitoring.
Aquatic Plants	The presence of excessive quantities that are causing impairment to the beneficial uses of the lake	Reduce quantities of nuisance aquatic plants	Reduce the quantities of nuisance aquatic plant biomass to levels that would not drive water column pH and dissolved oxygen levels to extremes or result in increasing the concentrations of unionized ammonia to toxic levels. Validated through Phased TMDL Monitoring.

Table 2-2
Arizona Trophic Classifications*
ADEQ Website 305(b) 1999

Trophic State	Chl-a (μg/L)	Total P mg/L	Secchi Depth (m)
Oligotrophic	<7	<0.010	>3.7
Mesotrophic	7 – 12	0.010 – 0.020	2.0 – 3.7
Eutrophic	>12	>0.020	<2.0

* ADEQ may apply other indices (e.g., nitrogen) depending on site-specific or limiting conditions; the index below is a refinement that includes nitrogen. Though it needs to be reworked to reflect Southwest conditions, ADEQ has included use of this index in the year 2000 Water Quality Assessment Report

*TSI	Trophic State	Chlor-a (ug/L)	SD (m)	Total P (ug/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"

3.0 WATERSHED AND LAKE MODELING: SOURCE ANALYSIS FOR LOADINGS, NUTRIENT MASS BALANCE, LINKAGE OF STRESSORS TO WATER QUALITY ENDPOINTS

3.1 Technical Approach

This section addresses four of the primary elements of this TMDL study: 1) conduct a source analysis for loadings, 2) develop a nutrient mass balance model for Rainbow Lake, 3) link the pollutant loads (stressors) to water quality endpoints, and 4) allocate loads to source categories that ensure water quality objectives are met. A watershed loading model (GWLF) and an in-lake processes model (BATHTUB) were used to perform the analysis for these elements of the TMDL. The purpose of this section is to describe how existing data were used to characterize watershed source inputs and resulting water quality effects in Rainbow Lake. It is important to designate nutrient inputs by category because control strategies will vary depending on the relative contributions from categories to total nutrient loading.

The loading estimates were developed and analyzed using the GWLF (Generalized Watershed Loading Functions) watershed model (Haith et al., 1992). The loading analysis for the watershed is subdivided into point source and several non-point source categories. No significant point sources were identified in the watershed. The non-point source watershed loading categories assessed included septic systems, agriculture, forest, residential, commercial, barren land, and range. The GWLF model predicts water flows and loads of nitrogen, phosphorus, and sediments from the watershed. The flows and loads are calculated from watershed characteristics (land use type, soil characteristics, area, slope, vegetation cover, etc.) and precipitation data. The predicted flows and loads are then used as input to the lake model BATHTUB during the linkage analysis.

The nutrient mass balance quantifies the fluxes of nutrients into Rainbow Lake from watershed and atmospheric loadings; the fluxes out of the lake from outflows and macrophyte harvest; and internal cycling within the lake from nutrient sedimentation, sediment regeneration and release, and nutrient regeneration during plant decay. Nutrient loads from the watershed were estimated using flow and nutrient concentration data from the Walnut Creek inflow to Rainbow Lake. Outflow fluxes of nutrients were calculated using outflow rates and nutrient concentrations in the lake. Macrophyte harvest removal fluxes were calculated from harvest rates and nutrient concentrations in the plants. Internal lake nutrient pools associated with sediments and macrophytes are important sources of concern for the TMDL, since the sediment pools of nitrogen and phosphorus in eutrophic lakes are typically large, and since sediment release could potentially support high macrophyte and algal densities even if external loads from the watershed are reduced to minimal levels.

The lake model BATHTUB was used for the linkage analysis. This model calculates water quality variables such as nutrient concentrations, chlorophyll a concentrations (or algal densities), and turbidity based on the loadings, hydrology, lake geometry, and internal nutrient cycling processes within the lake. The watershed model provides the loads that drive the system, and the lake model calculates the lake response in terms of the water quality endpoints (N, P, chlorophyll a, secchi depth), which can in turn be compared with the water quality targets.

3.1.1 Source Analysis of Loadings

Nutrient loadings were calculated for the different source categories within the Rainbow Lake watershed using the GWLF Model Version 2.0 (Haith et al., 1992). The following sources were evaluated:

- Agriculture
- Forest
- Range
- Barren land
- Residential areas
- Commercial areas
- Groundwater
- Septic systems

Land use categories and corresponding coverage areas in the watershed were taken from the BASINS GIS database. The areas in each category are listed in Table 1-1. Agriculture in the watershed consists predominantly of livestock grazing.

The analyses were conducted using daily meteorological data (e.g., precipitation and temperature) from the Pinetop meteorological station for the16-year period from 1980 to 1995. This period was selected because the meteorological records were complete, the average conditions over the period were similar to the long-term average for the station, and representative high and low rainfall years occurred during the period. The following results were calculated from the model simulations:

- Annual inputs of nitrogen and phosphorus to Rainbow Lake for each of the 16 years

- Annual inputs of nitrogen and phosphorus to Rainbow Lake averaged over the 16-year period

- Annual inputs of nitrogen and phosphorus to Rainbow Lake during the years with the lowest precipitation (low flow year) and highest precipitation (high flow year) during the 16-year period. Precipitation during the low flow year (1989) was 40% less than the16-year average precipitation, and precipitation during the high flow year (1992) was 31% greater than the average precipitation.

The GWLF model calculates flows and nutrient loads at the downstream boundary of the watershed where Walnut Creek enters Rainbow Lake. It does not calculate conditions along the length of the stream, or at different locations within the watershed. However, contributions from different locations and land uses within the watershed are calculated and added to give the total downstream loads, and these individual source contributions are itemized in the model output. The GWLF model simulates both hydrological processes in the watershed and nutrient loads from different sources. The nutrient loads depend on both the types and intensities of land uses and on the hydrologic processes that transport the nutrients through the watershed and into the stream. The hydrological and nutrient loading processes are each described separately below.

3.1.1.1 Watershed Hydrology and Transport Processes

The GWLF model calculates both flows and nutrient loads on a daily basis using daily meteorological data (precipitation and temperature) to drive the model. Precipitation is assumed to occur as rain when the air temperature is above freezing (0°C), and as snow fall otherwise. Snowmelt is calculated by a degree-day relationship when a snow pack is present and air temperatures are above freezing. The precipitation data are used to calculate a daily hydrologic budget for the watershed that includes runoff processes at the surface, ground water flows below the surface, evapotranspiration losses, and stream flows at the bottom of the watershed where Walnut Creek enters Rainbow Lake. The stream flows equal the sum of the surface runoff and the shallow groundwater flows that feed the stream.

Runoff from each land use category in the watershed is calculated from the daily precipitation data using the U.S. Soil Conservation Service (SCS) Curve Number approach. The curve numbers vary with land use type, vegetation type, percent vegetation coverage, soil type, extent of impervious areas, agricultural practices, growing versus dormant season, and antecedent moisture conditions. Precipitation in excess of runoff is assumed to infiltrate into the soil (or to contribute to snow pack if the temperature is below freezing). The infiltrated water contributes to the groundwater flows below the surface. The subsurface soil region is divided vertically into three zones: 1) the upper unsaturated zone, 2) the shallow saturated (groundwater) zone that feeds the stream, and 3) the deep saturated (groundwater) zone that is below the level of the stream bed and therefore does not contribute to the stream flow. Water that enters the deep saturated zone is assumed to leave the system, since it does not contribute to the stream flows and nutrient loads entering the lake.

The shallow groundwater flows that feed the stream are calculated from daily water balances of the unsaturated and shallow saturated zones. The water balance for the upper unsaturated zone includes the processes of rainfall, snowmelt, and surface runoff that determine how much water infiltrates into the soil, as well as losses from evapotranspiration and percolation into the next lower zone. The water balance for the shallow saturated zone includes percolation into this zone from the above zone, groundwater discharge to the stream, and seepage into the deep saturated zone that is below the stream. Changes in soil moisture are calculated daily for both of these zones based upon the above process fluxes. Percolation between the top two zones occurs when the soil moisture in the upper unsaturated zone exceeds the soil moisture capacity. Groundwater discharge to the stream and seepage to the deep lower layer are modeled as linear functions of the soil moisture in the shallow saturated groundwater layer.

3.1.1.2 Watershed Nutrient Loads

Nutrient loads are calculated differently for each source category using the flow information described above. Each of the major approaches for calculating nutrient loads are described below.

Rural Land Use Loads

For rural land uses such as agriculture (grazing), range, forest, and barren land, nutrient loads are calculated for both dissolved and particulate forms of nitrogen and phosphorus. Dissolved loads are calculated as the product of the daily runoff flows and representative nutrient concentrations in runoff for each land use type. These concentrations are compiled from the literature from several studies and are summarized in the GWLF User's Manual (Haith *et al*., 1992). The dissolved nitrogen concentrations in runoff were set at 0.07 mg/l for forests, 2.8 mg/l for range, 3.0 mg/l for grazed agricultural areas, and 2.6 mg/l for barren land. The dissolved phosphorus concentrations in runoff were set at 0.012 mg/l for forests, 0.15 mg/l for range, 0.25 mg/l for grazed agricultural areas, and 0.10 mg/l for barren land.

Particulate nutrient loads are calculated as the product of the sediment yields eroded from each land use type and the corresponding nutrient concentrations in the soils. The erosion model is based on the Universal Soil Loss Equation (Wischmeier and Smith, 1978) approach. Erosion and sediment transport into the stream depend on the surface runoff rates, topography, soil characteristics, vegetation type and coverage, agricultural practices, and watershed size. A portion of the erosion loads are assumed to be deposited or filtered within the watershed before reaching the stream. This is represented by the sediment delivery ratio, which is a function of watershed size. Erosion loads are distributed to the stream throughout the year based on monthly transport capacities. These are calculated as a power function of the daily runoff values. Nutrient concentrations in the soils were compiled from the literature for different regions and summarized in the GWLF User's Manual (Haith et al., 1992). The soil nitrogen and phosphorus concentrations were set at 3000 and 1320 mg/kg, respectively. These represent moderate nitrogen and phosphorus concentrations in the soils.

Residential and Commercial Loads

Nutrient loads from residential and commercial areas are assumed to occur as particulate forms which occur only during storm runoff events. The nutrients are assumed to build up on land surfaces between storms due to various activities. Nutrient build-up (i.e., accumulation) rates are input to the model and vary with land use type, lot size, and the relative amounts of pervious and impervious areas. Both nutrient build-up and runoff are higher on the impervious areas. Residential and commercial areas were assumed to consist of 20% and 50% impervious surfaces, respectively. Commercial areas included all developed areas that were not residential, for example businesses and public buildings in the Pinetop-Lakeside area.

Nutrient build-up rates were taken from default values in the GWLF User's Manual (Haith et al., 1992) for the appropriate land use category and lot size. Nitrogen build-up rates in residential areas were set at 0.045 kg/ha-day in impervious areas and 0.012 kg/ha-day in pervious areas. The corresponding phosphorus build-up rates were 0.0045 kg/ha-day and 0.0016 kg/ha-day in the impervious and pervious areas, respectively. These values are typical of low density residential developments. Nitrogen build-up rates in commercial areas were set at 0.056 kg/ha-day in impervious areas and 0.012 kg/ha-day in pervious areas. The corresponding phosphorus build-up rates were 0.0067 kg/ha-day and 0.0019 kg/ha-day in the impervious and pervious areas, respectively.

Nutrient accumulation is modeled using the above build-up rates along with an exponential depletion function, so that nutrient concentrations build up to maximum levels in a few weeks without rain. The accumulated nutrients begin to wash off during storms. The wash off rates increase with runoff rates according to an exponential function. Runoff rates are calculated from precipitation data using the SCS Curve Number approach.

Groundwater Loads

Nutrient loads from shallow groundwater flows occur as dissolved forms. These loads are calculated as the product of the groundwater flow rate and the dissolved nutrient concentrations in groundwater. These concentrations were taken from the default values in the GWLF User's Manual (Haith et al., 1992), and were set at 0.180 mg/l for nitrogen and 0.015 mg/l for phosphorus. These values represent areas in the western U.S. that are 50-75% forest.

Groundwater flows were calculated from the daily precipitation data using the water balance approach described above for the shallow saturated zone that feeds the stream. The portion of the groundwater flow that enters the stream was determined through model calibration, as described below in Section 3.1.1.4.

Septic System Loads

Nutrient contributions from septic system sources were calculated based on estimates of the number of people using septic systems in the watershed, together with model calibration as described below in Section 3.1.1.4. Information from the Pinetop-Lakeside Chamber of Commerce and other county and state agencies with census information indicated that the population in the watershed is about 25,000 to 50,000 during the summer (June through August) and about 3,500 to 8,000 during the rest of the year. The population estimates vary between agencies, but the area has grown rapidly during the last few years. Much of the area has been converted to sewer systems in recent years. However, some residences are still on septic systems, including some summer home developments in the watershed. No accurate information was available on the number of septic systems in use. Interviews with some local agencies indicated that as much as 10 to 20 percent of the population could be on septic systems, while other agencies suggested much lower numbers. Since the actual number of septic system users was unknown, this quantity was treated as a calibration parameter and was adjusted during model calibration. The resulting values were 1,000 septic system users during the summer and 100 users during the rest of the year. This suggests that only a few percent of the population remains on septic systems. Some of the summer home developments use septic systems, but these houses are typically occupied for only a few weeks out of the year. The septic systems were assumed to be properly designed and sited, so that they produced only nitrogen loads and not phosphorus loads to the waterways. In properly functioning septic systems, phosphorus in effluent is absorbed and retained by the soil, so no phosphorus loads enter the waterways.

Septic system loads occur as dissolved nutrients and are transported to the stream or lake through shallow groundwater discharge. The loads are calculated using per capita daily nutrient loading rates and plant uptake rates. Plants are assumed to remove a fraction of the per capita nutrient loads before they enter the stream. Plant uptake occurs only during the growing season, which was assumed to be May through October. Per capita nutrient loads in septic effluent and plant uptake rates were based on the default values in the GWLF User's Manual (Haith et al., 1992). The per capita effluent loading rates were 12.0 g/day for nitrogen and 2.5 g/day for phosphorus. The per capita plant uptake rates during the growing season were 1.6 g/day for nitrogen and 0.4 g/day for phosphorus, and zero during the rest of the year. Plants were therefore assumed to remove about 13 percent of the nitrogen and about 16 percent of the phosphorus during the growing season. The total septic system loads were calculated by multiplying the per capita loading rates by the corresponding populations on septic systems, and then subtracting the plant uptake fluxes. The phosphorus loads were assumed to be zero, since phosphorus in effluent is typically absorbed and retained by the soil in properly designed septic systems.

3.1.1.3 Hydrology and Transport Model Parameters

The runoff, erosion, and groundwater flow calculations used to predict the above nutrient loads require several model input parameters. These are described below.

Runoff

Runoff is calculated on a daily basis for each land use category using the U.S. Soil Conservation Service (SCS) Curve Number approach. The curve numbers vary with land use type, vegetation type, percent vegetation coverage, soil type, extent of impervious areas, agricultural practices, growing versus dormant season, and antecedent moisture conditions. Since the soil types varied within a given land use category, runoff curve numbers were determined separately for each soil type, and then area-weighted composite values were calculated for each land use category. The areal distributions of soil types (soil hydrologic groups A through D) for each land use were taken from the STATSGO database in BASINS. Soil Conservation Service (SCS) runoff curve numbers were assigned for each soil type within a land use category based on a combination of land use type and soil hydrologic condition parameters. The curve numbers were taken from the tables in the GWLF User's Manual (Haith et al., 1992), which were originally obtained from the U.S. Soil Conservation Service (U.S. SCS, "Technical Release No. 25, 2nd Edition", 1986).

Runoff is calculated from the daily meteorological data, and is dependent on the current precipitation (and snow melt), and on the average moisture conditions during the previous 5 days. The model runs were initiated in May so it could be assumed that the snow pack and antecedent moisture conditions were zero. Runoff from residential and commercial areas were calculated separately for the pervious and impervious portions, since runoff rates and nutrient loads are substantially different over pervious and impervious areas.

Evapotranspiration

Daily evapotranspiration losses are calculated by multiplying the potential evapotranspiration by an evapotranspiration cover coefficient. The cover coefficient represents the fraction of the potential evapotranspiration that is actually attained for a given vegetation cover. The potential evapotranspiration is calculated as a function of the air temperature and the number of daylight hours. Evapotranspiration cover coefficients were calculated for each land use category based on land use and vegetation type. Area-weighted composite values were calculated for the entire watershed for different seasons. A value of 1.0 was assumed for all plants during the growing season, and a value of 0.3 was used for bare soils and deciduous trees during the dormant season. The growing season was considered to consist of all months with monthly average air temperatures exceeding 10°C (May through October). For residential and commercial areas, the evapotranspiration cover coefficient was assumed to equal the pervious fraction of land.

Erosion

The soil erosion calculations are based on the Universal Soil Loss Equation, and require several model parameters. These include erosivity coefficients, sediment delivery ratio for the watershed, and the soil erodability values, slopes, lengths, cover and management factors, and supporting practice factors for each of the land use categories.

Rainfall erosivity coefficients describe the effects of rainfall intensity and precipitation patterns on soil erosion. These values vary with region and season. Rainfall erosivity coefficients were calculated separately for the warm season (April through September) and cool season (October through March). Since specific values were not available for Arizona, the average of all values tabulated in the GWLF User's Manual (for other regions of the United States) were used. These values were 0.28 for the warm season months and 0.15 for the cool season months.

The sediment delivery ratio accounts for the attenuation of sediment through deposition and filtering as it moves through the watershed. It represents the fraction of the erosion loads calculated from the Universal Soil Loss Equation that are ultimately transported to the stream at the downstream boundary of the watershed. The sediment delivery ratio decreases with watershed area. A value of 0.18 was selected based on the total watershed area and the empirical relationship (Vanoni, 1975) shown in the GWLF User's Manual (Haith et al., 1992).

Soil erodability factors (K) describe the erosion potential of a particular soil type, and depend on both the grain size distribution and the organic content of the soils. Soil erodability factors are available from soil surveys, and were taken from the STATSGO database in BASINS. Since the soil characteristics varied in the watershed, area-weighted averages of the soil erodability factors were calculated for each land use category.

Topographic information for each land use category (slopes and lengths) were taken from the Digital Elevation Model in BASINS and from USGS topographic maps. Topographic factors in the GWLF model were calculated with equations from Wischmeier and Smith (1978), which incorporate the slopes and lengths of each land use area. For larger forested areas with varying topography, the regions were broken into several sections of similar slope, and a composite factor was calculated using weighting factors as described in Wischmeier and Smith (1978).

Cover and management factors (C) in the Universal Soil Loss Equation represent the reduction in erosion potential due to vegetation cover or agricultural practices relative to the erosion that would occur if the soil were bare. These values depend on the vegetation type, percent canopy cover or ground cover, and the vegetation condition. Information on vegetation characteristics were obtained from Laing *et al.* (1986) and from interviews with watershed experts at the local U.S. Forest Service District and Arizona Game and Fish Department. The appropriate cover and management factors were then selected for each land use category using the tables in the GWLF User's Manual (Haith et al., 1992). Supporting practice factors (P) in the Universal Soil Loss Equation represent the reduction in erosion potential due to soil conservation practices (e.g., contouring, terracing). These values were set to 1.0 for all land use categories.

Groundwater Flow

The groundwater portion of the model requires three model parameters: the initial soil moisture capacity in the unsaturated zone, the groundwater recession coefficient, and the groundwater seepage coefficient.

The initial soil moisture capacity in the unsaturated zone was obtained from information in the BASINS database. An area-weighted average was calculated for the watershed, resulting in a value of 10.0 cm.

The groundwater recession coefficient describes the rate at which shallow groundwater flows to the stream change after surface runoff flows have stopped (i.e., during a receding hydrograph). It is normally determined by examining temporal changes in stream flow records. Since limited stream flow data are available for Walnut Creek just above Rainbow Lake, a default value was selected from information in the GWLF User's Manual (Haith et al., 1992). Typical values range from 0.01 to 0.2 per day, so a midpoint value of 0.1 per day was selected.

The groundwater seepage coefficient represents transport of shallow groundwater to the deep groundwater zone below the stream bed. Since this parameter is difficult to measure directly, it is normally determined by model calibration, as described below.

3.1.1.4 GWLF Model Calibration

Calibration of the GWLF Model involved two steps. First, the hydrological portion of the model was calibrated so that the predicted stream flow response to the precipitation data matched the available stream flow measurements in Walnut Creek just above Rainbow Lake. Then, the nutrient loading portion of the model was calibrated by adjusting certain parameters so that predicted concentrations of nitrogen and phosphorus in Walnut Creek just above Rainbow Lake matched the monitoring data in the stream. An attempt was made to use the default model parameters from the GWLF User's Manual (Haith et al., 1992) whenever possible, and to adjust only a few parameters that are site-specific or for which limited data were available. The default parameters were compiled from the literature from many studies conducted throughout the country. Many different values were tabulated that considered the effects of land use type, intensity of use, soil characteristics, topography, vegetation type, percent vegetation coverage, meteorological conditions, hydrologic conditions, and other site-specific factors. For parameters that vary with regions, the appropriate values for east central Arizona or for the western or southwestern U.S. were selected.

The hydrological portion of the model was calibrated by adjusting the groundwater seepage coefficient until the predicted long-term average flows from the watershed matched the measured average flows from the monitoring data in Walnut Creek just above Rainbow Lake. The resulting value for the seepage coefficient was 0.08 per day.

The nutrient loading portion of the model was calibrated by adjusting a few parameters until the predicted nutrient concentrations matched measured nutrient concentrations in Walnut Creek above Rainbow Lake. This was accomplished by adjusting the residential nutrient build-up rates to values representative of low density developments, and by adjusting the number of septic system users in the watershed. This resulted in septic system estimates of 1000 users during the summer and 100 users during the rest of the year. These values are reasonable based on the existing information available, but they could be refined through a septic system survey. Otherwise, all model parameters used in the analyses were taken from the default values listed in the GWLF User's Manual (Haith et al., 1992).

3.1.2 Nutrient Budget Analysis

Nutrient budgets were constructed for total nitrogen and total phosphorus in Rainbow Lake based on mass balances of watershed inputs, outflows, and internal fluxes in the system. The budgets were based on average hydrologic and nutrient conditions in the lake. A general description of the assumptions and sources of data is presented here. The results of the analyses are presented in Section 3.3.2 below.

Water Budget

A water budget was developed representing the long-term average conditions in the lake. The lake characteristics used in the analysis are summarized in Table 3-1, and are based on the values reported in the Diagnostic/Feasibility Study (ADEQ, 1996). The average surface area of Rainbow Lake is 116 acres (46.9 hectares) and the average volume is 800 acre-feet (0.987 x 10^6 cubic meters). The lake has a mean depth of 6.9 feet (2.1 meters) and a maximum depth of 14.1 feet (4.3 meters).

The lake water budget includes stream inflow, precipitation, evaporation, outflow from the dam, and groundwater seepage. Inflow from Walnut Creek was based on an average of eight bimonthly values from ADEQ in 1992 and 1993, and 13 measurements taken during five trips in 1995 by Baker and Farnsworth (1995). Precipitation into the lake was calculated as the product of the long-term average precipitation and lake surface area. Evaporation was calculated as the product of the evaporation rate (45 in/year) and lake surface area. Outflow and seepage were calculated by difference as stream inflow plus precipitation minus evaporation to get a mass balance of water. Outflow and seepage are treated as a single quantity since seepage is difficult to measure and since they are both the same in terms of nutrient removal from the lake.

The water budget data used in the nutrient budget analysis are summarized in Table 3-2.

Table 3-1
Lake Characteristics of Rainbow Lake

Parameter	Value
Lake volume (acre-feet)	800
Lake surface area (acres)	116
Mean depth (ft)	6.9
Max depth (ft)	14.1
Precipitation rate (ft/yr)	1.9
Evaporation rate (ft/yr)	3.8
Watershed area (acres)	5,357

Table 3-2
Water Budget Summary for Rainbow Lake

Hydrologic Parameter	Value
Inflow (acre-feet/year)	2,278
Precipitation (acre-feet/year)	218
Evaporation (inches/year)	45
Outflow and seepage (acre-feet/year)	2,059
Residence time (days)	142
Watershed runoff ratio	0.226

Nutrient Budget
The lake nutrient budget consists of atmospheric, hydrologic, sediment, and macrophyte components.

Atmospheric loadings were based on default deposition values from the BATHTUB model (10 kg/ha-year total nitrogen and 0.3 kg/ha-year total phosphorus), which are representative of general deposition rates of these nutrients. These rates were multiplied by lake surface area to estimate atmospheric loadings.

Inflows of nitrogen and phosphorus were calculated from the average flow measured in Walnut Creek multiplied by the average nutrient concentrations in the inflow water (0.99 mg/L total nitrogen and 0.09 mg/L total phosphorus). Outflows of nitrogen and phosphorus were calculated from outflow and seepage (calculated from the water budget) multiplied by the average nutrient concentrations in the lake (0.86 mg/L total nitrogen and 0.083 mg/L total phosphorus). The nutrient concentrations in Walnut Creek and Rainbow Lake were averaged from the ADEQ monitoring data.

Sediment nutrient release was based on phosphorus release rates measured in sediment cores from Rainbow Lake by Baker and Farnsworth (1995). The aerobic core value of 0.27 g/m^2-year was used for phosphorus release. Nitrogen release was estimated using this value and the ratio of nitrogen to phosphorus in Rainbow Lake sediments (13.9), as measured by ADEQ during 1992-1993.

Deposition of nutrients in sediments was based on phosphorus accumulation rates in Rainbow Lake estimated by Baker and Farnsworth (1995) from sediment cores. Values from two sediment cores were averaged, resulting in a phosphorus deposition rate of 1.3 g/m^2-year. The nitrogen deposition rate was estimated using this value and the ratio of nitrogen to phosphorus in Rainbow Lake sediments (13.9) measured by ADEQ during 1992-1993.

The sediment deep burial rate was estimated from sediment core profile dating at Rainbow Lake conducted by Baker and Farnsworth (1995), yielding an estimate of sediment deep burial rate of approximately 0.55 cm/year at a depth of about 20 to 30 cm. This depth was assumed to represent the lower, inactive sediment layer, which is below the typical macrophyte root depth. Deep burial rates were calculated using this sedimentation rate (0.55 cm/year) multiplied by average sediment nutrient concentrations (3,256 mg/L nitrogen and 235 mg/L phosphorus) measured in Rainbow Lake by ADEQ during 1992-1993.

Nutrient removal from macrophyte harvest was calculated from harvest rates by AGFD and nutrient concentration in the plants. Harvest rates were high during the 1980s when the plants were dense. The average harvest rate from 1982 to 1990 was 390 tons/yr. The plant densities have declined in recent years, so that only a single harvest of 65 tons occurred from 1994 to 1998. Averaged over this 5 years period, the current average annual harvest is only 13 tons/yr, about 3% of the previous rates. Harvest removal fluxes were calculated for both the previous high rates and the recent low rate.

Macrophytes were assumed to contain 2.5% nitrogen dry weight, 0.5% phosphorus dry weight, and an 88% water content.

Nutrient release due to macrophyte decomposition was estimated using typical values of biomass turnover and the above nutrient concentrations in the plants. Potential rates were calculated assuming the high macrophyte densities previously found in the lake. Although current plant densities are lower, high densities could occur again in the future. BATHTUB model analyses (discussed below) indicate that current plant densities could be less than 10% of previous densities. This is consistent with the low harvest rates in the last few years. Nutrient release fluxes were calculated assuming a typical biomass turnover rate of 2.5 times the peak density. The peak density during the growing season was estimated at 500 g/m^2 dry weight based on information in the literature, and was the same value used by Baker and Farnsworth (1995) for Rainbow Lake. The entire bottom area of the lake was assumed to contain macrophytes, as observed during a survey by AGFD during 1982. During decomposition, 28 percent of the plant tissue was estimated to be refractory (Jewell 1971), and therefore to release nutrients at a lower rate than the remaining labile fraction. The labile fraction is assumed to release nutrients directly to the water, while the refractory portion may accumulate in the sediments. However, decomposition in sediments may also eventually release much of these nutrients back to the water, but at a slower rate.

Since macrophytes obtain nitrogen and phosphorus from the sediments, the nutrient pools in the sediments were estimated and compared with macrophyte harvest rates to determine if harvest could be considered an effective nutrient removal process and could eventually limit plant growth through sediment nutrient depletion. The nutrient pools to a depth of 25 cm, the typical root depth of the plants, were calculated using the sediment nutrient concentrations measured in Rainbow Lake by ADEQ during 1992-1993.

3.1.3 Linkage of Nutrient Loads to Water Quality Endpoints

The steady-state lake model BATHTUB (Walker, 1996) was used in the linkage analysis to determine the water quality response of Rainbow Lake to different loading scenarios. This model calculates water quality variables such as nutrient concentrations, chlorophyll a concentrations (or algal densities), and turbidity. BATHTUB is a steady-state empirically based model. It calculates steady-state nutrient and water balances based on the loadings, hydrology, lake geometry, and internal nutrient cycling processes within the lake. The resulting nutrient levels are then used in a series of empirical relationships to calculate chlorophyll a and turbidity. These relationships were derived from field data from many different lakes. The calculated values represent long-term values during the summer growing season that would result if loadings remain the same.

Average values of Rainbow Lake hydrologic characteristics (Tables 3-1 and 3-2) were used in the model simulations since they were most representative of long-term average conditions. The model was set up using the average flows and the average nutrient concentrations in the Walnut Creek inflow from the ADEQ monitoring data. These values were consistent with the long-term average flows and nutrient loads predicted from the GWLF watershed model. Atmospheric loads were based on the default values in BATHTUB. The model was then calibrated by adjusting internal nutrient release fluxes for macrophyte decomposition and sediment release until predicted nutrient levels in the lake matched the average nutrient concentrations from the monitoring data.

Phosphorus was calibrated first, using the sediment release fluxes estimated from the nutrient budget (based on values from Baker and Farnsworth, 1995) and assuming any additional phosphorus releases were due to macrophyte decomposition. Nitrogen was calibrated next, dividing the calibrated release fluxes between sediments and macrophytes based on the relative proportions of phosphorus release calibrated previously. The total areal fluxes calibrated for phosphorus and nitrogen, which includes the sum of both macrophyte decomposition and sediment release, were about 9% and 2%, respectively, of the corresponding phosphorus and nitrogen values calculated in the nutrient budget assuming maximum macrophyte densities. This value is consistent with recent observations of lower macrophyte densities in Rainbow Lake. The current harvest rate is approximately 3% of the harvest rate during the 1980s.

The distribution of nitrogen and phosphorus releases between macrophyte decomposition and sediment release in BATHTUB was different than in the nutrient budget, since the same nitrogen:phosphorus (N:P) ratio was assumed for both sources in the BATHTUB calibrations. The nutrient budget used a high N:P ratio of 13.9 for the sediment release, and a lower N:P ratio of 5.0 for macrophyte decomposition. The sediment value was based on the nutrient ratio measured in Rainbow Lake sediments (ADEQ, 1992-93), and the macrophyte value was based on typical values from the literature. The BATHTUB calibrated N:P ratio for both sources was much lower, about 1.2. Nitrogen release rates from sediments and macrophytes were lowered during calibration to match predicted nitrogen concentrations in the water column.

The BATHUB model includes several different options and submodels. In general, the most recommended options (defaults) were selected. The phosphorus and nitrogen models used the second-order nutrient settling formulations. The chlorophyll-*a* model used the most comprehensive and general approach, which includes the effects of nitrogen, phosphorus, light, and flushing rate (rather than the default model, which does not consider nitrogen). Turbidity was calculated using the default model.

Nutrient availability in inflows was assumed to equal the total nutrient concentrations in the inflows. The default option for nutrient availability in inflows uses relationships that include the sums of both total nutrient concentrations and dissolved inorganic nutrient concentrations (phosphate or inorganic nitrogen), with weighting factors for each of these forms. This option was not used since internal release fluxes from sediments and macrophytes were modeled as inflows (as required by the BATHTUB model), and since phosphorus release from these sources was assumed to occur as phosphate. The default option would result in phosphorus availability much greater than the total amount of phosphorus released under these circumstances, since the weighting factor for phosphate availability is greater than 1 (the value is close to 2). The default relationships for nutrient availability in inflows in BATHTUB are based on empirical analyses of stream data, where phosphate is a small fraction of the total phosphorus (because much of the total phosphorus is associated with suspended particles). Therefore, it was not appropriate to use these relationships for macrophyte and sediment release of nutrients, which are major sources in Rainbow Lake. In addition, phosphate measurements were not available for the Walnut Creek inflow, since only total phosphorus was measured, so it would not have been possible to use the default relationships even for this source.

The BATHTUB model was calibrated using the long-term average loading conditions and monitoring data, and then several analyses were performed using different loading scenarios:

- Loadings from the watershed were reduced incrementally to represent different watershed nonpoint source control options

- Under existing watershed loadings, different macrophyte densities in the lake were assumed to represent different macrophyte harvest options

- Assuming no macrophytes were present in the lake, successive reductions in watershed loading rates from current average conditions were applied to represent watershed source controls in conjunction with macrophyte elimination

These scenarios covered the whole range of available options, and indicate what levels of improvement can be expected and which types of loading categories (watershed loads vs. macrophytes) will be most effective in improving water quality in the lake. In addition to the above scenarios, which are based on long-term average conditions, two additional scenarios were analyzed to represent the effects of hydrologic extremes. These were for a high flow and a low flow year. The flow rates and nutrient concentrations in inflows were based on the results of the GWLF model analyses for the years with the highest and lowest precipitation in the meteorological records. However, these extreme conditions would not persist for very long, so the other scenarios above are more useful for the TMDL analyses.

3.2 Existing Sources and Effects

There are three potential sources of nutrients into Rainbow Lake. These are **point sources** (a discharge whose source is known and can be directly quantified); **non-point sources** (discharges that have no obvious single source (seepage, runoff) and are difficult to quantify) and **in-lake processes** (in-lake sources and processes that recycle nutrients). Each of these is discussed in the following sections.

3.2.1 Point Sources

Currently, there are no point-source discharges into Rainbow Lake or elsewhere in the Walnut Creek Basin. The EPA (1977) identified one point source discharge, Charlie Clark's Restaurant, as a potential source for nutrients to Rainbow Lake during the 1975 National Eutrophication Survey study of Rainbow Lake. The discharge from this restaurant is no longer a point-source of nutrients into the basin.

3.2.2 Non-Point Sources

Non-point sources include septic systems, runoff, erosion, and grazing. ADEQ (1996) stated that eutrophication of Rainbow Lake may be attributable to the extent of previous use of septic tanks and a historic point-source discharge into the Walnut Creek Basin. In 1981, several people living in a housing subdivision in the basin became ill with gastroenteritis. This caused the Arizona Department of Health Services (ADHS) to monitor the wells in the Billy Creek and Walnut Creek Basins. They determined that 42% of the wells tested were contaminated with fecal coliform bacteria or nitrate and that 86% of the contaminated wells were located in areas where septic tanks were the major means of waste disposal, including the Walnut Creek Basin. A more recent study performed by ADEQ in 1991 and 1992 determined that septic systems were no longer a significant source of nutrients or coliforms into the watershed. Personal communication with state and local authorities has however, revealed that there is a lack of general consensus regarding the status of the current role of septic systems as sources of nutrients.

Baker and Farnsworth (1995) and ADEQ (1996) report that there are no apparent major sources of non-point source pollution. Those that appear to be present in the basin include agriculture (orchards and gardens, pastures), urban runoff, construction, hydro-habitat modification, highway construction and maintenance, recreation, and on-site wastewater systems (septic tanks).

3.2.3 In-Lake Processes

Baker and Farnsworth (1995) calculated the nutrient budget for the Rainbow Lake watershed and estimated that Rainbow Lake has a negative phosphorus retention rate (-10%) and is a source of phosphorus. Sediment cores taken from Rainbow Lake indicate that phosphorus concentrations have been and currently are elevated.

Sediment nutrients are directly recycled to the water column via diffusion and indirectly recycled via uptake by macrophytes and release during senescence. The surplus of lake/sediment nutrients stimulates algal and plant growth. As the algae and plants grow, they consume CO_2 which causes the lake pH to rise. When the algae and plants die, bacterial action promotes decay and nutrients are released either back into the water column or into the sediments. Nitrogen released during decomposition produces ammonia. The amount of ammonia that is converted to the toxic unionized form is directly related to pH and temperature (i.e., higher pH yields higher unionized ammonia concentrations). Thus, the process is as follows:

- Elevated nutrients cause plants to become stimulated and they grow;
- As they grow, they consume CO_2. This causes the water pH to rise;
- When the plants die or become fragmented, bacterial action begins the decomposition process;
- Decomposition releases the nutrients back into either the water column or the sediments, decreases dissolved oxygen concentrations, and produces ammonia;
- Nutrient concentrations are recycled;
- Low dissolved oxygen can lead to fish kills;
- High pH levels increase the concentration of unionized ammonia;
- Unionized ammonia is extremely toxic to aquatic organisms and can result in fish and invertebrate kills.

These processes appear to be the driving force behind the elevated nutrient concentrations in Rainbow Lake and resultant elevated pH values.

3.3 Loading Analysis and Nutrient Budget Results

The analysis of nutrient loading sources within the Rainbow Lake watershed and the results of the nutrient mass balance analysis are presented in this section.

3.3.1 Source Analysis of Loadings

Simulated loadings of total and dissolved nitrogen (Figure 3-1) and phosphorus (Figure 3-2) in Rainbow Lake from within the watershed varied with annual precipitation over the 16-year period (1980 to 1995). Nutrient loads during low flow years (e.g., 1989) were relatively low, while high flow years (e.g., 1992) resulted in substantially higher loadings of nutrients. The phosphorus loads during the high flow year were more than 3 times as high as the loads during the low flow year, and the nitrogen loads were more than twice as high as the low flow loads.

On average over the 16-year period, residential runoff and septic systems contributed the highest levels of nitrogen input to the lake (Figure 3-3a). During a low flow year, when septic input is the greatest source of nitrogen, loadings from residential runoff decline but remain significant (Figure 3-4a). During a high flow year, nitrogen inputs from commercial areas, groundwater, and agriculture (predominantly grazed land) increased relative to levels produced by the largest sources (i.e. residential areas and septic systems) (Figure 3-4b). Nitrogen contributions from forest and range were negligible (Figures 3-3a and 3-4).

The quantities of phosphorus within the watershed were substantially lower than those of nitrogen. The relative magnitudes of phosphorus contributions to the lake from different sources were roughly similar for the long term average and high flow simulations (Figures 3-3b and 3-5). Although contributions of phosphorus from all sources were relatively low, residential areas generated the highest levels of phosphorus input under each precipitation and flow scenario (Figures 3-3 and 3-5). Septic systems and range produced negligible loads of phosphorus compared with other sources (Figure 3-3b). Phosphorus associated with septic systems is generally adsorbed by soils and not released to the water if the septic system is functioning properly.

3.3.2 Nutrient Mass Balance

The results of the nutrient mass balance analyses are presented in Table 3-3. The nitrogen and phosphorus budgets in Rainbow Lake include watershed inputs, outflows, and internal flux components. Nutrient inputs originate from atmospheric loading and inflows from the watershed. Nutrient losses occur through water outflows (dam releases and groundwater seepage) and macrophyte harvesting. Internal releases of nutrients occur within the lake from macrophyte decomposition and sediment exchange processes. Some of the nutrients eventually become buried below the active surface sediments which effectively sequesters them and makes them unavailable for cycling with the water column.

Inflows from the Rainbow Lake watershed are the major external loading source. Irrigation return flows from a diversion in nearby Billy Creek discharge into Walnut Creek above Rainbow Lake, and are included in the watershed loading estimates. However, based on the information in Baker and Farnsworth (1995), these diversion return flows are less than 5% of the total flows in Walnut Creek, and are therefore not

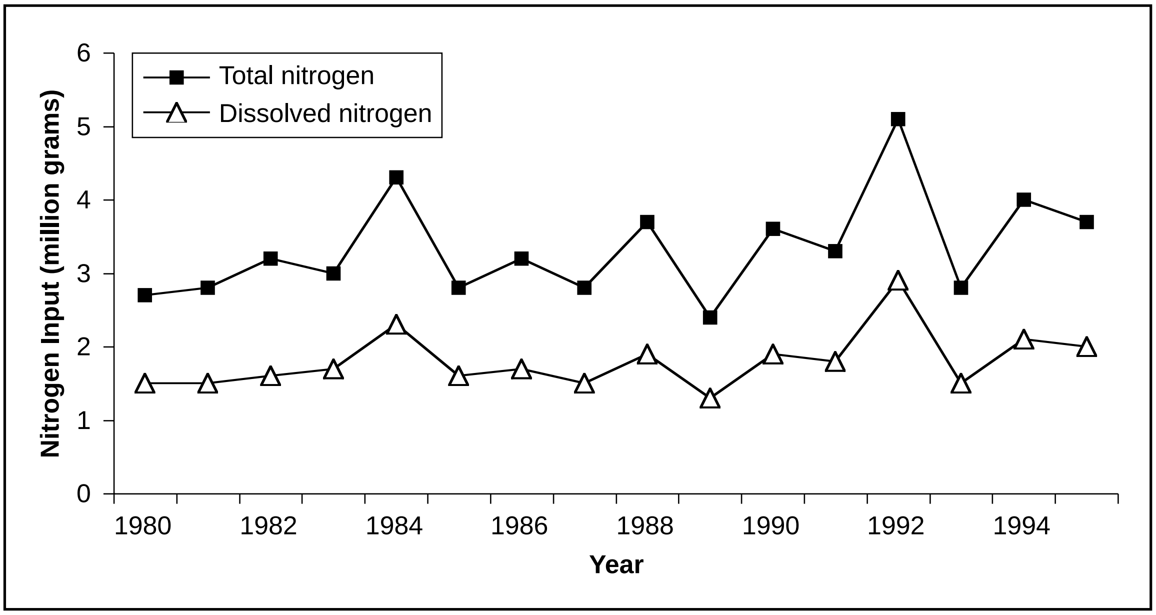


Figure 3-1. Annual total nitrogen and dissolved nitrogen inputs to Rainbow lake.

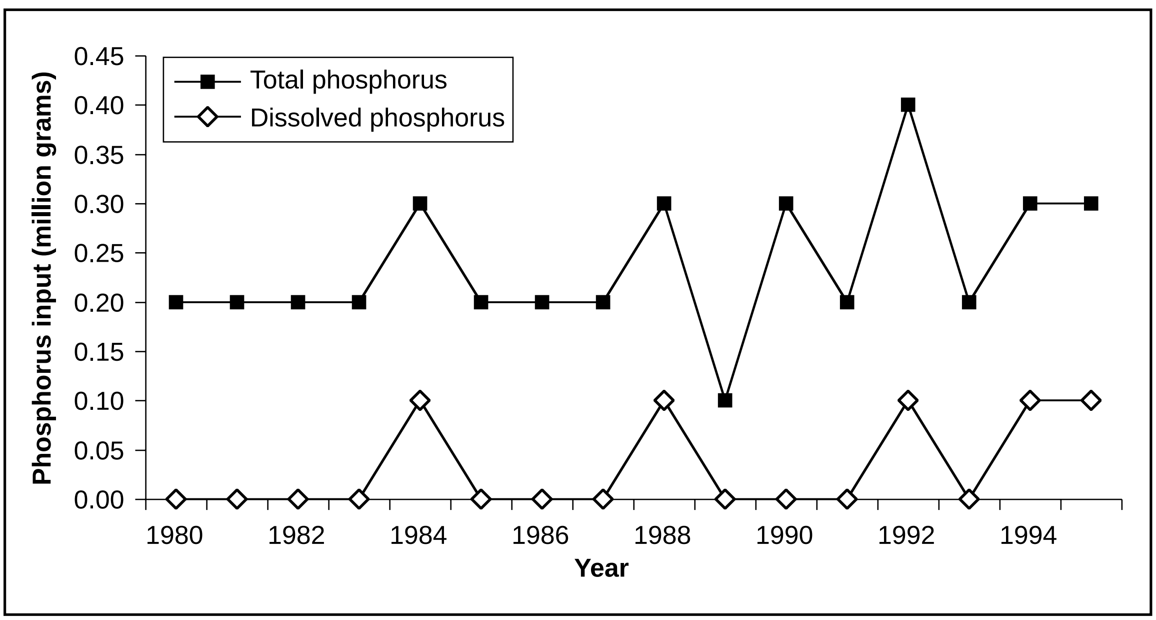


Figure 3-2. Annual total phosphorus and dissolved phosphorus inputs to Rainbow lake.

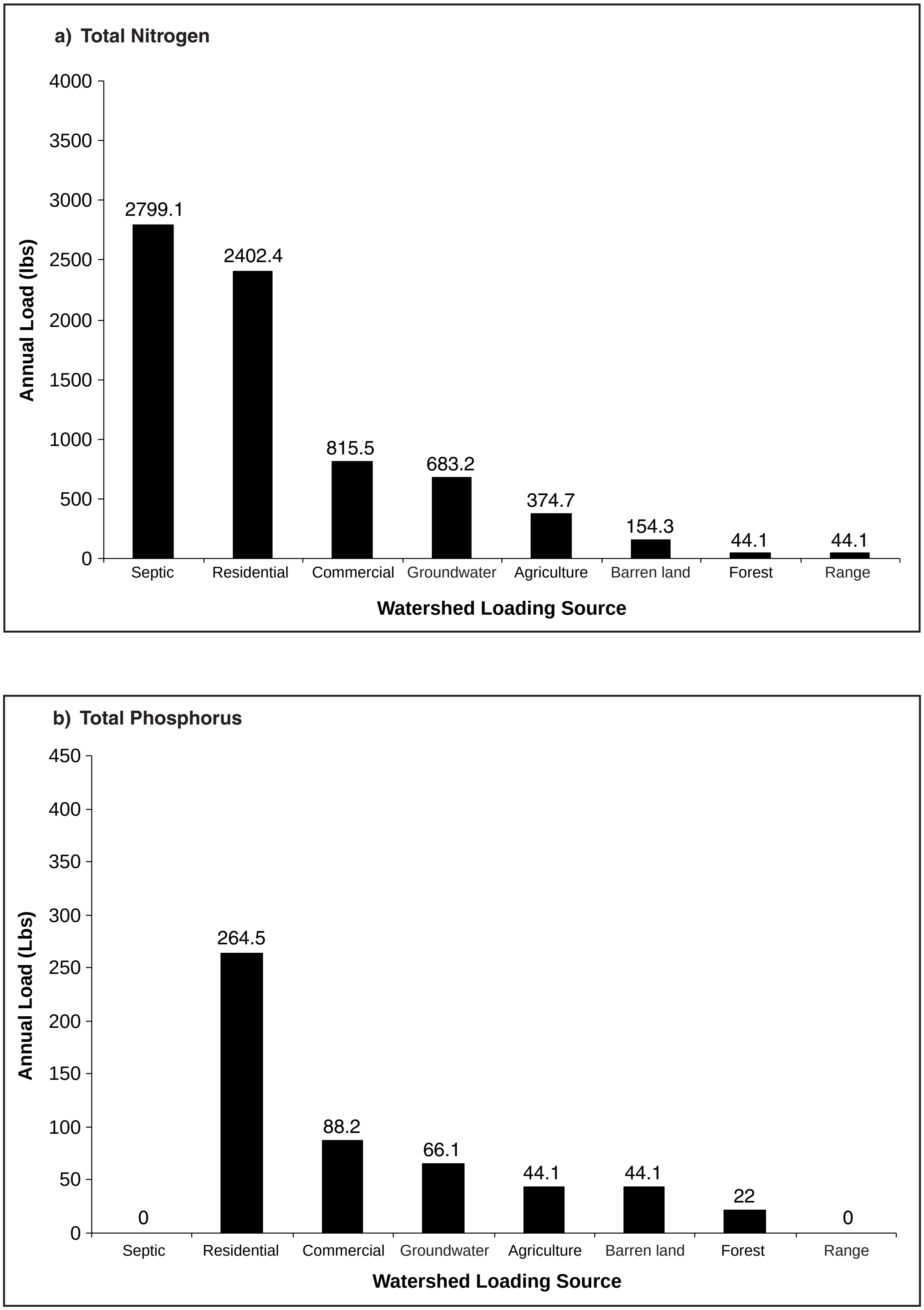
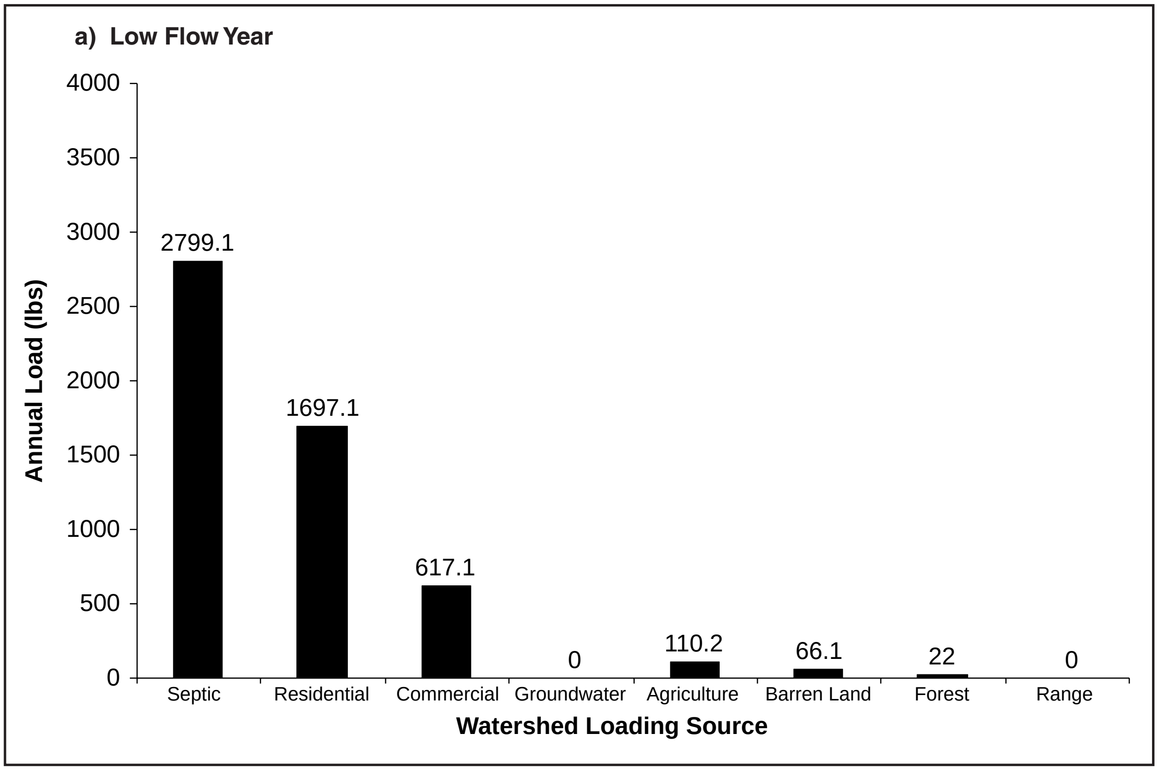


Figure 3-3. Long-term averages of annual (a) total nitrogen and (b) total phosphorus contributions to Rainbow Lake.



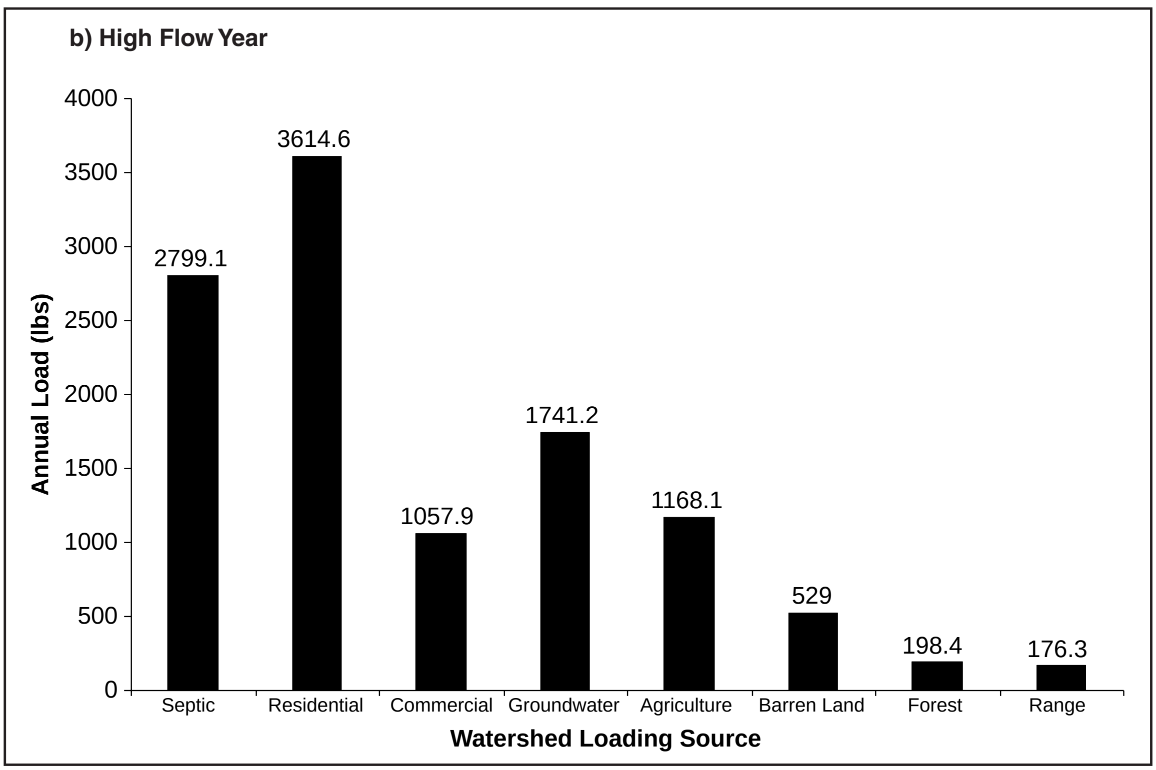


Figure 3-4. Annual total nitrogen contributions to Rainbow Lake during (a) low flow and (b) high flow years.

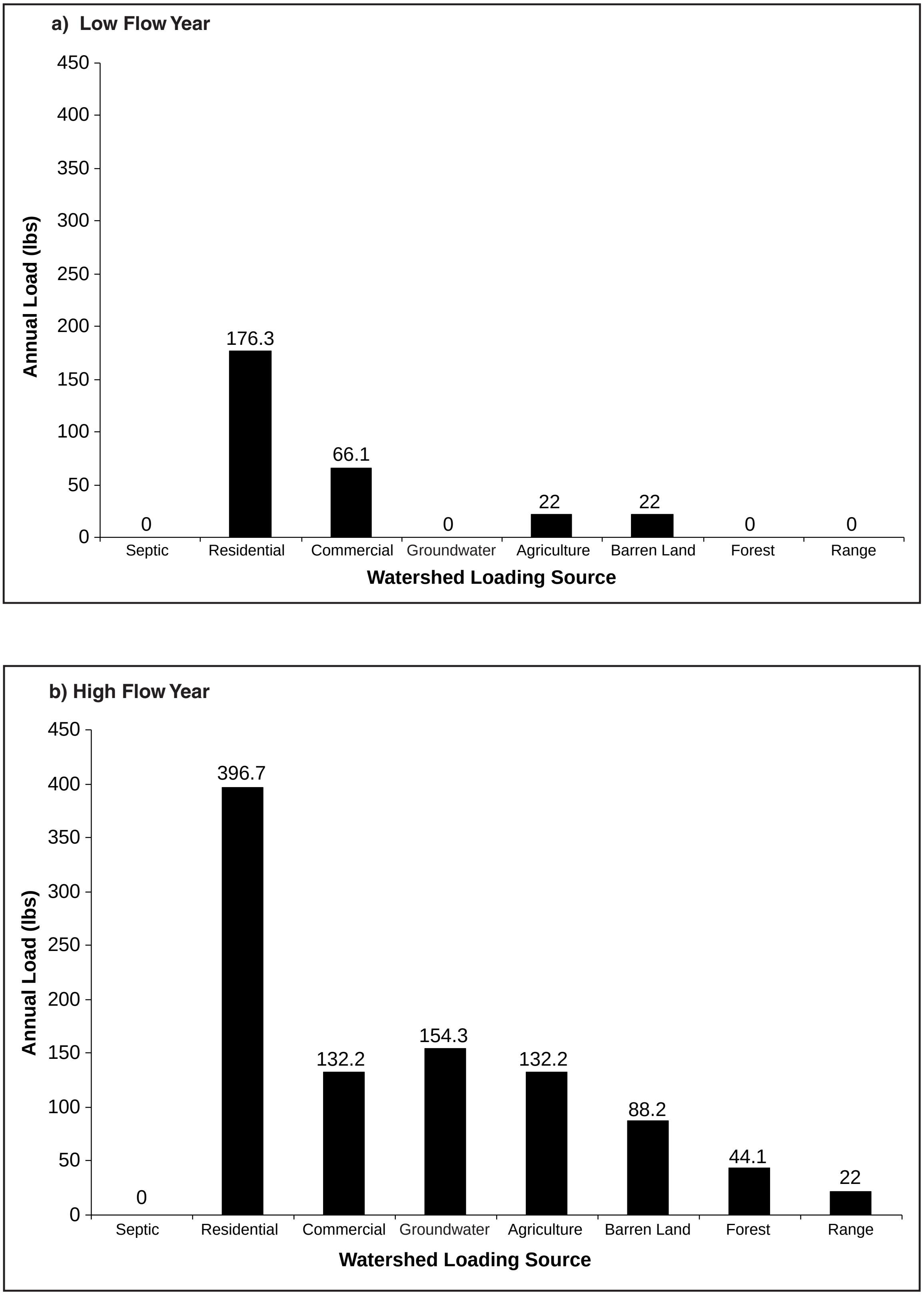


Figure 3-5. Annual total phosphorus contributions to Rainbow Lake during (a) low flow and (b) high flow years.

significant. Atmospheric loads are approximately an order of magnitude lower than the watershed loads. Internal loads such as macrophyte decomposition are also significant sources. Using the maximum macrophyte densities previously observed in the lake to estimate the potential nutrient release rates, the macrophyte decomposition fluxes are several times larger than the watershed loads. However, current macrophyte densities appear to be less than 10% of the previous densities based upon recent harvest data and the BATHTUB model calibration results. Therefore, the current internal loading rates from macrophytes and sediments are probably similar to the external loading rates from the watershed. The calculated outflow fluxes are on the order of 20% smaller than the external loads. This suggests that there is a net accumulation of nutrients in Rainbow Lake, in spite of the large internal sources of nutrients. This is due to the accumulation and settling of nutrients in phytoplankton, as well as the settling of particulate nutrients introduced through watershed loading processes.

The nutrient fluxes from macrophyte decomposition in Table 3-3 are potential values, since high macrophyte densities typical of infested aquatic systems were assumed in the analysis. Although current macrophyte densities are lower than the levels applied in the nutrient budget calculations, there is a potential for increased growth of macrophytes in the future.

Sediment deposition fluxes for nitrogen and phosphorus are comparable to the sums of watershed loading and recent macrophyte decomposition flux estimates. The deposition fluxes are based on measurements in Rainbow Lake sediments by Baker and Farnsworth (1995). Sediment deposition fluxes are larger than external loadings, indicating significant internal cycling fluxes within the lake. The deposition fluxes are associated with settling algae, senescing macrophytes, and suspended sediment inflows from Walnut Creek.

Sediment deposition and deep burial fluxes were approximately equal for both nutrients. This indicates that most of the nutrients deposited in the sediments eventually become buried in the deep sediment pool, where they are unavailable for cycling in the water. However, the continued cycling of nutrients in the upper active sediment layer will continue to be an important source of nutrients to the lake. Both nitrogen and phosphorus are released from the sediments at about 20% of the deep burial and deposition rates. The sediment release rates are much less than the maximum nutrient release rates calculated for macrophyte decomposition, but are probably similar to the lower current estimates of macrophyte decomposition fluxes.

Macrophyte harvest rates were compared to the sediment nutrient pools to determine if harvest could eventually reduce sediment nutrients to low levels that would inhibit further macrophyte growth. Based on sediment concentrations measured at Rainbow Lake by ADEQ and assuming a root depth of 25 cm, the sediment nutrient masses available to macrophytes are 381,000 kg of nitrogen and 27,400 kg of phosphorus. Comparison of the harvest removal fluxes to the sediment nutrient pools shows that it would take several hundred years to deplete the sediment nutrients, even at the high harvest rates that

Table 3-3
Nutrient Budget For Rainbow Lake

	Total nitrogen (lbs/yr)	Total phosphorus (lbs/yr)
Atmospheric loading	1,034	31.1
Inflow (from watershed)	6,129	558
Outflow (includes seepage)	4,806	465
Potential macrophyte decomposition:		
Labile	23,369	1,034
Refractory	9,039	6,129
Total	32,408	4,806
Sediment release	3,880	280
Sediment deposition	18,717	1,345
Sediment deep burial	18,519	1,334
Macrophyte harvest	(high) 2,337 (low) 78.0	467 15.6

occurred during the 1980s. At the low current harvest rates, it would take thousands of years to deplete sediment nutrients. The actual times would be much longer since nutrients will continue to accumulate in sediments. Therefore, macrophyte harvest cannot reduce the potential for future macrophyte growth through significant nutrient depletion. However, harvest is effective for dealing with the immediate problems associated with high plant densities in the water.

3.4 Linkage of Nutrient Loadings to In-Lake Water Quality Indicators

The lake model BATHTUB (Walker, 1996) was used in conjunction with the ADEQ monitoring data, the GWLF watershed model results, and the nutrient mass balance results in the linkage analysis to predict the Rainbow Lake water quality response to different nutrient loading scenarios. Most of the analyses focused on the average loading conditions, which were based on the ADEQ monitoring data in Walnut Creek just above the entrance to Rainbow Lake. These were the same data that were used to calibrate the long-term average nutrient loads predicted by the GWLF watershed model.

External nutrient loads from the watershed were estimated with GWLF for three different meteorological conditions: the long-term average, the wettest year, and the driest year of the 16-year record. The long-term average loading conditions were used in most of the linkage analyses. Although the wetter periods produce higher flows and nutrient loads from the watershed, the resulting nutrient and phytoplankton concentrations in the lake are lower due to the higher flushing rates. The dry periods produce lower flows and lower nutrient loads, but result in higher nutrient and phytoplankton concentrations since there is much less flushing, and since there is less dilution of septic system loads, which are assumed to be the same regardless of precipitation. Although the dryer years are therefore more critical as far as water quality conditions in the lake, these hydrologic extremes cannot persist for very long and are therefore not representative of the long-term water quality conditions in the lake. As shown in the results presented below, it will be difficult to totally eliminate water quality problems in Rainbow Lake because of limitations in its natural setting (shallow depth and historical nutrient accumulation in sediments). Therefore, most of the analyses focused on changes to the long-term average loading conditions, rather than focusing on the driest year. However, the BATHTUB predictions for the driest and wettest years are included in the analyses.

The BATHTUB model was used to predict the concentrations of total phosphorus, total nitrogen, and chlorophyll-a in Rainbow Lake in response to different nutrient loading scenarios. Three major sets of conditions were analyzed:

1. Effects of scaled reductions in watershed nutrient loads
2. Effects of scaled reductions in macrophytes
3. Effects of scaled reductions in watershed nutrient loads with all macrophytes removed from the lake.

The concentrations of total phosphorus, total nitrogen, and chlorophyll-a that were predicted under the different environmental conditions and scenarios are compared to the ADEQ trophic classifications that are used for the 305 (b) statewide water quality assessment process. These comparisons are presented in Figures 3-6 to 3-11 and discussed in greater detail in the following sections. The results and discussions focus on nutrient and phytoplankton (chlorophyll-a) concentrations and the resulting trophic status, rather than directly on water quality variable such as pH and dissolved oxygen. pH and dissolved oxygen vary diurnally with photosynthesis and respiration rates in the lake. In order to predict the effects of different nutrient loads on these variables, a much more complex nutrient biogeochemical and ecosystem model would be required. In addition, much more extensive data, including some diurnal sampling and much more temporal coverage throughout the year, would be required to set up and calibrate such a model. This type of modeling was beyond the scope and data availability of this TMDL study. Therefore, nutrient and chlorophyll-a concentrations and their relationships to trophic status are used as indicators to estimate when pH and dissolved oxygen problems will occur in Rainbow Lake. High pH and low dissolved oxygen are typical in lakes that are characterized as eutrophic.

BATHTUB does not simulate macrophytes directly, but their effects on internal nutrient cycling can be modeled by specifying macrophyte decomposition as an areal nutrient source (similar to sediment release fluxes). Additional internal sources of nutrients were necessary to obtain good calibration of the model, which indicates the importance of these sources in Rainbow Lake. However, BATHTUB does not consider the effects of

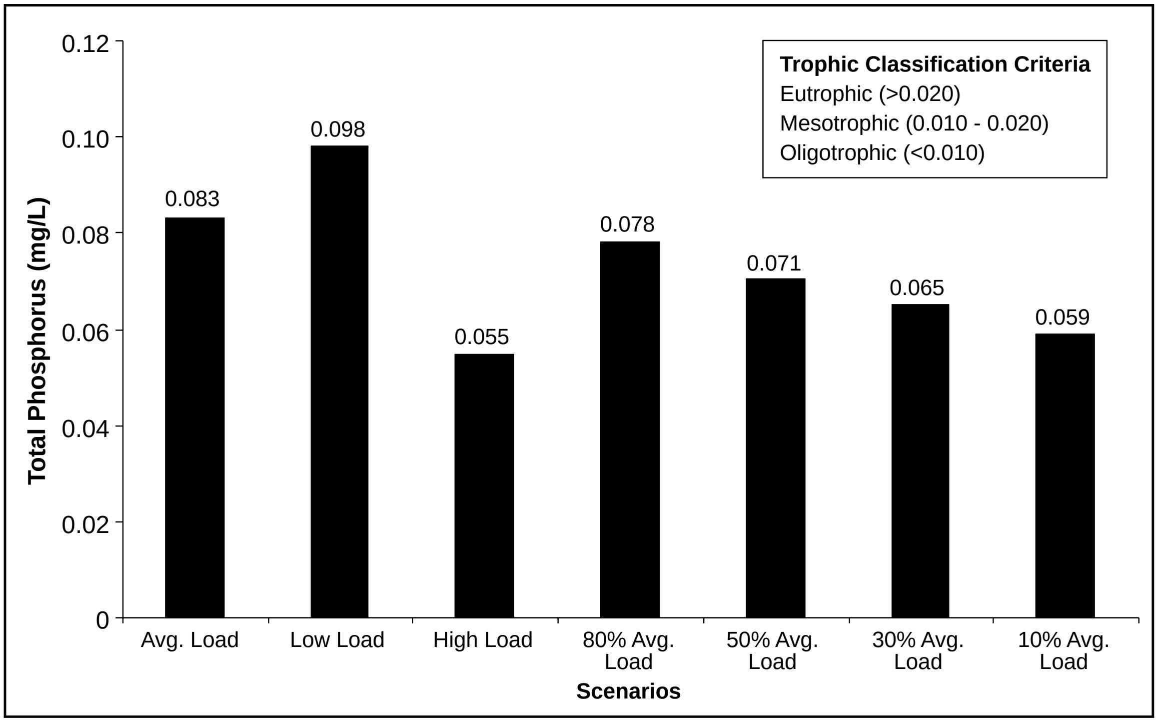


Figure 3-6. In-lake effects of scaled reductions in watershed nutrient loadings on total phosphorus in Rainbow Lake (High load also includes greater flushing)

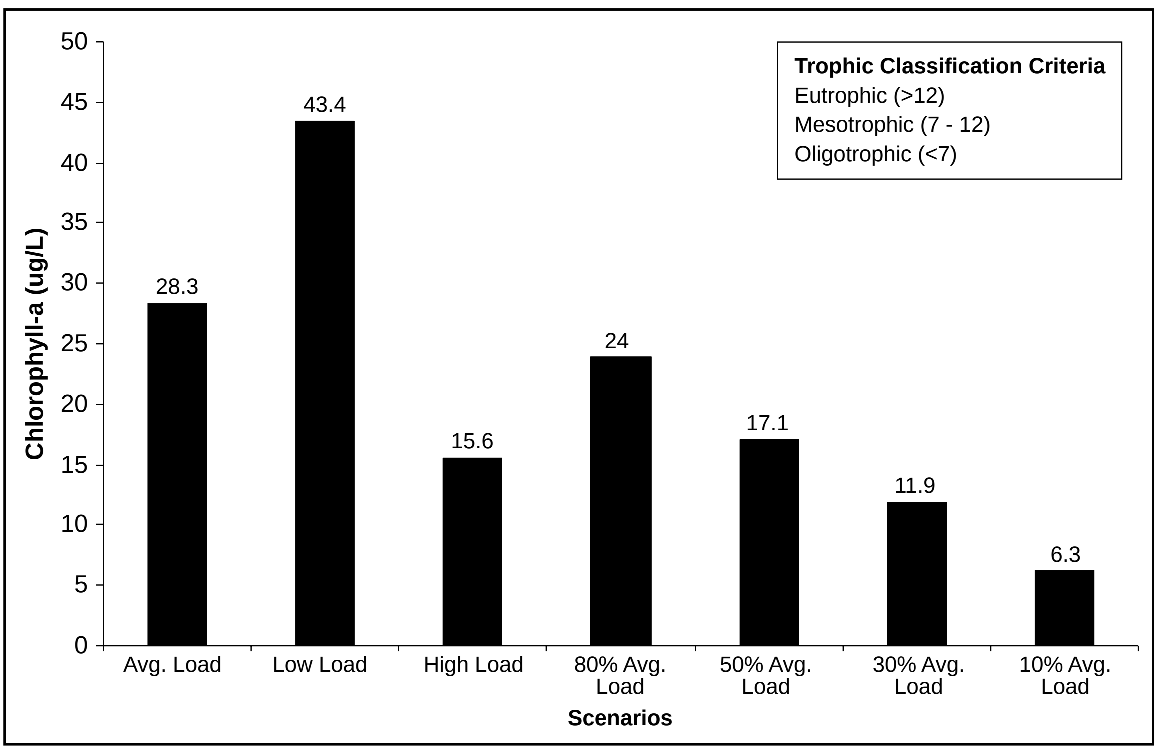


Figure 3-7. In-lake effects of scaled reductions in watershed nutrient loadings on chlorophyll-a concentrations in Rainbow Lake.

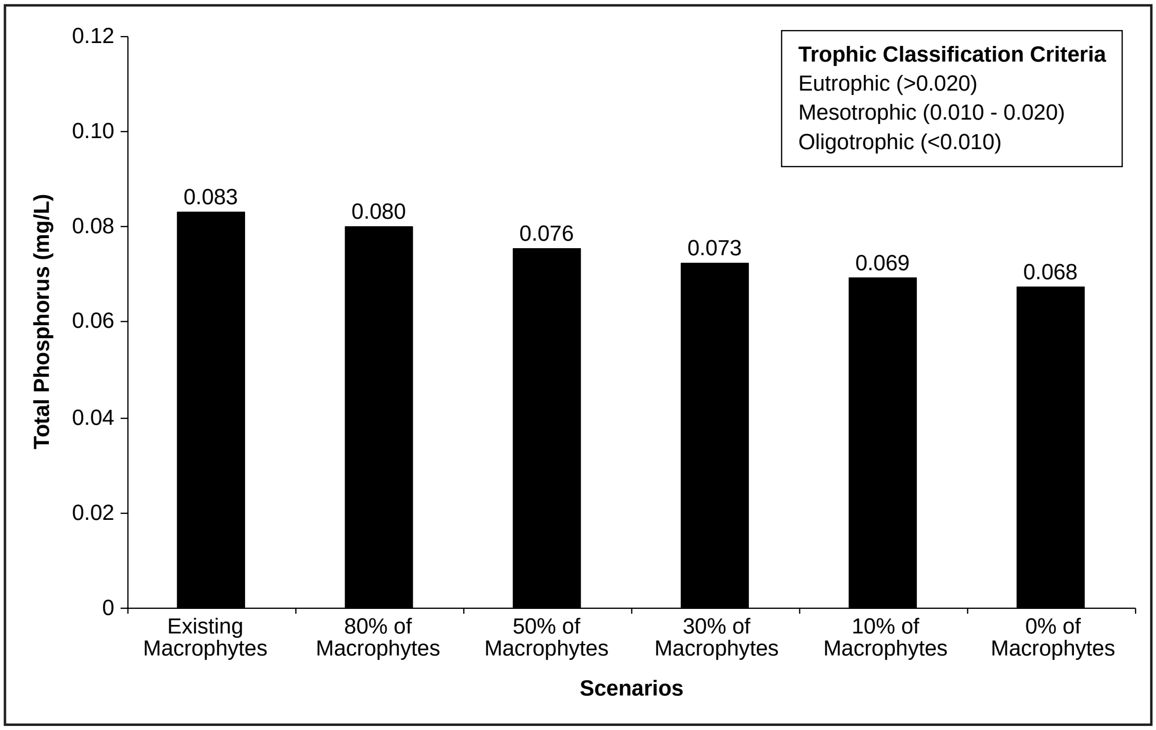


Figure 3-8. Effects of scaled reductions in macrophytes on total phosphorus concentrations in Rainbow Lake.

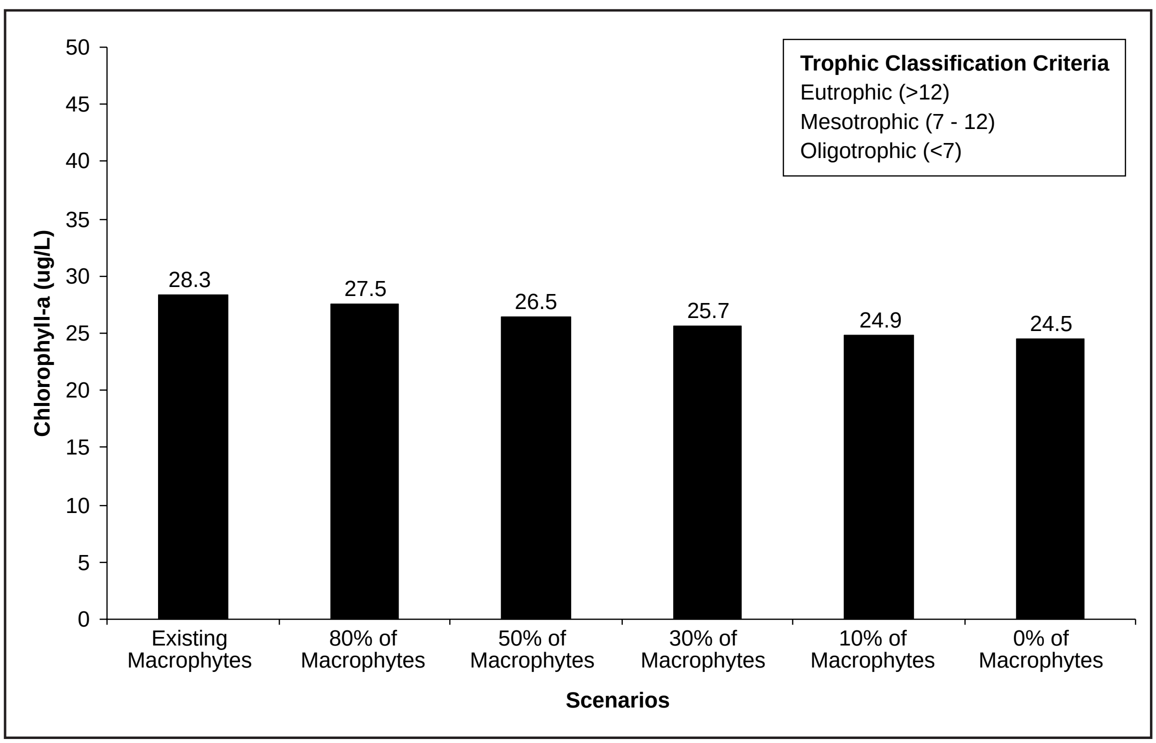


Figure 3-9. Effects of scaled reductions in macrophyte biomass on chlorophyll-a concentrations in Rainbow Lake.

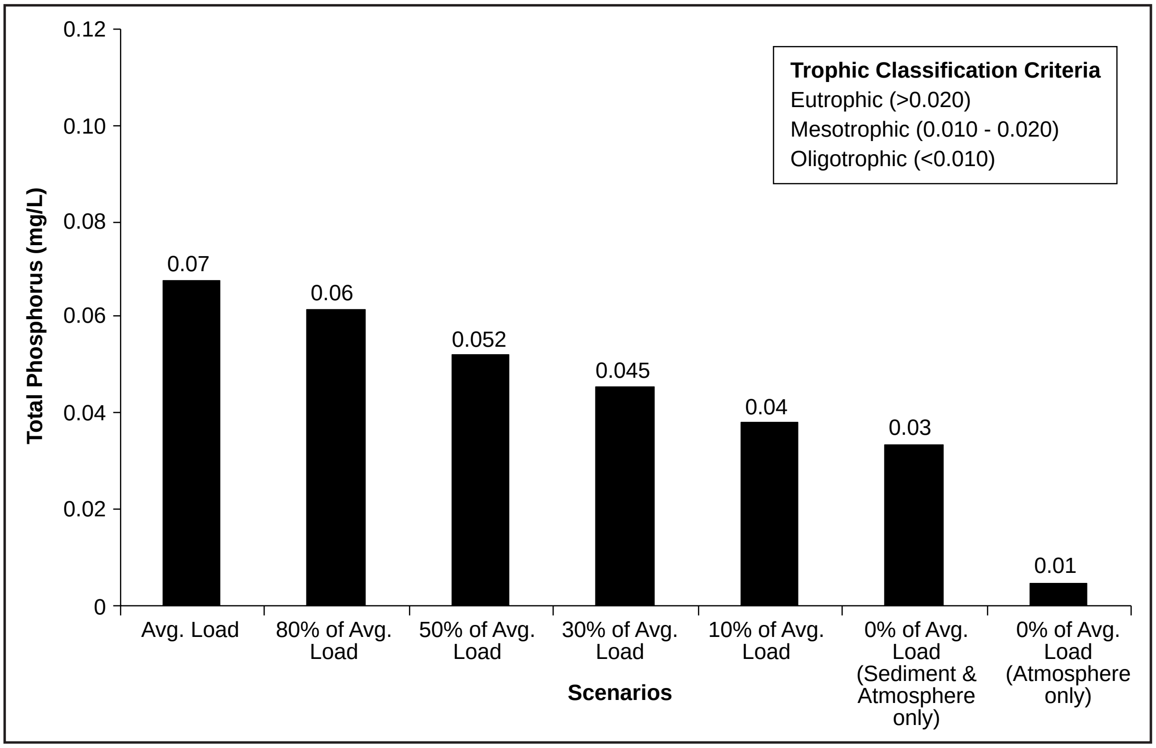


Figure 3-10. In-lake effects of zero macrophytes and scaled reductions in watershed nutrient loadings on total phosphorus concentrations in Rainbow Lake.

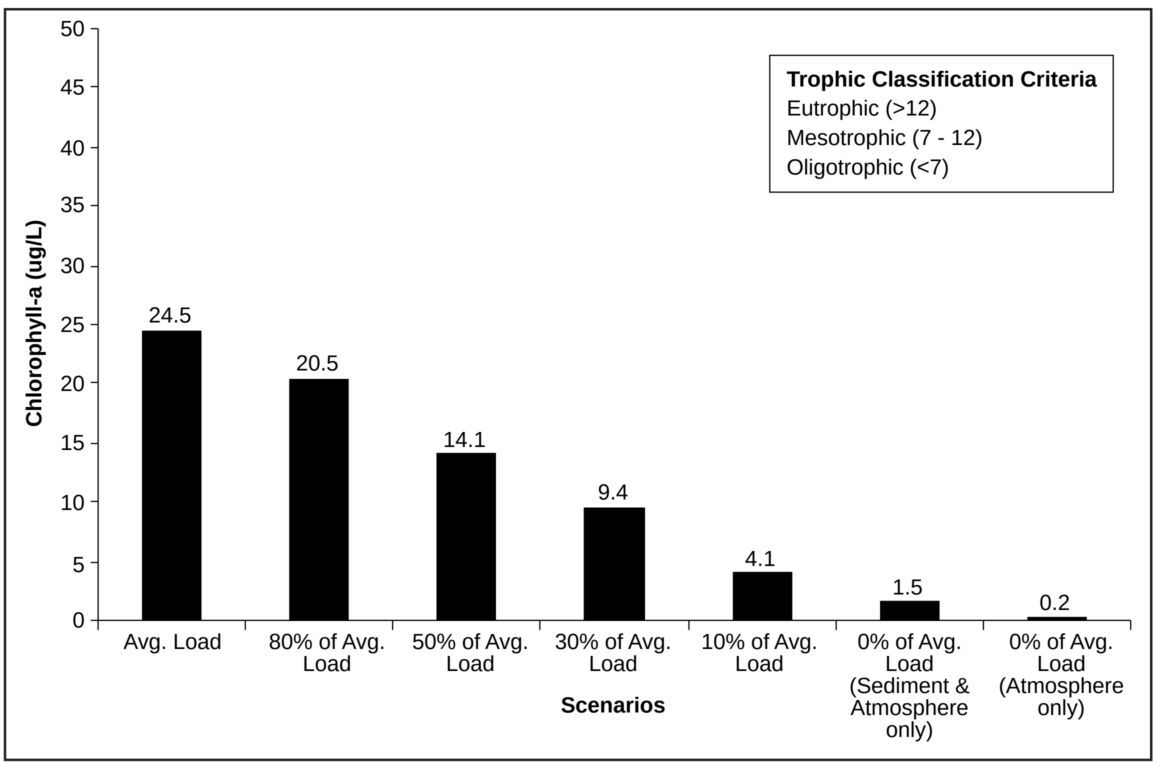


Figure 3-11. In-lake effects of zero macrophytes and scaled reductions in watershed nutrient loadings on chlorophyll-a concentrations in Rainbow Lake.

macrophyte shading on the predicted phytoplankton (chlorophyll-a) concentrations. This makes the predicted chlorophyll-a concentrations conservative, and explains why they may appear higher than the ADEQ monitoring data from 1992-1993. However, the predicted values are similar to the values measured by Baker and Farnsworth in 1995. Phytoplankton densities in Rainbow Lake are typically highest in the spring, before the macrophyte canopies have grown enough to block much of the light in the surface waters. As macrophyte densities are reduced through harvesting or through natural cycles of macrophyte declines, increases in the available light can be expected to produces greater phytoplankton densities, similar to those calculated in the BATHTUB predictions.

3.4.1 Effects of Scaled Reductions in Watershed Nutrient Loadings

Seven different scenarios were analyzed to predict the effects of scaled reductions in watershed nutrient loads to Rainbow Lake. These were (1) average watershed loads, (2) high precipitation watershed loads, (3) low precipitation watershed loads, (4) 80% of existing average loads, (5) 50% of existing average loads, (6) 30% of existing average loads, and (7) 10% of existing average loads. The effects of these scenarios are discussed in the following sections.

Total Phosphorus – The predicted total phosphorus concentration in the lake ranged from a low value of 0.055 mg/L under high flow load conditions to a high of 0.32 mg/L under low flow load conditions (Figure 3-6). The model predicted that total phosphorus concentrations in Rainbow Lake would decrease only moderately regardless of how much the external loads were reduced. A 90% reduction in average watershed loads produced only a 29% reduction in phosphorus. This is due to the importance of internal nutrient sources such as macrophyte decomposition and sediment release. Load variations associated with differences in watershed precipitation (i.e., high versus low flow years) produced the biggest response due to flushing effects. Using the flows and corresponding nutrient loads from the GWLF model, in-lake phosphorus concentrations were highest for the low load scenario, which appears contradictory. This was because lake flushing was reduced due to the low inflows, increasing the impacts of internal nutrient releases on water column concentrations. In addition, the nutrient concentrations in inflow water predicted by GWLF were higher for the low flow scenario than the high flow scenario due to less dilution of some load types during transport through the watershed. The high flow scenario reduced the total phosphorus concentration in the lake by 34% from the average loads, while the low flow scenario increased the total phosphorus concentration by 18%.

Rainbow Lake remained in the eutrophic category regardless of how much external phosphorus loads were reduced. This indicates that external loadings of phosphorus may be less important than internal cycling in the lake. This is further reinforced by the slight dilution of total phosphorus concentrations in the lake during periods of high watershed loads and flows and increased total phosphorus concentrations in the lake during periods of low flows and loadings.

Chlorophyll-a – The predicted chlorophyll-a concentrations in the lake ranged from a low value of 6.3 ug/L under high flow load conditions to a high of 43 ug/L under low flow load conditions (Figure 3-7). The model predicted that chlorophyll-a concentrations in Rainbow Lake could be reduced by 78% if external nutrient loads were reduced by 90%. This value may seem significant, however achieving a 90% reduction in external watershed loads would be extremely difficult (if not impossible). A more realistic approach would be to expect a 50% reduction in external nutrient loads, which could be achieved by effectively controlling septic systems and implementing BMPs for the other sources. A 50% reduction in external nutrient loads would reduce the in-lake chlorophyll-a concentration by approximately 40% to a value of 17 ug/L. Based in the Brezonick TSI, a chlorophyll level less than 20 ug/L should not result in extreme algae blooms as long as flushing is adequate. Also, the chlorophyll-a concentrations predicted here are somewhat higher than the ADEQ monitoring data for 1992-1993. This may be due in part to the fact that the BATHTUB model does not include the effects of macrophyte shading on algal growth.

3.4.2 Effects of Scaled Reductions in Macrophytes

Six different scenarios were analyzed to predict the effects of scaled reductions in macrophyte biomass in Rainbow Lake. All scenarios assumed average watershed loading conditions, since these are more representative of long-term conditions in the lake. The scenarios were (1) existing macrophytes, (2) 80% of existing macrophytes, (3) 50% of existing macrophytes, (4) 30% of existing macrophytes, (5) 10% of existing macrophytes, and (6) no macrophytes. The effects of these scenarios are discussed in the following sections.

Total Phosphorus – The predicted total phosphorus concentrations in the lake ranged from a low value of 0.068 mg/L under average load conditions with no macrophytes to a high of 0.083 mg/L under current average load and macrophyte conditions (Figure 3-8). Complete removal of lake macrophytes gained a reduction in total phosphorus of approximately 29 percent.

Macrophyte removal was a little less effective than the corresponding percent reductions in watershed loads. Part of this is due to the fact that macrophytes are currently not as abundant as they were 10 years ago. The model results indicated that they are less than 10% of previous densities. Rainbow Lake remained in the eutrophic category regardless of how much of the macrophytes were removed from the lake.

Chlorophyll-a – The predicted chlorophyll-a concentrations in the lake ranged from a low value of 24 ug/L under average load conditions with no macrophytes to a high of 28 ug/L under current average loads with existing macrophyte densities (Figure 3-9). The model predicted that chlorophyll-a concentrations in Rainbow Lake would be reduced by approximately 13% if all of the macrophytes were removed from the lake. Even though this amount of reduction is significant, the model predicts that a fairly high concentration of chlorophyll-a will remain in the lake. Macrophytes are currently much less abundant than they were 10 years ago, so their removal does not influence chlorophyll-a concentrations as much as it would have in the past.

3.4.3 Effects of Having No Macrophytes and Scaled Reductions in Watershed Nutrient Loadings

Seven different scenarios were analyzed to predict the effects of scaled reductions in watershed nutrient loadings together with total macrophyte removal. These scenarios illustrate the levels of watershed controls that would be required to significantly improve the water quality of Rainbow Lake, even if all macrophytes were eliminated, for example by the application of herbicides. Even though total macrophyte removal is not realistic due to the shallow depth of the lake, these scenarios are useful to examine the lake response to external loads under optimal conditions of minimum internal loading. The scenarios evaluated were (1) average watershed loads, (2) 80% of average loads, (3) 50% of average loads, (4) 30% of average loads, (5) 10% of average loads, (6) no watershed loads (0%) (sediment and atmospheric sources only), and (7) atmospheric sources only. The effects of these scenarios are discussed in the following sections.

Total Phosphorus – The predicted total phosphorus concentrations in the lake ranged from a low value of 0.038 mg/L under 10% of the existing average loading conditions without macrophytes to a high of 0.068 mg/L under existing average loading conditions with no macrophytes (Figure 3-10). The model predicted that total phosphorus concentrations in Rainbow Lake could be reduced by approximately 55% if external loads were reduced by 90% and macrophytes were eliminated. It is unreasonable to expect a 90% reduction of external nutrient loadings. A more realistic expectation is an external load reduction of 50% (achievable by reducing septic loads and implementing BMPs for other sources). This would reduce the in-lake total phosphorus concentration by approximately 37%. Two additional scenarios were predicted by the model. These scenarios reduced the nutrient inputs to sediment plus atmospheric sources only and atmospheric sources only. Based on these assumptions, total phosphorus concentrations in Rainbow Lake would be reduced to 0.034 and 0.005 mg/L, respectively.

Rainbow Lake remained in the eutrophic category for phosphorus even if all of the watershed loads and all of the macrophytes were eliminated. Sediment sources alone are sufficient to produce eutrophic conditions. Rainbow Lake could be classified as oligotrophic if only atmospheric sources were allowed to enter the lake.

Chlorophyll-a – The predicted chlorophyll-a concentrations in the lake ranged from a low value of 4.1 ug/L under 10% of the existing average loading conditions without macrophytes to a high of 25 ug/L under existing average loading conditions with no macrophytes (Figure 3-11). The model predicted that chlorophyll-a concentrations in Rainbow Lake would be reduced by 86% if all of the macrophytes were removed from the lake and external nutrient loads were reduced by 90%. Two additional scenarios were predicted by the model. These scenarios reduced the nutrient inputs to sediment plus atmospheric sources only and atmospheric sources only. Based on these assumptions, chlorophyll-a concentrations in Rainbow Lake would be reduced to 1.5 and 0.2 ug/L, respectively.

The model predicted that Rainbow Lake would remain eutrophic with respect to chlorophyll-a until all of the macrophytes were removed and external nutrient loads were reduced by more than 60%. The lake would become mesotrophic if 70% of the external loads were reduced and all macrophytes were removed. Oligotrophic conditions could be obtained if more than 80 or 90% of the external loads were reduced and macrophytes were eliminated.

The results of the model predictions indicated that, regardless of the different environmental conditions and scenarios that were modeled, Rainbow Lake would remain eutrophic according to the phosphorus criteria even if all watershed loads and macrophytes were eliminated and only sediment sources remained. The chlorophyll-a results are less stringent, suggesting that the lake could be mesotrophic if all macrophytes were removed and watershed loads were reduced by 60 or 70%, or even oligotrophic if all macrophytes were removed and watershed loads were reduced by more than 80 or 90%. Although it may be possible to reduce watershed nutrient loads to close to 50% by eliminating all septic systems and implementing BMPs in residential, commercial, and agricultural areas, this is not sufficient to obtain mesotrophic conditions in Rainbow Lake. Also, the shallow depths of Rainbow Lake make it impossible to eliminate all macrophytes without the intensive use of herbicides. Therefore, Rainbow Lake will probably remain eutrophic under any realistic loading scenarios. This is due to several factors:

- The shallow lake depth results in a large surface:volume ratio,
- A larger surface:volume ratio means that the relative contributions of sediment and atmospheric nutrients becomes greater,
- Shallow lake depth means that light can reach a large portion of the water column and stimulate phytoplankton and macrophyte growth, and
- Macrophyte growth enhances nutrient concentrations in the water through nutrient extraction from the abundant sediment pools and subsequent release to the water column during senescence.

It is unreasonable to expect external nutrient loadings to be restricted to sediment and atmospheric sources only. However, the model does predict that even though the lake would remain eutrophic, the overall water quality could be improved by implementing certain management practices that would result in reducing the degree of lake eutrophication. This would ultimately effect how frequently the narrative and numeric water quality standards are violated, and therefore, be more protective of the beneficial uses of the lake.

4.0 RECOMMENDATIONS FOR ALLOCATIONS, IMPLEMENTATION, AND MONITORING

The TMDL management objectives for Rainbow Lake are to bring the reservoir into compliance with the water quality standards for narrative nutrient and numeric pH. The purpose of this section is to present recommendations for residents within the Rainbow Lake watershed and the Arizona Department of Environmental Quality to consider that can be used to meet the TMDL management objective. The recommendations address four topics related to this TMDL study:

- How can nutrient loads within the watershed be apportioned to meet the TMDL management objective? The project team provides estimates for nutrient loading allocations for nutrients by source categories that will be necessary to partially achieve the TMDL management objectives. The allocations are presented as percent reductions required within each loading source category included in the analysis.

- What are some of the possible implementation alternatives available to the community and ADEQ to achieve the nutrient loading reductions that are required to meet water quality objectives? The community in consultation with ADEQ can best decide what the most acceptable and preferred mix of management options for achieving the desired nutrient reductions. The recommendations include infrastructure upgrades (e.g., mitigation of unused septic systems, extending sewer service, lining irrigation canals), lake dredging and macrophyte harvesting, and Best Management Practices (e.g., residential BMPs, and conservation irrigation practices).

- The TMDL will need to be a phased TMDL because of the uncertainty associated with the relationship between the stressor (nutrient loadings) and response indicators (e.g., phosphorus concentrations, pH, Chlorophyll a - algae concentrations, unionized ammonia, DO, macrophyte densities). The phased TMDL will need to include a monitoring component to better characterize the effect of management alternatives that are undertaken on in-lake nutrient concentrations and other in-lake processes (e.g., growth response of algae and macrophytes, pH fluctuations, ammonia toxicity). The ADEQ Clean Lakes Program will assist in designing a monitoring plan to: a) test the validity of the percentage reduction scenario adopted in the allocation plan, and b) track the in-lake success of TMDL implementation.

- This TMDL analysis identified the need for ADEQ, U.S. EPA, and stakeholders to consider whether the current water quality standards for shallow, high-mountain lakes are appropriate. Management of lake eutrophication (productivity) is vital to lake health. However, due to atmospheric effects on the buffering capacity of high elevation lakes, some degree of "natural background" higher pH is expected. ADEQ has prioritized the need to review the appropriateness of certain numeric standards and designated use criteria for shallow lake systems, as well as the interpretation of narrative nutrient standards.

4.1 Allocations

The following nutrient allocations and reductions may still result in occasional exceedances of in-lake pH and dissolved oxygen standards. However, the prescribed allocations will reduce the frequency, duration, and magnitude of water quality standard violations and significantly enhance the capability of Rainbow Lake to fulfill its designated uses. That is, Rainbow Lake will remain eutrophic but the degree of eutrophication will be reduced and maintained at a reduced level. The nutrient reduction objectives that are expressed in the allocations are targeted on nonpoint sources and in-lake sources of nutrients.

There were ten source categories identified in the source analysis and nutrient mass balance. These source categories included septic systems, residential landuse, commercial landuse, groundwater, agricultural landuse, barren land, forest land, range land, and two in-lake sources macrophyte decomposition and sediment release. The Rainbow Lake TMDL allocations are expressed as percent reductions from annual loading to the lake. Two different sets of allocation scenarios were analyzed. The results of both scenarios are included in this study to demonstrate the fact that there may be several load reduction scenarios that would achieve the TMDL. In both scenarios, four of the ten source categories were assigned allocations that would require reductions in source loadings from their existing levels. These include septic systems, residential landuse, macrophyte decomposition, and sediment release.

The first scenario represents a more extreme upper limit with 100% reduction in septic loads, 50% in residential loads, 50% removal of macrophytes (reducing loading from decomposition), and a 50% allocation from sediment release achieved through an optional dredging program. Both scenarios were evaluated with and without the dredging component. The second set of allocation scenarios represents a more realistic goal with

75% reduction in loading from septic, the other allocations remain the same as in the first scenario. ADEQ has selected Scenario 2 allocations; though dredging is not required for reduction in sediment release, it will remain a potential management option.

Tables 4-1 and 4-2 (Nitrogen Loading and Allocations) present the nitrogen loads and allocations for scenarios 1 and 2 respectively. Tables 4-3 and 4-4 (Phosphorus Loading and Allocations) present the corresponding phosphorus loads and allocations. Both the existing loads from the different source categories and their allocations (targeted percent reductions) are summarized in these tables. Information for three situations is included in each table, including estimates of existing loads, allocations with dredging, and allocations without dredging. The estimated ranges of total annual targeted reductions through the proposed allocations for the first set of scenarios (i.e., Scenario 1 with and without dredging) are 4,209 to 4,378 pounds of nitrogen, and 302 to 442 pound of phosphorus (Tables 4-1 and 4-3). The corresponding percent reductions in total nutrient loads are 52 to 54 percent for nitrogen and 26 to 38 percent for phosphorus. For the second set of scenarios, the estimated ranges of total annual targeted reductions through the proposed allocations are 3,509 to 3,678 pounds of nitrogen, and 302 to 442 pounds of phosphorus (Tables 4-2 and 4-4). The corresponding percent reductions in total nutrient loads are 43 to 46 percent for nitrogen and 26 to 38 percent for phosphorus.

The allocation scenarios were evaluated for their effect on in-lake water quality indicators using the BATHTUB model to simulate conditions within Luna Lake. Three water quality indicators were included in the analysis: total phosphorus, chlorophyll-a, and total nitrogen (Figures 4-1, 4-2, and 4-3).

The in-lake concentrations of total phosphorus were estimated to decrease from existing conditions by 26% in the no dredging scenario to a 38% decline in the dredging scenario. The range of total phosphorus concentrations predicted by the model range from 0.083 milligrams per liter under existing conditions to 0.054 in the dredging scenario. Even under the most stringent allocation scenario (i.e., with dredging), projected phosphorus concentrations would remain in the eutrophic range.

A similar pattern exists for total nitrogen and chlorophyll-a, with substantial reductions in water column concentrations for both parameters, although again, even with dredging, the estimated concentrations for chlorophyll-a also remain in the eutrophic range.

Table 4-1
Rainbow Lake Recommended Allocations for Nitrogen (Scenario 1)

Source Category	Existing Nitrogen Total Loading (TL) (Lbs/yr)	% Existing Total Watershed/ Lake Loading	% Targeted Reduction of Category	Amount Nitrogen Reduced (Lbs/yr)	Remaining Load (RL) (Lbs/yr)
Septic	2,800	35%	100%	2800	0
Residential	2,403	30%	50%	1,201.5	1,201.5
Commercial	816	10%	0%	0	816
Groundwater	683	8%	0%	0	683
Agriculture	375	5%	0%	0	375
Barren Land	154	2%	0%	0	154
Forest	44	0.5%	0%	0	44
Range	44	0.5%	0%	0	44
Macrophyte Decomposition	414	5%	50%	207	207
Sediment Release	339	4%	0%	0	339
(Dredging)			(50%)	(169.5)	(169.5)
Total	8,072	100%		4,208.5	3,863.5
(Dredging)				(4,378)	(3,694)

% of total existing nitrogen load remaining = 48%
= (46%)

% total watershed loadings of nitrogen reduced = 52%
= (54%)

Note: Numbers in parentheses represent values associated with the dredging scenario.

Table 4-2
Rainbow Lake Recommended Allocations for Nitrogen (Scenario 2)

Source Category	Existing Nitrogen Total Loading (TL) (Lbs/yr)	% Existing Total Watershed/ Lake Loading	% Targeted Reduction of Category	Amount Nitrogen Reduced (Lbs/yr)	Remaining Load (RL) (Lbs/yr)
Septic	2,800	35%	75%	2,100	700
Residential	2,403	30%	50%	1,201.5	1,201.5
Commercial	816	10%	0%	0	816
Groundwater	683	8%	0%	0	683
Agriculture	375	5%	0%	0	375
Barren Land	154	2%	0%	0	154
Forest	44	0.5%	0%	0	44
Range	44	0.5%	0%	0	44
Macrophyte Decomposition	414	5%	50%	207	207
Sediment Release	339	4%	0%	0	339
(Dredging)			(50%)	(169.5)	(169.5)
Total	8,072	100%		3,508.5	4,563.5
(Dredging)				(3,678)	(4,394)

% of total existing nitrogen load remaining = 57%
= (54%)

% total watershed loadings of nitrogen reduced = 43%
= (46%)

Note: Numbers in parentheses represent values associated with the dredging scenario.

Table 4-3
Rainbow Lake Recommended Allocations for Phosphorus (Scenario 1)

Source Category	Existing Phosphorus Total Loading (TL) (Lbs/yr)	% Existing Total Watershed/ Lake Loading	% Targeted Reduction of Category	Amount Phosphorus Reduced (Lbs/yr)	Remaining Load (RL) (Lbs/yr)
Septic	0	0%	100%	0	0
Residential	264	23%	50%	132	132
Commercial	88	8%	0%	0	88
Groundwater	66	6%	0%	0	66
Agriculture	44	4%	0%	0	44
Barren Land	44	4%	0%	0	44
Forest	22	2%	0%	0	22
Range	0	0%	0%	0	0
Macrophyte Decomposition	339	29%	50%	169.5	169.5
Sediment Release	280	24%	0%	0	280
(Dredging)			(50%)	(140)	(140)
Total	1,147	100%		301.5	845.5
(Dredging)				(441.5)	(705.5)

% of total existing phosphorus load remaining = 74%
= (62%)

% total watershed loadings of phosphorus reduced = 26%
= (38%)

Note: Numbers in parentheses represent values associated with the dredging scenario.

Table 4-4
Rainbow Lake Recommended Allocations for Phosphorus (Scenario 2)

Source Category	Existing Phosphorus Total Loading (TL) (Lbs/yr)	% Existing Total Watershed/ Lake Loading	% Targeted Reduction of Category	Amount Phosphorus Reduced (Lbs/yr)	Remaining Load (RL) (Lbs/yr)
Septic	0	0%	75%	0	0
Residential	264	23%	50%	132	132
Commercial	88	8%	0%	0	88
Groundwater	66	6%	0%	0	66
Agriculture	44	4%	0%	0	44
Barren Land	44	4%	0%	0	44
Forest	22	2%	0%	0	22
Range	0	0%	0%	0	0
Macrophyte Decomposition	339	29%	50%	169.5	169.5
Sediment Release	280	24%	0%	0	280
(Dredging)			(50%)	(140)	(140)
Total	1,147	100%		301.5	845.5
(Dredging)				(441.5)	(705.5)

% of total existing phosphorus load remaining = 74%
= (62%)

% total watershed loadings of phosphorus reduced = 26%
= (38%)

Note: Numbers in parentheses represent values associated with the dredging scenario.

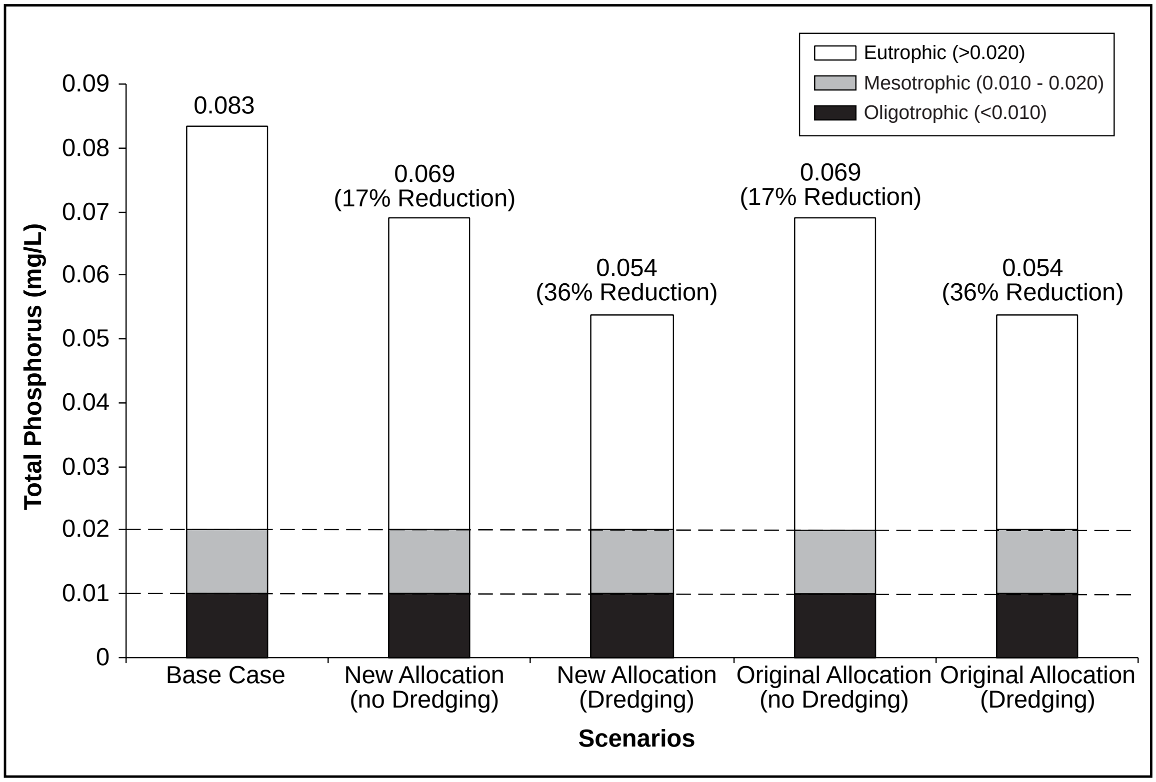


Figure 4-1. Effects scenarios of remedial actions on total phosphorus concentrations in Rainbow Lake.

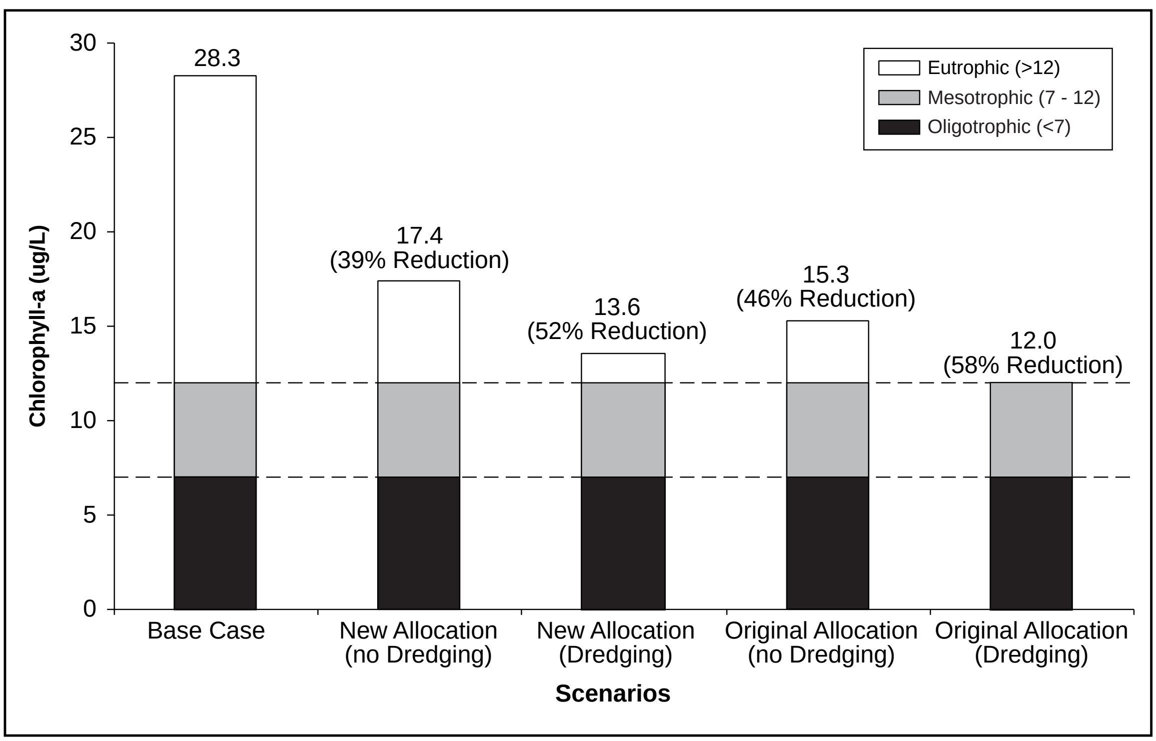


Figure 4-2. Existing scenarios of remedial actions on chlorophyll-a concentrations in Rainbow Lake.

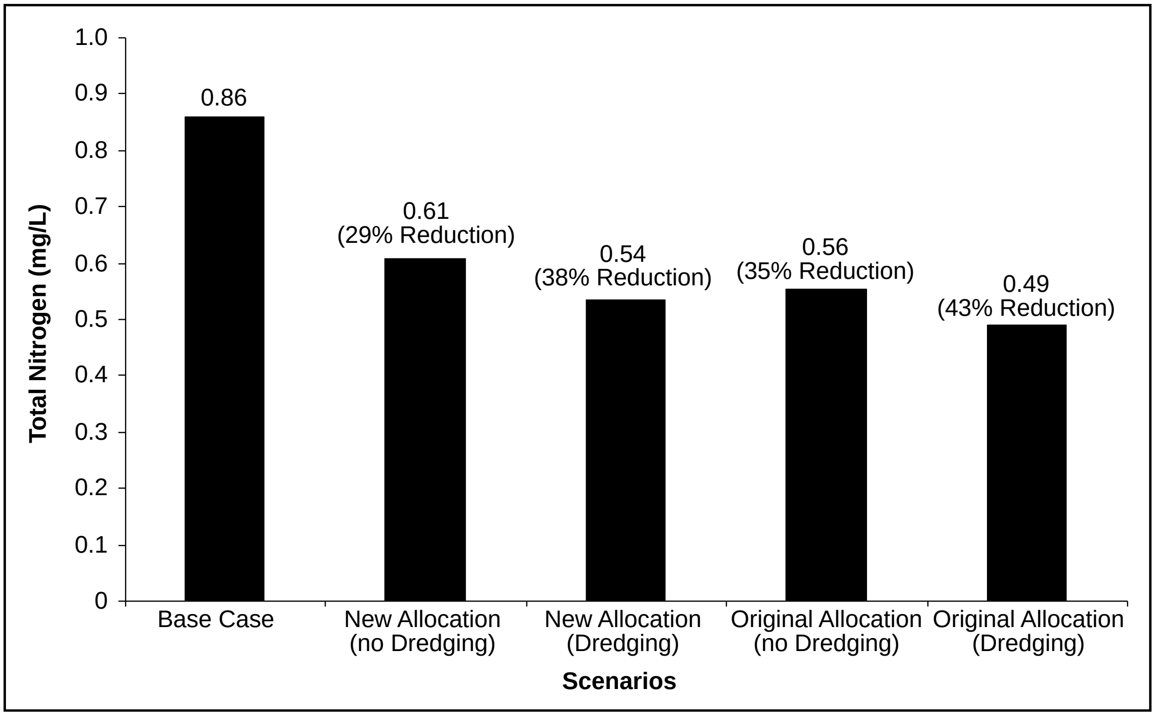


Figure 4-3. Effects scenarios of remedial actions on total nitrogen concentrations in Rainbow Lake.

As mentioned, total nitrogen is used on a case-by-case basis in ADEQ's trophic classification index when data indicate nitrogen may be the limiting nutrient for algal growth. Ratios for Rainbow Lake suggest co-limitation by phosphorus and nitrogen. With or without dredging, the projected reduction in total nitrogen concentration under Scenario 2 falls into the eutrophic range. However, even without dredging, the projected 30% reduction is expected to make a significant difference.

The allocations for individual source categories are discussed in greater detail below.

Septic: Nutrient loading from septic systems uses an estimate of 100 year round and 1,000 seasonal systems within the vicinity of the lake. This estimate is based on discussions with officials from local agencies and model calibration adjustments. The estimated lake loading for phosphorus and nitrogen from septic tanks is 0 pounds per year for phosphorus and 2,800 pounds per year for nitrogen. The nitrogen allocation for septic is a 75% reduction or 2,100 pounds per year. This allocation reduces the total nitrogen loading to the lake by approximately 26% (8,072 pounds to 5,972 pounds). Controlling nitrogen is a TMDL nutrient objective because nitrogen can be the limiting nutrient for algal growth. Also, reducing nitrogen will reduce ammonia concentrations. Algal growth contributes to extreme pH swings, which also contribute to ammonia toxicity.

Residential: The residential source category makes significant contributions to both the nitrogen and phosphorus loads to Rainbow Lake. Residential source loadings are estimated to contribute 2,403 pounds of nitrogen and 264 pounds of phosphorus to Rainbow Lake each year. The allocation for phosphorus and nitrogen is a 50% reduction per year to 1,202 pounds for nitrogen and 132 pounds for phosphorus.

Sediment Release: The allocation for sediment release will require that Rainbow Lake be dredged to remove the nutrient rich layer of deposited material on the bottom of the lake. The allocation for this category must account for some level of natural background release of nutrients that will come from the newly exposed soil following dredging. The estimate allocation of a 50% reduction is believed to be conservative and takes into consideration sediments will begin accumulating immediately and serve as a new source of nutrients. Sediment release is estimated to contribute 339 pounds of nitrogen and 280 pounds of phosphorus each year. The allocation of 50% reduces this source to 170 pounds of nitrogen and 140 pounds of phosphorus.

Macrophyte Decomposition: Assigning macrophyte decomposition an allocation assumes that a regular macrophyte harvest program will be maintained. Macrophyte decomposition is the single largest source of phosphorus to Rainbow Lake contributing 339 pounds per year, which is 29% of the total load. Macrophyte decomposition is estimated to contribute 5% of (414 pounds) of the annual nitrogen load.

TMDL Margin of Safety

TMDLs must include a Margin of Safety that assures water quality standards will be met. The following list of factors that were included in the technical analysis comprise the Margin of Safety for the Rainbow Lake TMDL:

- The watershed loading model (GWLF) evaluated loadings over a long period of time that included a wide range of climatic, precipitation, and flow patterns. The analysis included extreme high and low flow events over the period of record providing boundaries for the assessment.

- The in-lake process analysis did not include the effect of shading by macrophytes on algal production in the lake.

- In the nutrient budget calculations the project team assumed high macrophyte densities for the nutrient release flux from macrophyte decomposition.

4.2 Implementation Options

Septic: The septic allocation is confounded by inconsistent information on the number of septic systems remaining in use in the Rainbow Lake area. Therefore, the first step for implementation for the septic allocation is to conduct a survey to determine the number of remaining systems that are in use and the extent to which unused systems are continuing to leach. The community could then consider the benefits of mitigating unused systems and active systems that are not functioning properly. If there are a large number of active systems the community could consider extending sewer lines to unserviced areas near the lake.

Residential: Residential nutrients loads are a result of increased impervious surface and soil amendments (e.g., fertilizers for lawns) used by residents, among other materials associated with development. There are many voluntary BMPs that could be used to reduce runoff from residential areas and other development. ADEQ's Nonpoint Source program can be consulted for specific techniques and potential sources of funding for BMP implementation. The 50% reduction targeted by this allocation is not an unrealistic goal for a well conceived program of BMPs for the Pinetop community.

Dredging: Dredging addresses the sediment release source category by removing the nutrient rich layers of soil that have been deposited on the lake bottom. The dredging goal would remove the top meter of sediments that have accumulated most of the nutrients (Baker and Farnworth 1995). The soils below the accumulated sediments also contain nutrients. Therefore, it is not possible to remove 100% of the nutrients released from the sediments. Dredging would also improve water quality conditions by increasing the depth of the lake limiting the reemergence of macrophytes in certain portions of the lake. Dredging would also increase the storage capacity of the reservoir. The feasibility of dredging is discussed in detail Baker and Farnsworth 1995.

Macrophyte Harvest: Macrophyte decomposition is addressed both through dredging and macrophyte harvesting. Macrophytes would be largely eliminated by any dredging operation, but only temporarily. Macrophytes are known to thrive even in oligotrophic conditions. Macrophytes will re-colonize Rainbow Lake within a short period time after dredging has been completed. The well-established macrophyte harvest program should address this allocation requirement. There are other management options that can be considered other than mowing. Biological control of macrophytes is a potential alternative.

Other Best Management Practices: This implementation option does not directly address any of the source category allocations. However, Best Management Practices that would help maintain higher levels of water in the lake could significantly contribute to improved water quality. These BMPs would be directed to improving the efficiency of irrigation water that is drawn from the lake, possibly reducing the total amount of water that would need to be taken from the lake. In addition, lining irrigation canals from the lake would reduce seepage losses. The increased volume would serve to dilute the remaining nutrients thus reducing overall algal productivity. The emergence of macrophytes on exposed lakebed would also be slowed. Use of a flocculent to control sediment nutrient release, and/or non-toxic shading compounds or trophic manipulation to control algal growth, may also be explored.

Watershed Forum: Rainbow Lake provides different beneficial uses to a wide range residents within the Pinetop community and surrounding areas. Many of the implementation recommendations will require local support and initiative. The local community may want to consider forming a watershed forum to build support for the nonpoint source BMPs that will be necessary to improve water quality in Rainbow Lake. A watershed forum would provide residents with a mechanism for coordinating activities to design, pursue funding for, and apply solutions to water quality problems within the Rainbow Lake watershed. ADEQ has a watershed approach program that could provide general assistance to the forum upon request from the local community.

4.3 Monitoring

ADEQ, the local community, and other cooperating agencies should consider initiating a monitoring program for Rainbow Lake to assess whether the overall objectives of this TMDL study are being met (i.e., no violations of narrative nutrient and numeric pH water quality standards).

Currently, Rainbow Lake is classified as being a eutrophic water body. Ideally, this TMDL would recommend methodologies that would improve the trophic status of the lake and result in Rainbow Lake being reclassified as mesotrophic. However, model predictions indicate that this level of improvement is most likely unattainable. This does not mean, however, that the water quality of the lake cannot be improved. As mentioned in section 3.5, Rainbow Lake's eutrophic status can be improved by degrees. This improvement can be achieved via the various management procedures that have been discussed above. With this in mind, the specific objective of this monitoring program is to assess whether the management procedures are achieving their stated objectives and improving the water quality of Rainbow Lake.

There is a crucial need for a monitoring program for the parameters that have are identified as water quality indicators within this TMDL study. ADEQ, the local community, and other cooperating agencies must have a monitoring program in place because of key uncertainties that could exist in estimating pollutant loading and in predicted lake response. The TMDL management activities that are undertaken to achieve the recommended allocations should be guided by responses measured through a monitoring program, rather than estimates provided in this study.

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