Red Rock Lake
Use Attainability Analysis

Prepared for
Riley-Purgatory-Bluff Creek Watershed District

June 2006

Executive Summary

Overview

This report contains the results of a Use Attainability Analysis (UAA) of Red Rock Lake. The UAA is a structured scientific assessment of the chemical, physical, and biological conditions in a water body. The analysis includes diagnosis of the causes of observed problems and prescription of alternative remedial measures (such as a diagnostic-feasibility study) that will result in the attainment of the intended beneficial uses of Red Rock Lake. The analysis is based upon historical water quality data, results of an intensive lake monitoring program in 1999, sediment sampling in 2003 and 2005, evaluations of the application of best management practices for the watershed, and computer simulations of watershed runoff. Computer simulations were used to estimate watershed runoff (phosphorus and flow) under existing and proposed future land use and under varying climatic conditions.

Riley-Purgatory-Bluff Creek Watershed District Water Quality Goals

The approved *Riley-Purgatory-Bluff Creek Watershed District Water Management Plan,* 1996, articulated five specific goals for Red Rock Lake. These goals address recreation, water quality, aquatic communities, water quantity, and wildlife. Wherever possible, Riley-Purgatory-Bluff Creek Watershed District (RPBCWD) goals for Red Rock Lake have been quantified using a standardized lake rating system termed Carlson's Trophic State Index (Carlson 1977). This rating system considers the lake's total phosphorus, chlorophyll *a*, and Secchi disc transparency measurements to assign it a water quality index number that reflects its general level of fertility. The resulting index values generally range between 0 and 100, with increasing values indicating more fertile conditions.

Total phosphorus, chlorophyll *a*, and Secchi disc transparency are key water quality parameters upon which Carlson's Trophic State Index (TSI) statistics are computed, for the following reasons:

- Phosphorus generally controls the growth of algae in lake systems. Of all the substances needed for biological growth, phosphorus is typically the limiting nutrient.
- Chlorophyll *a* is the main pigment in algae. Therefore, the amount of chlorophyll *a* in the water indicates the abundance of algae present in the lake.
- Secchi disc transparency is a measure of water clarity and is inversely related to the abundance of algae.

Although any one or all three parameters can be used to compute TSI, water transparency is most often used, since people's perceptions of water clarity are most directly related to recreational use impairment. The TSI rating system is scaled to place a mesotrophic (medium fertility level) lake on the scale between 40 and 50, and high and low fertility lakes (eutrophic and oligotrophic) toward the high and low ends of the TSI range, respectively. Characteristics of lakes in different trophic status categories are listed below with their respective TSI ranges:

1. **Oligotrophic**—[20 ≤ TSI ≤ 38] clear, low productivity lakes, with total phosphorus concentrations less than or equal to 10 μg/L, chlorophyll *a* concentrations less than or equal to 2 μg/L, and Secchi disc transparencies greater than or equal to 4.6 meters (15 feet).
2. **Mesotrophic**—[38 ≤ TSI ≤ 50] intermediate productivity lakes, with 10 to 25 μg/L total phosphorus, 2 to 8 μg/L chlorophyll *a* concentrations, and Secchi disc measurements of 2 to 4.6 meters (6 to 15 feet).
3. **Eutrophic**—[50 ≤ TSI ≤ 62] high productivity lakes, with 25 to 57 μg/L total phosphorus, 8 to 26 μg/L chlorophyll *a* concentrations, and Secchi disc measurements of 0.85 to 2 meters (2.7 to 6 feet).
4. **Hypereutrophic**—[62 ≤ TSI] extremely productive lakes, with total phosphorus concentrations greater than 57 μg/L, chlorophyll *a* concentrations greater than 26 μg/L, and Secchi disc measurements less than 0.85 meters (less than 2.7 feet).

The RPBCWD goals for Red Rock Lake include the following:

1. The **Recreation Goal** is to provide water quality that fully supports the lake's MDNR ecological class 42 rating (i.e., a Trophic State Index (TSI_{SD}) of 59 or lower). This goal is attainable with the implementation of lake management practices as described in this UAA.
2. The **Water Quality Goal** is a trophic state index score that meets or exceeds the necessary level to attain and maintain full support of fishing. A Trophic State Index (TSI_{SD}) of 59 or lower fully supports the lake's fishery. This goal is attainable with the implementation of lake management practices discussed in this UAA.
3. The **Aquatic Communities Goal** is a water quality that fully supports fishing, according to the Minnesota Department of Natural Resources (MDNR) "Ecological Use Classification." This goal is attainable with the implementation of lake management practices listed herein.
4. The **Water Quantity Goal** for Red Rock Lake is to manage surface water runoff from a regional flood, the critical 100-year frequency storm event. This goal has been achieved.
5. The **Wildlife Goal** for Red Rock Lake is to protect existing, beneficial wildlife uses. The wildlife goal has been achieved.

Minnesota Pollution Control Agency Standard

A Minnesota Pollution Control Agency standard for shallow lakes has been proposed and is expected to be finalized in 2006. The total phosphorus standard for shallow lakes in the Twin Cities

Metropolitan Area (North Central Hardwood Forest Ecoregion) is a concentration of 60 μg/L or less. The Secchi disc standard is at least 1.0 meters. The shallow lakes standard has been set with the intention "to permit the propagation and maintenance of a healthy community of cool or warm water sport or commercial fish and associated aquatic life, and their habitats. These waters shall be suitable for aquatic recreation of all kinds, including bathing, for which the waters may be usable." The standard is found in proposed changes to Minnesota Rules Chapter 7050.0222, Subp. 4. Class 2B Waters. This standard can be met with the implementation of lake and watershed management practices as described in this UAA.

Water Quality Problem Assessment

An evaluation of water quality data for Red Rock Lake from 1972 to 1999 was completed to determine the current status of the lake's water quality. Results of this evaluation indicate that the lake's water quality is poor and has basically remained in this condition over time. The poor water quality has its origins in historical and current inputs of phosphorus and the accumulation of phosphorus in lake sediments. The poor water quality of Red Rock Lake is perpetuated by the presence of invasive submersed aquatic vegetation (*Potamogeton crispus*, i.e. curlyleaf pondweed), phosphorus release from sediments, inputs of storm water runoff that is high in phosphorus, and inputs of waters from Mitchell Lake (i.e, its outflow waters) which is of poor water quality.

Historical Water Quality Trends

Trend analyses from 1972 through 1999 indicate that there has been no significant change in Red Rock Lake's water quality. The results of the regression analyses indicate that Secchi disc transparency has decreased at a rate of 0.02 meters per year; chlorophyll *a* concentration in the surface waters (upper 6 feet) has increased at the rate of 0.44 μg/L per year; and total phosphorus concentration in the surface waters has been increasing at a rate of 0.67 μg/L per year. The changes in Secchi disc, chlorophyll *a,* and total phosphorus are not significantly different from zero. Hence, the data indicate the lake's current water quality problems are unlikely to be reduced unless management practices are implemented to improve the lake's water quality.

A comparison between baseline (i.e., 1972 to 1987) and current (1988 to 1999) trophic state index (TSI) values indicates that Red Rock Lake met the MDNR-criteria ($TSI_{SD}<59$) for the lake's fishery during the baseline period, but not during the current period. The data indicate the lake is unlikely to meet MDNR criteria unless management practices are implemented to improve the lake's water quality.

Current Water Quality

The current water quality of Red Rock Lake is poor and recreational activities are impaired by invasive aquatic vegetation growth, curlyleaf pondweed (*Potamogeton crispus*), and summer algal blooms that are very severe. In 1999 Red Rock Lake's average summer concentration of total phosphorus, concentration of chlorophyll *a*, and Secchi disc transparency were 86 µg/L, 49 µg/L, and 0.9 m, respectively. This current water quality condition of Red Rock Lake is largely the result of storm water inputs with high levels of phosphorus, historical inputs of sediment and phosphorus, and the current influence of invasive aquatic plants on the mobilization of phosphorus from lake sediments. As a result, the 1999 total phosphorus, chlorophyll *a*, and Secchi disc data indicate that Red Rock Lake ranges from eutrophic to hypereutrophic in the summer.

Phosphorus Budget

There are five major sources of phosphorus loading to Red Rock Lake: stormwater inputs from the lake's watershed, inputs from Mitchell Lake, release of phosphorus from lake sediments, the release of phosphorus from decaying aquatic plant material (curlyleaf pondweed), and atmospheric deposition. Watershed modeling and in-lake modeling under different climatic conditions and for existing watershed land uses indicates that annual total phosphorus loads to the lake range from 333 pounds for a dry year to 765 pounds for a wet year (Figure EX-1). The average rate of watershed loading to the 97-acre lake is 3.8 pounds of phosphorus per acre of lake per year under existing watershed land use conditions and 5.5 pounds of phosphorus per acre of lake per year under future land use conditions. This rate of phosphorus loading is excessive and causes water quality problems (L = 0.43 $g/m^2/yr$ under existing watershed land uses; L = 0.61 $g/m^2/yr$ under future land uses).

Watershed modeling for the 1,262-acre Red Rock Lake watershed shows that from 175 (dry year) to 607 (wet year) pounds of phosphorus loading to the lake originates from the surrounding watershed. During an average year watershed loading provides approximately 44 percent of the total phosphorus load to the lake, while internal loading (phosphorus loading during the summer from lake sediments and decaying plant material) provides approximately 30 percent of the total phosphorus load to the lake (Figure EX-2). During an average year, outflow from Mitchell Lake contributes approximately 13 percent of the total phosphorus load to the lake. The remaining phosphorus load comes from atmospheric deposition (13 percent).

During an average year, the high concentration of phosphorus that is observed in Red Rock Lake is significantly affected by internal lake processes that mobilize phosphorus from lake sediments by direct release of phosphorus from the sediments and by uptake and subsequent release of phosphorus by submerged aquatic plants. For an average year it is estimated that the direct release of phosphorus from Red Rock Lake bottom sediments is responsible for approximately 20 percent of the total phosphorus load to Red Rock Lake while aquatic plants are responsible for 10 percent of the total phosphorus load to Red Rock Lake.

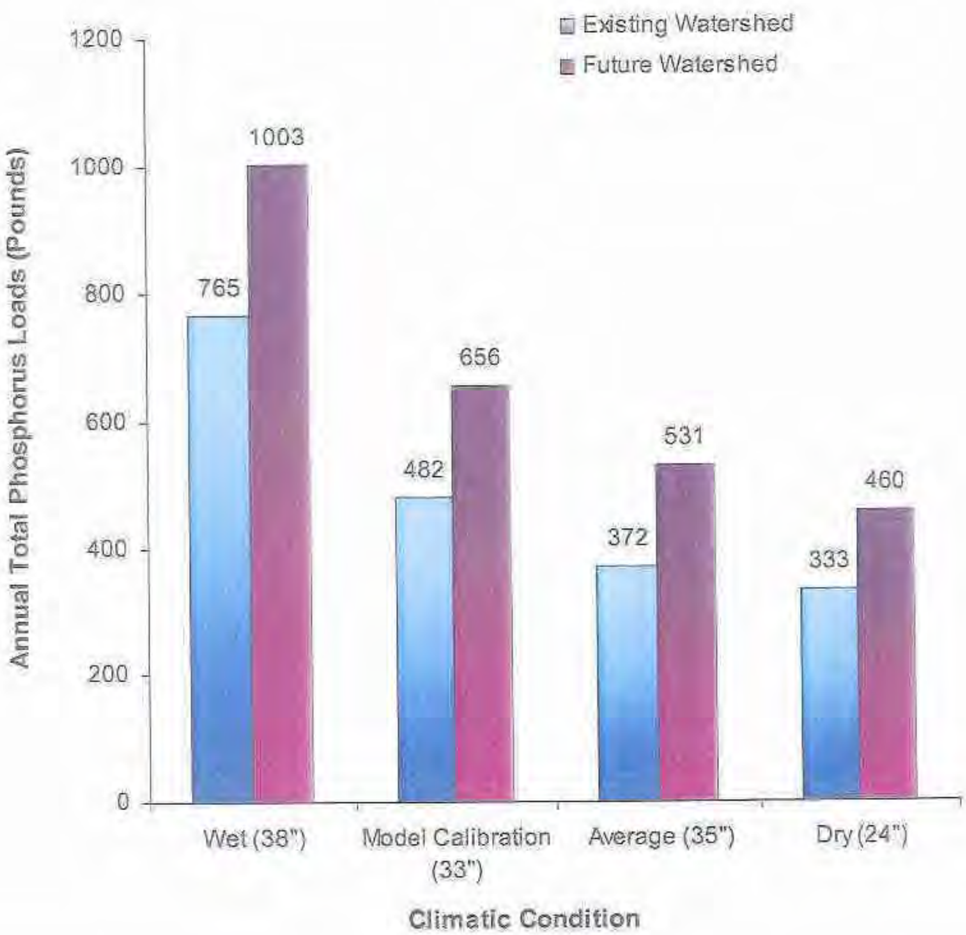

Figure EX-1 Total Phosphorus Loading to Red Rock Lake with Varying Climatic Conditions and with Existing and Future Watershed Land Uses

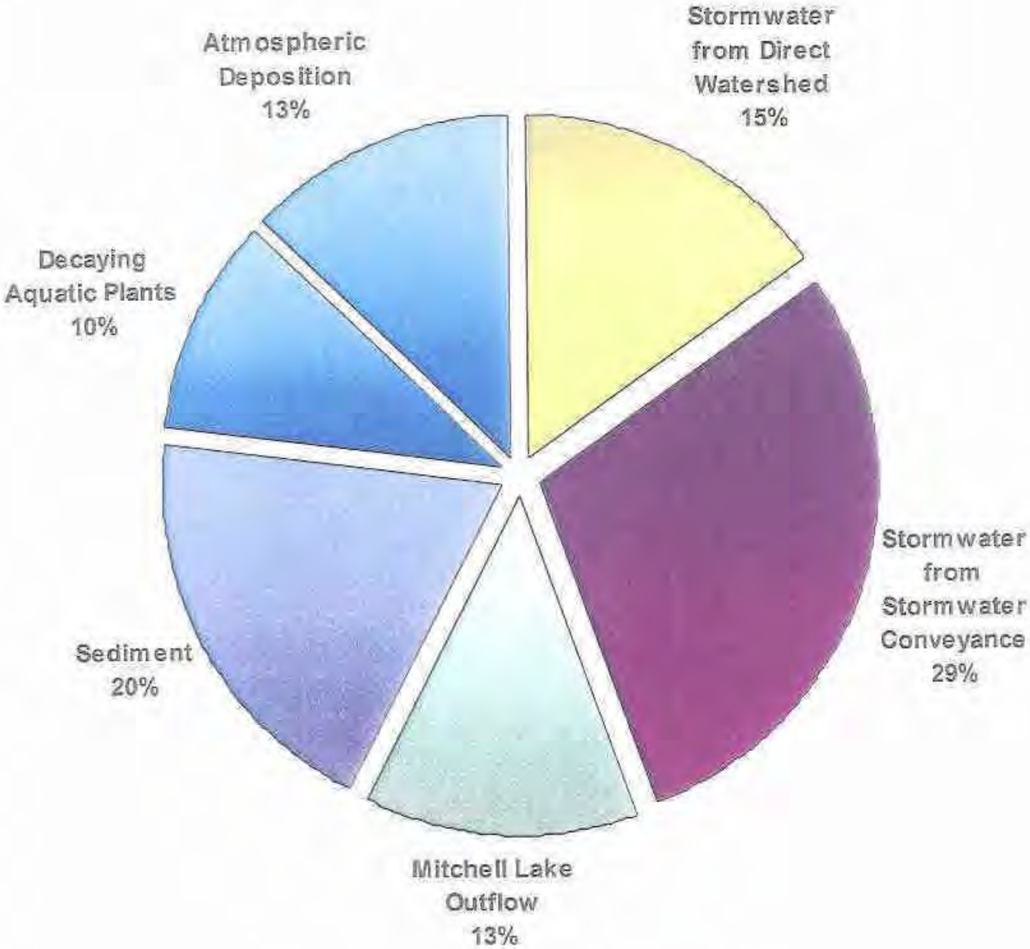

Figure EX-2 Proportion of Phosphorus Loading by Source (Average Climatic Condition, Existing Land Use)

Aquatic Plants

Macrophyte surveys were completed in Red Rock Lake on June 25 and August 27, 1999. The exotic (nonnative) species, curlyleaf pondweed (*Potamogeton crispus*), was found throughout the lake's littoral zone (i.e., at depths six feet or less) during June. The annual die-off of this plant in June released phosphorus to the lake, contributing towards increased algal growth for the remainder of the summer. In 2005, aquatic plant coverage of Red Rock Lake increased and curlyleaf pondweed coverage increased accordingly. In 1999, submersed aquatic plants covered a total area of 39.5 acres, 41 percent of the lake's surface area. During 2005, submersed aquatic plants covered a total area of 85.2 acres, 88 percent of the lake's surface area. Management of curlyleaf pondweed is recommended to protect the lake's water quality, protect the native plant community, to improve the lake's fishery, and to insure that curlyleaf pondweed does not dominate the aquatic plant community when the clarity of Red Rock Lake improves.

Recommended Goal Achievement Alternatives

One lake improvement alternative will achieve or exceed the District goal during all but the future wet climatic condition.

1) Manage curlyleaf pondweed in Red Rock and Mitchell lakes by herbicide (endothall) until no regrowth is observed and no viable turions are collected (estimate 4 years),

2) Introduce beetles (Galeracella pusilla, Galeracella calmariensis) in purple loosestrife infested areas to control shoreline purple loosestrife, and

3) Four consecutive years of alum treatment of Red Rock Lake and Mitchell Lake to follow the second year of herbicide treatment .

Should current research efforts determine that lime is a better tool for the management of curlyleaf pondweed than herbicide treatment, four years of alum-lime treatment will replace items (1) and (3).

The expected cost and benefits of this alternative is presented in Table EX-1 and Figure Ex-3.

Table EX- 1. Benefits and Costs of Management Alternatives

Management Alternative	Trophic State Index (TSI_{SD}) Value				Cost
	District Goal	Wet Year_1997 (38 inches of precipitation)	Average Year_1999 (35 inches of precipitation)	Dry Year_2000 (24 inches of precipitation)	
Existing Watershed Land Uses					
Herbicide Treatment (4 years), Alum Treatment (4 years), and Purple Loosestrife Management by Beetles Introduction	≤ 59	59	53	57	$1,100,000
Future Watershed Land Uses					
Herbicide Treatment (4 years), Alum Treatment (4 years), and Purple Loosestrife Management by Beetles Introduction	≤ 59	63	56	57	$1,100,000

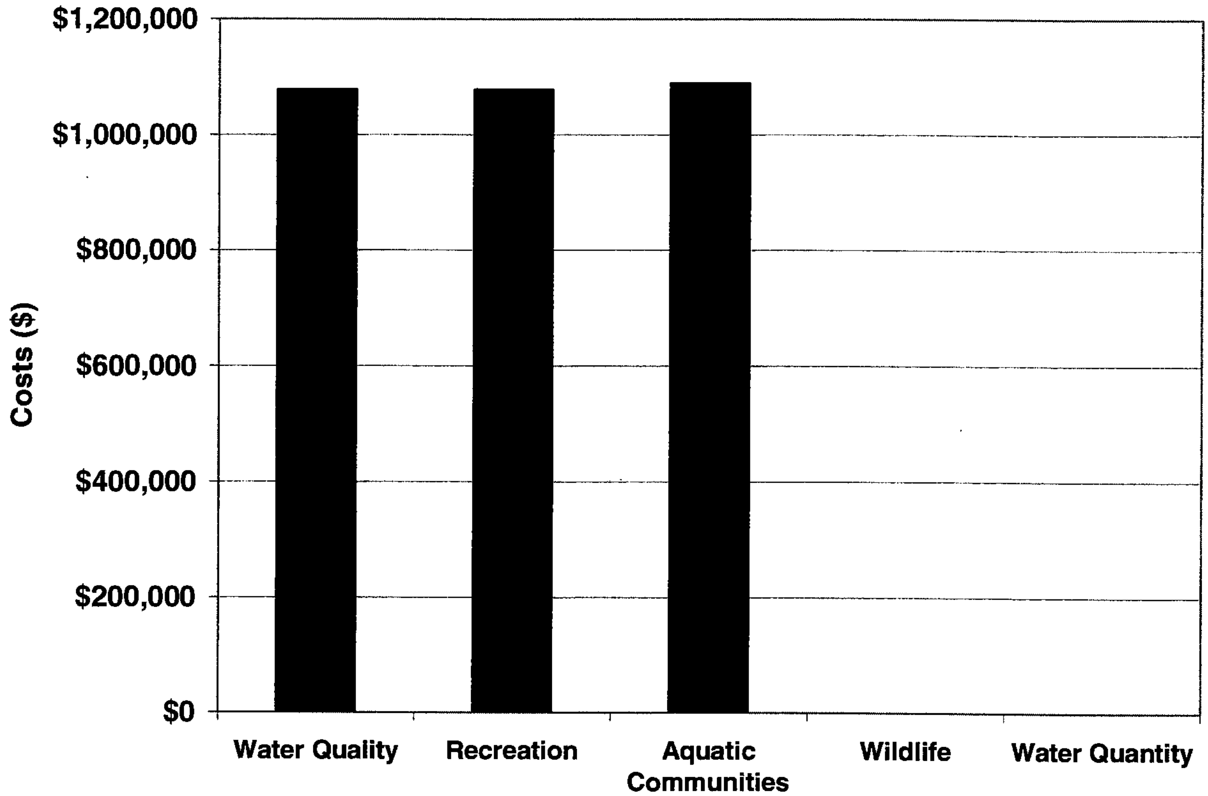

Figure EX-3 Costs to Meet or Exceed Goals Under All But the Wet Climatic Condition

Cost details of this management alternative are presented in Table EX-2.

Table EX-2. Cost Details of Management Alternative*

Year	Treatment or Sample Type	Red Rock Lake	Mitchell Lake**	Red Rock Lake and Mitchell Lake
1	Endothall ™ Treatment	$31,373	$37,574	$68,947
	Aquatic Plant Survey	$11,400	$11,400	$22,800
	Purple Loosestrife Survey	$2,850	-	$2,850
	Subtotal	**$45,623**	**$48,974**	**$94,597**
2	Endothall ™ Treatment	$31,373	$37,574	$68,947
	Aquatic Plant Survey	$11,400	$11,400	$22,800
	Purple Loosestrife Survey	$2,850	-	$2,850
	Subtotal	**$45,623**	**$48,974**	**$94,597**

Year	Treatment or Sample Type	Red Rock Lake	Mitchell Lake**	Red Rock Lake and Mitchell Lake
3	Endothall ™ Treatment	$31,373	$37,574	$68,947
	Aquatic Plant Survey	$11,400	$11,400	$22,800
	Purple Loosestrife Survey	$2,850	-	$2,850
	Lake WQ Monitor	$11,400	$11,400	$22,800
	Alum Treatment	$40,128	$43,662	$83,790
	Subtotal	**$97,151**	**$104,036**	**$201,187**
4	Endothall ™ Treatment	$31,373	$37,574	$68,947
	Aquatic Plant Survey	$11,400	$11,400	$22,800
	Purple Loosestrife Survey	$2,850	-	$2,850
	Lake WQ Monitor	$11,400	$11,400	$22,800
	Alum Treatment	$40,128	$43,662	$83,790
	Sediment Monitor	$2,280	$2,280	$4,560
	Subtotal	**$99,431**	**$106,316**	**$205,747**
5	Aquatic Plant Survey	$11,400	$11,400	$22,800
	Lake WQ Monitor	$11,400	$11,400	$22,800
	Alum Treatment	$40,128	$43,662	$83,790
	Sediment Monitor	$2,280	$2,280	$4,560
	Subtotal	**$65,208**	**$68,742**	**$133,950**
6	Aquatic Plant Survey	$11,400	$11,400	$22,800
	Lake WQ Monitor	$11,400	$11,400	$22,800
	Alum Treatment	$40,128	$43,662	$83,790
	Sediment Monitor	$2,280	$2,280	$4,560
	Subtotal	**$65,208**	**$68,742**	**$133,950**
7	Aquatic Plant Survey	$11,400	$11,400	$22,800
	Lake WQ Monitor	$11,400	$11,400	$22,800
	Sediment Monitor	$2,280	$2,280	$4,560
	Subtotal	**$25,080**	**$25,080**	**$50,160**
8	Lake WQ Monitor	$11,400	$11,400	$22,800
	Sediment Monitor	$2,280	$2,280	$4,560
	Subtotal	**$13,680**	**$13,680**	**$27,360**
	Lake WQ Monitor	$11,400	$11,400	$22,800
	Sediment Monitor	$2,280	$2,280	$4,560
	Subtotal	**$13,680**	**$13,680**	**$27,360**
10	Lake WQ Monitor	$11,400	$11,400	$22,800
	Sediment Monitor	$2,280	$2,280	$4,560
	Report	$34,200	-	$34,200
	Subtotal	**$47,880**	**$13,680**	**$61,560**
	Total	**$518,564**	**$511,904**	**$1,030,468**

*Costs are in 2006 dollars.
**The Mitchell Lake costs in this column do not represent all of the costs in the treatment program recommended in the Mitchell Lake UAA. The costs listed here are only for management practices necessary to improve the water quality of Red Rock Lake.

Selected Implementation Plan

The selected implementation plan is herbicide treatment of curlyleaf pondweed in Red Rock Lake and Mitchell Lake for four years followed by four years of alum treatment in Red Rock Lake and Mitchell Lake. This implementation plan has been selected because lake analysis results indicate that the overall productivity of Red Rock Lake needs to be significantly reduced to restore the lake to a more ecologically balanced condition. This means that phosphorus release from sediments and from the decay of curlyleaf pondweed needs to be controlled. In addition, curlyleaf pondweed management is required to avoid additional growth by this nuisance species as water quality improves. Because the phosphorus content of the nutrient rich water flowing from Mitchell Lake to Red Rock Lake needs to be controlled, phosphorus release from sediments and from the decay of curlyleaf pondweed needs to be controlled in Mitchell Lake. Should current research efforts determine that lime is a better tool for management of curlyleaf pondweed than herbicide treatment, four years of alum-lime treatment will replace the four years of herbicide treatments and four years of alum treatments in Red Rock and Mitchell Lakes.

Beetles (*Galerucella pusilla, Galerucella calmariensis*) will be introduced in purple loosestrife infested areas to control shoreline purple loosestrife and promote native vegetation.

This plan will require monitoring throughout the restoration effort to evaluate effectiveness and determine whether the prescribed management plan remains appropriate. Aquatic plants, lake water, quality, and lake sediments should be monitored. Monitoring data will be used to adjust the implementation plan as warranted.

Proposed 7050 Rules for Lakes

Because of its poor water quality, Red Rock Lake is currently listed on Minnesota's 303(d) impaired waters list. Under proposed 7050 Standards for lakes, Red Rock Lake would remain on the impaired waters list unless the lake's water quality improved such that the Standards were attained. Management of the Mitchell and Red Rock Lakes' curlyleaf pondweed communities and treatment of Mitchell and Red Rock Lakes with alum (i.e., implementation of the recommended water quality improvement plan) is expected to improve the lake's water quality so that the proposed 7050 standards are attained under all but the future wet climatic condition.

Implementation of one additional water quality improvement project would attain the proposed 7050 standards under all climatic conditions. Treatment of Mitchell Lake outflow waters, which flow into Red Rock Lake, with alum (60 percent removal of total phosphorus load assumed) would enable Red

Rock Lake to attain the proposed 7050 standards under all climatic conditions. However, because an inflow alum treatment facility is both expensive to build and operate, this alternative is not recommended at this time. Since the water quality improvement estimates in this UAA are conservative, it is possible that the actual water quality improvement to Red Rock Lake following plan implementation may exceed expectations. Monitoring the lake during and following implementation of the lake's water quality improvement plan will ascertain changes in the lake's water quality and will determine whether the lake's water quality meets 7050 standards under all climatic conditions. If additional water quality improvement is needed to improve the lake's water quality under the wet climatic condition, an alum treatment facility to treat Mitchell Lake's outflow waters may be considered.

Red Rock Lake Use Attainability Analyses

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1.0 Surface Water Resources Data

The approved *Riley-Purgatory-Bluff Creek Watershed District Water Management Plan*, 1996, inventoried and assessed Red Rock Lake. The plan articulated five specific goals for Red Rock Lake. These goals address recreation, aquatic communities, water quality, water quantity, and wildlife. This report (1) evaluates the existing and potential beneficial uses intended in these goals, (2) contains an analysis of the factors that potentially impair or limit those beneficial uses, particularly problems identified in the inventory and assessment, and (3) expands upon specific aspects of the inventory and assessment of Red Rock Lake contained in the approved Water Management Plan.

A use attainability analysis of Red Rock Lake was completed to provide the scientific foundation for a lake-specific best management plan that will maintain or attain the existing and potential beneficial uses of Red Rock Lake. A use attainability analysis evaluates existing and potential beneficial uses of a water resource. "Use attainment" refers to the designated beneficial uses, such as swimming and fishing. Factors that potentially impair or limit existing beneficial uses, including problems identified in the inventory and assessment, are investigated in the use attainability analysis. Lake analyses rely on previously collected field data and continue with watershed evaluations using water quality modeling.

The main tools used for the technical analysis are an advanced water quality model that predicts the amount of pollutants that reach a lake via stormwater runoff and an in-lake model that is used to better understand in-lake processes. Calibrating a lake model requires an accurate measurement of land use and stormwater inputs. Impacts of upland detention and treatment of stormwater are included in the model.

The primary pollutant of concern for Red Rock Lake is the nutrient phosphorus. Phosphorus is a natural element found in rocks, soils, and organic material. In water, phosphorus exists in either a particulate phase or a dissolved phase. Phosphorus occurs naturally in low quantities and is not harmful when its concentration is low. However, phosphorus becomes a harmful pollutant when excess quantities are added to waterbodies, causing its concentration to be high relative to natural, background levels. In freshwater lakes and rivers, phosphorus is the growth-limiting nutrient for algae (small aquatic plants) and its concentration determines the quantity of algae in these waterbodies. If excessive amounts of phosphorus are added to the water, algae are produced in large quantities called "algal blooms." Algal blooms cause the water to appear green and, in severe cases, appear as floating mats of plant material on the water's surface and produce an unpleasant smell as plant materials decay. Impairment of the aesthetic and recreational uses of the water bodies are caused by the algal blooms and harm occurs to the habitat or home of the fish and other living organisms in the water. When large quantities of algae die (algal blooms), bacteria decompose them and use up oxygen in the lake's bottom waters, restricting fish to the warmer surface waters.

The Red Rock Lake UAA evaluates the relationship between phosphorus loading to the lake and the lake's water quality. The lake's water quality, recreational, and aquatic life goals are compared with the lake's current and expected future water quality. Management practices to reduce phosphorus loading to the lake from its watershed and from internal sources (i.e., plant decay and sediment) are evaluated to attain the lake's water quality, recreational, and aquatic life goals.

1.1 Land Use

During rainstorms, stormwater runoff conveys phosphorus to the lowest point in the land area. When a lake is located in a land area, it is the lowest point and receives the runoff from the land area, including the phosphorus load contained in the runoff. The land that drains to a lake is called a watershed. The water quality of a lake is determined by the quality of the waters running into the lake during rainstorms and by internal lake processes (i.e., plant decay and release of phosphorus from sediments). The land use practices within a watershed impact the lake and its water quality. Impacts result from the export of sediment and nutrients, primarily phosphorus, to a lake from its watershed. Each land use contributes a different quantity of water and a different quantity of phosphorus to the lake, thereby affecting the lake's water quality differently. Urbanized land uses convey higher loads of phosphorus to lakes than undisturbed land uses such as forests and wetlands. Urbanized land uses typically have large areas of impervious surfaces (i.e., paved surfaces and buildings) which prevent the infiltration of stormwater. Water quickly runs off these surfaces to a lake. Storm runoff cleans the impervious surfaces and rapidly carries sediment and phosphorus, both particulate and dissolved, to lakes via overland flow or storm sewers. The urbanized system of rapidly conveying storm runoff to lakes is far different from undisturbed land (e.g., forest) in which large quantities of rainwater soak into the ground and little phosphorus is conveyed to lakes.

An advanced water quality model was used to measure the impacts of land uses within the Red Rock Lake watershed on the lake's water quality. An accurate measurement of land use was required to calibrate the model. Hence, historic, current, and proposed future land uses in the Red Rock Lake watershed were evaluated. The results of this evaluation are discussed in the following paragraphs.

The 1,262-acre Red Rock Lake watershed is comprised of:

- Red Rock Lake (97 acres)
- Wetlands and stormwater treatment ponds (72 acres).
- Land that drains directly to Red Rock Lake (332 acres). Runoff from the lake's directly tributary watershed is not treated prior to entering the lake.
- Land that drains directly to stormwater treatment ponds (761 acres) and indirectly to Red Rock Lake by a stormwater conveyance system. Stormwater is treated by ponds before entering the lake.

Because Mitchell Lake's outflow is conveyed to Red Rock Lake, the watershed tributary to Mitchell Lake is also considered part of Red Rock Lake's watershed. The land that drains to Mitchell Lake is a part of Red Rock Lake's indirect watershed because stormwater is treated by Mitchell Lake before entering Red Rock Lake. The Mitchell Lake watershed is comprised of:

- Mitchell Lake (119 acres at a water elevation of 870.55)
- Land that drains directly to Mitchell Lake (154 acres).
- Land that drains directly to stormwater treatment ponds (707 acres) and indirectly to Mitchell Lake by a stormwater treatment system.
- Round Lake (32 acres) and land that drains to Round Lake (412 acres). Stormwater draining to Round Lake is treated by the lake and conveyed to Mitchell Lake when outflow from Round Lake occurs. Relatively little outflow occurs from Round Lake.

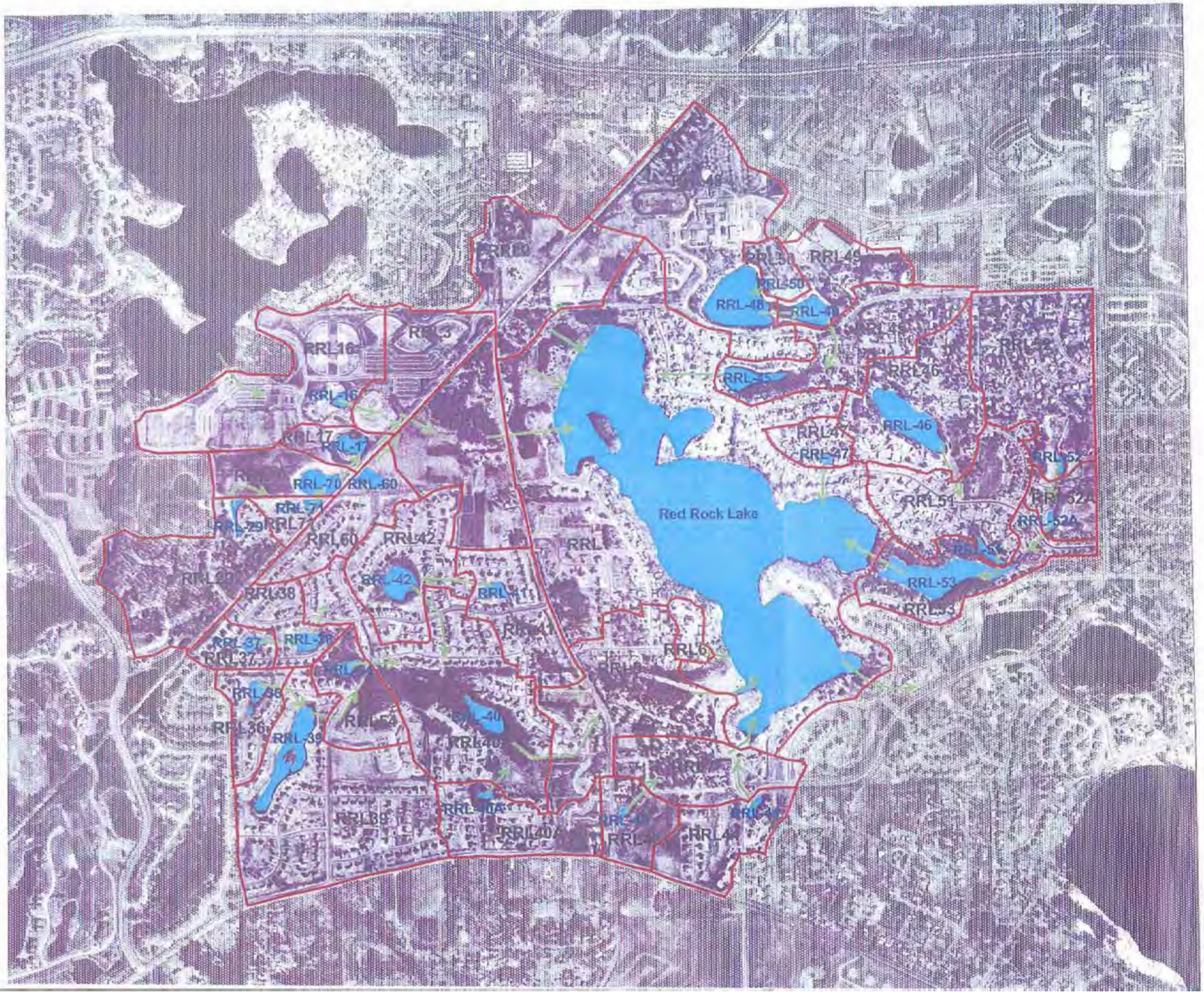
The watershed tributary to Mitchell Lake is discussed in detail in *Mitchell Lake Use Attainability Analysis* (Barr 2004). The following discussion of the Red Rock Lake watershed does not include the watershed tributary to Mitchell Lake.

The Red Rock Lake watershed was divided into subwatersheds for the UAA modeling effort. The lake's existing (1997) and projected future (2020) subwatersheds are shown in Figures 1 and 2, respectively.

Figure 1

Red Rock Lake UAA
Exisiting Subwatersheds

Riley Purgatory Bluff Creek
Watershed District



Legend

Red Rock Lake Ponds

Flow Arrows

Red Rock Lake Existing Subwatersheds

N W E S

200 0 200 400 Meters

1000 0 1000 2000 Feet

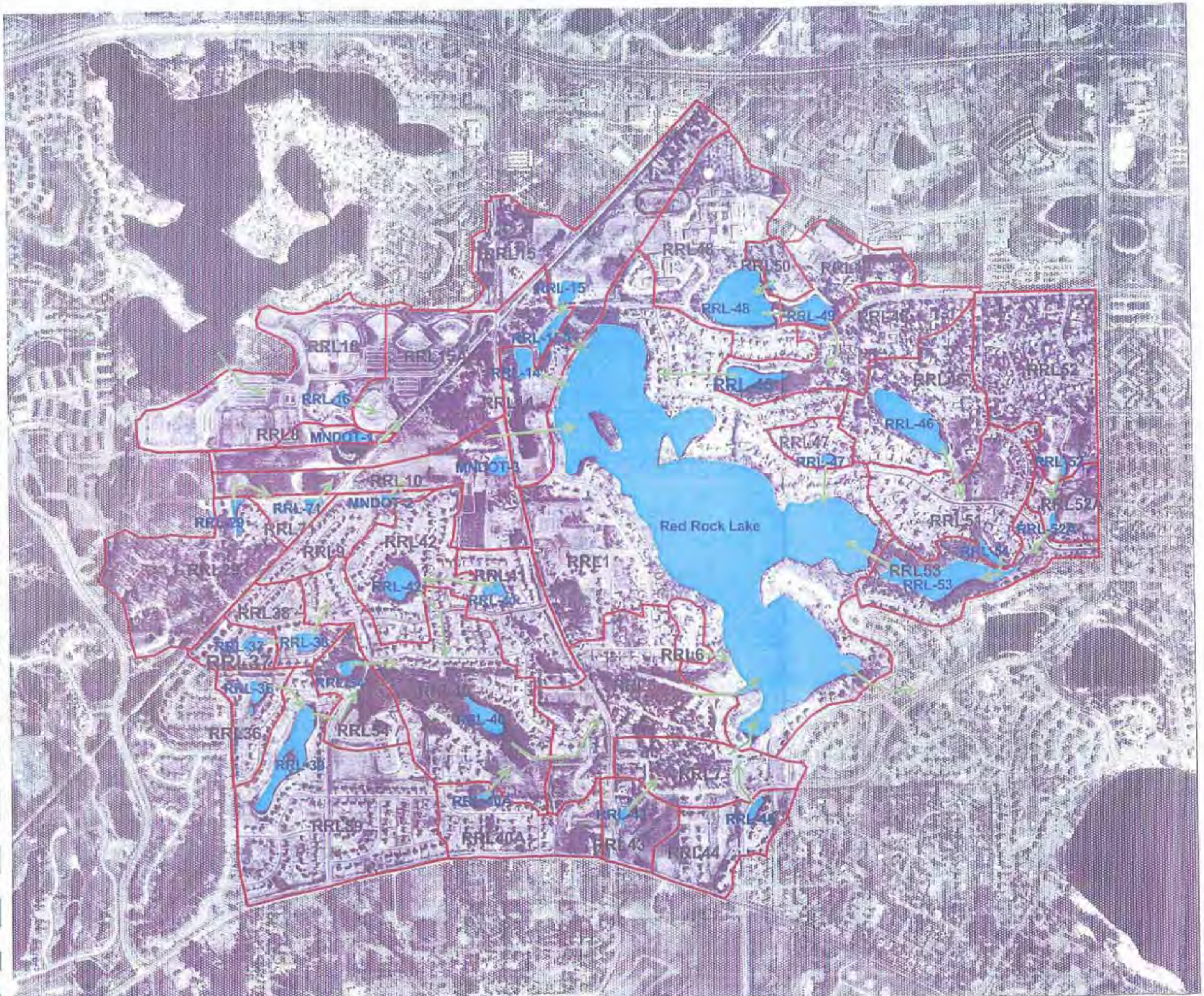


Figure 2

Red Rock Lake UAA
Future Subwatersheds

Riley Purgatory Bluff Creek
Watershed District

Legend

Red Rock Lake Ponds

Flow Arrows

Red Rock Lake FutureSubwatersheds

N W E S

200 0 200 400 Meters

1000 0 1000 2000 Feet

The historical land use of a lake can have a significant bearing on the current and future water quality of a lake. Figure 1 shows a recent aerial photograph of the watershed and Figure 3 shows an aerial photograph of the lake taken on May 9, 1947. A comparison of these figures shows that the land use has changed from primarily agricultural to suburban over the second half of the 20th century. Historical agricultural inputs of high phosphorus sediment has likely had an effect on internal phosphorus loading in the present day.

Land use data for the Red Rock Lake UAA modeling efforts were derived from the Metropolitan Council Generalized Land Use Maps for the year 1997 (current land use) and 2020 (projected future land use). A detailed description of the current and future land uses of the Red Rock Lake watershed are presented in Tables 1 and 2, respectively. Maps of the current and future land uses of the Red Rock Lake watershed are presented in Figures 4 and 5, respectively. A graphical depiction of existing and projected future land uses is shown in Figure 6.

1.2 Major Hydrologic Characteristics

At a water elevation of 840.33 feet, Red Rock Lake has a surface area of 97 acres, a maximum depth of 15 feet, and an average depth of 4 feet. Water enters the lake either by direct precipitation or by stormwater inflows from yards and green space directly adjacent to the lake or from stormsewers (See Figure 1), including flow from Mitchell Lake. Water exits the lake through a piped outlet located on the south east side of the lake. The major hydrologic and hydraulic characteristics of the lake are provided in Table 3.

Table 3. Average Lake Volume, Annual Discharge Volume, and Estimated Hydraulic Residence Time of Red Rock Lake for a Range of Climatic Conditions (Existing Watershed Landuse)

Water Year (Inches of Precipitation)	Average Lake Volume (ac-ft)	Estimated Annual Lake Outflow Through Outlet (ac-ft)	Avg. Seep .(ac-ft)	Evap. (ac-ft)	Precip .(ac-ft)	Stream and Overland Inflow (ac-ft)	Hydraulic Residence Time (years)
1997 (33 inches)	372.84	-1,951	395	-307	306	1,604	0.16
1998 (27 inches)	376.05	-1,143	395	-320	235	813	0.26
1999 (30 inches)	380.57	-1,146	395	-385	279	855	0.25
2000 (23 inches)	363.19	-675	395	-379	192	456	0.35

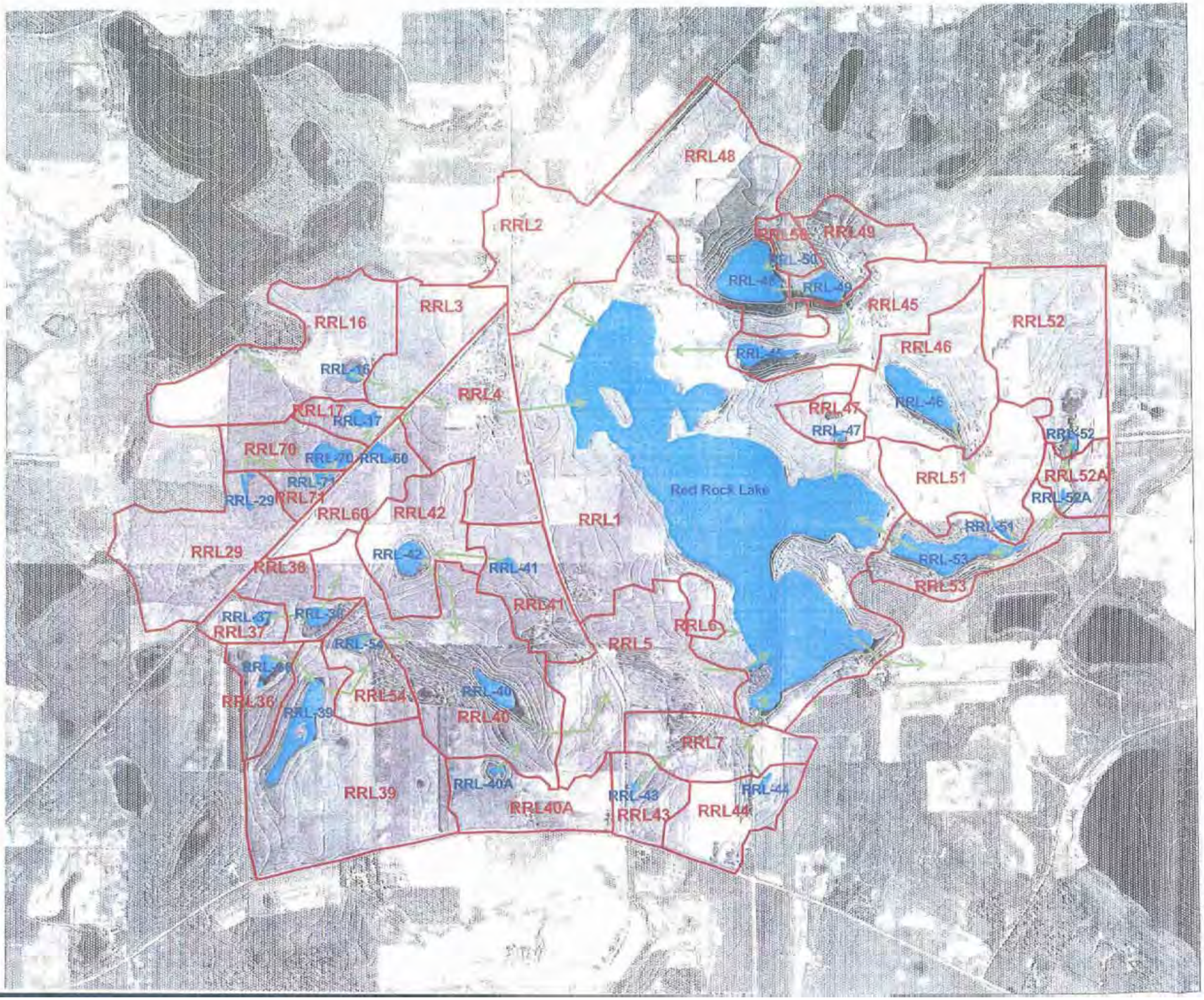


Figure 3

Red Rock Lake UAA
Historical Land Use

Riley Purgatory Bluff Creek
Watershed District

Table 1 - Existing Land Use in the Red Rock Lake Watershed

Subwatershed Name	Commercial (acres)	Institutional (acres)	Industrial/ Office (acres)	Low Density Residential (acres)	Medium Density Residential (acres)	Natural/Park/ Open (acres)	Open Water (acres)	Total (acres)
RRL1	0.0	11.0	0.0	105.8	0.1	49.4	122.6	288.9
RRL16	0.0	0.0	0.0	2.0	0.0	51.2	0.4	53.6
RRL17	0.0	0.0	0.0	0.0	0.0	7.3	1.1	8.5
RRL2	7.0	15.7	0.0	2.4	4.7	10.9	0.0	40.8
RRL29	0.0	0.0	0.0	24.5	0.0	19.0	0.5	44.0
RRL3	0.0	0.0	0.0	0.4	0.9	24.1	0.0	25.4
RRL36	0.0	0.0	0.0	12.6	0.0	0.0	0.8	13.5
RRL37	0.0	0.0	0.0	8.0	0.0	0.0	0.7	8.7
RRL38	0.0	0.0	0.0	12.9	0.0	0.0	1.1	14.0
RRL39	0.0	8.0	0.0	61.1	0.0	3.4	4.6	77.2
RRL4	0.0	0.1	0.0	6.0	0.0	36.6	0.0	42.7
RRL40	0.0	3.0	0.0	50.8	0.0	14.4	1.7	70.0
RRL40A	0.0	0.4	0.0	17.5	0.4	7.4	0.2	25.9
RRL41	0.0	2.1	0.0	22.3	0.0	0.4	0.7	25.5
RRL42	0.0	0.0	0.0	29.0	0.0	0.1	2.0	31.1
RRL43	0.0	0.4	0.0	3.4	0.0	9.7	0.3	13.7
RRL44	0.0	0.0	0.0	8.8	3.1	10.1	0.4	22.5
RRL45	0.0	1.6	0.0	30.5	1.3	1.7	1.9	37.0
RRL46	0.0	0.0	0.0	34.2	0.0	1.6	5.9	41.7
RRL47	0.0	0.0	0.0	6.8	0.2	1.2	0.3	8.4
RRL48	0.0	34.6	1.2	6.2	0.0	20.4	8.7	71.0
RRL49	0.0	1.4	7.1	4.4	0.0	4.5	3.4	20.6
RRL5	0.2	6.9	0.0	40.7	0.1	4.3	0.0	52.3
RRL50	0.0	0.0	0.1	0.0	0.0	6.1	0.1	6.3
RRL51	0.0	0.0	0.0	30.9	0.0	5.9	0.4	37.1
RRL52	0.1	0.0	0.0	37.0	3.1	9.3	0.2	49.7
RRL52A	0.0	0.0	0.0	2.6	0.0	8.4	0.3	11.3
RRL53	0.0	0.0	0.0	18.7	0.0	4.4	6.7	29.8
RRL54	0.0	7.2	0.0	7.7	0.0	2.9	0.6	18.3
RRL6	0.0	0.0	0.0	3.9	0.0	1.0	0.0	4.9
RRL60	0.0	0.0	0.0	16.5	0.0	3.1	1.0	20.7
RRL7	1.0	0.0	0.0	19.3	0.0	4.8	0.0	25.1
RRL70	0.0	0.0	0.0	1.1	0.0	12.3	2.2	15.6
RRL71	0.0	0.0	0.0	6.1	0.0	0.0	0.0	6.1
Total	8.3	92.6	8.4	634.2	14.0	335.9	168.8	1262.1

Table 2 - Future Land Use in the Red Rock Lake Watershed

Subwatershed Name	Commercial (acres)	Highway (acres)	Institutional (acres)	Industrial/ Office (acres)	Low Density Residential (acres)	Medium Density Residential (acres)	Natural/Park/ Open (acres)	Open Water (acres)	Total (acres)
RRL1	0.0	3.3	10.5	0.0	119.5	0.0	9.9	120.9	264.1
RRL10	0.0	25.7	0.8	0.0	9.1	1.2	0.0	0.0	36.8
RRL14	0.0	16.2	0.0	0.0	0.0	0.0	0.0	1.1	17.3
RRL15	0.0	33.0	3.9	8.8	1.2	4.5	0.5	1.0	52.9
RRL15A	0.0	40.7	0.2	0.0	0.4	0.0	22.0	1.9	65.3
RRL16	0.0	0.2	0.0	0.0	1.3	0.0	51.7	0.4	53.6
RRL29	0.0	0.0	0.0	0.0	42.7	0.8	0.0	0.5	44.0
RRL36	0.0	0.0	0.0	0.0	12.6	0.0	0.0	0.8	13.5
RRL37	0.0	0.0	0.0	0.0	8.0	0.0	0.0	0.7	8.7
RRL38	0.0	0.0	0.0	0.0	6.9	6.0	0.0	1.1	14.0
RRL39	0.0	0.0	7.9	0.0	62.3	0.0	0.0	7.0	77.2
RRL40	0.0	0.0	6.0	0.0	43.2	7.5	11.6	1.7	70.0
RRL40A	0.0	0.0	0.4	0.0	20.4	3.1	1.7	0.2	25.9
RRL41	0.0	0.0	1.6	0.0	23.3	0.0	0.0	0.7	25.5
RRL42	0.0	0.1	0.0	0.0	14.2	14.8	0.0	2.0	31.1
RRL43	0.0	0.0	10.4	0.0	2.4	0.8	0.0	0.3	13.7
RRL44	0.0	0.0	2.8	0.0	15.4	3.9	0.0	0.4	22.5
RRL45	0.5	0.0	2.7	0.0	29.5	0.0	0.0	4.4	37.0
RRL46	0.0	0.0	0.0	0.0	36.2	0.0	0.0	5.5	41.7
RRL47	0.0	0.0	0.0	0.0	8.2	0.0	0.0	0.3	8.4
RRL48	0.0	0.0	31.0	9.4	8.1	0.0	0.0	7.4	55.9
RRL49	0.0	0.0	3.4	8.5	6.7	0.0	0.0	2.1	20.6
RRL5	0.0	0.0	7.1	0.0	41.8	0.7	2.8	0.0	52.3
RRL50	0.0	0.0	0.0	5.8	0.5	0.0	0.0	0.1	6.3
RRL51	0.0	0.0	0.0	0.0	35.1	0.0	1.6	0.4	37.1
RRL52	0.0	0.0	0.0	0.5	18.4	21.0	9.6	0.2	49.7
RRL52A	0.0	0.0	0.0	0.0	2.6	0.0	8.5	0.3	11.3
RRL53	0.0	0.0	0.0	0.0	19.3	0.0	3.7	6.7	29.8
RRL54	0.0	0.0	10.4	0.0	7.4	0.0	0.0	0.6	18.3
RRL6	0.0	0.0	0.0	0.0	4.9	0.0	0.0	0.0	4.9
RRL7	0.0	0.0	0.6	0.0	24.4	0.2	0.0	0.0	25.1
RRL71	0.0	0.0	0.0	0.0	5.6	0.7	0.0	0.0	6.3
RRL8	0.0	0.8	0.0	0.0	0.0	0.0	3.6	0.5	4.9
RRL9	0.0	0.1	0.0	0.0	0.0	16.0	0.0	0.0	16.1
Grand Total	0.5	120.1	99.5	33.0	631.5	81.1	127.2	169.2	1262.1

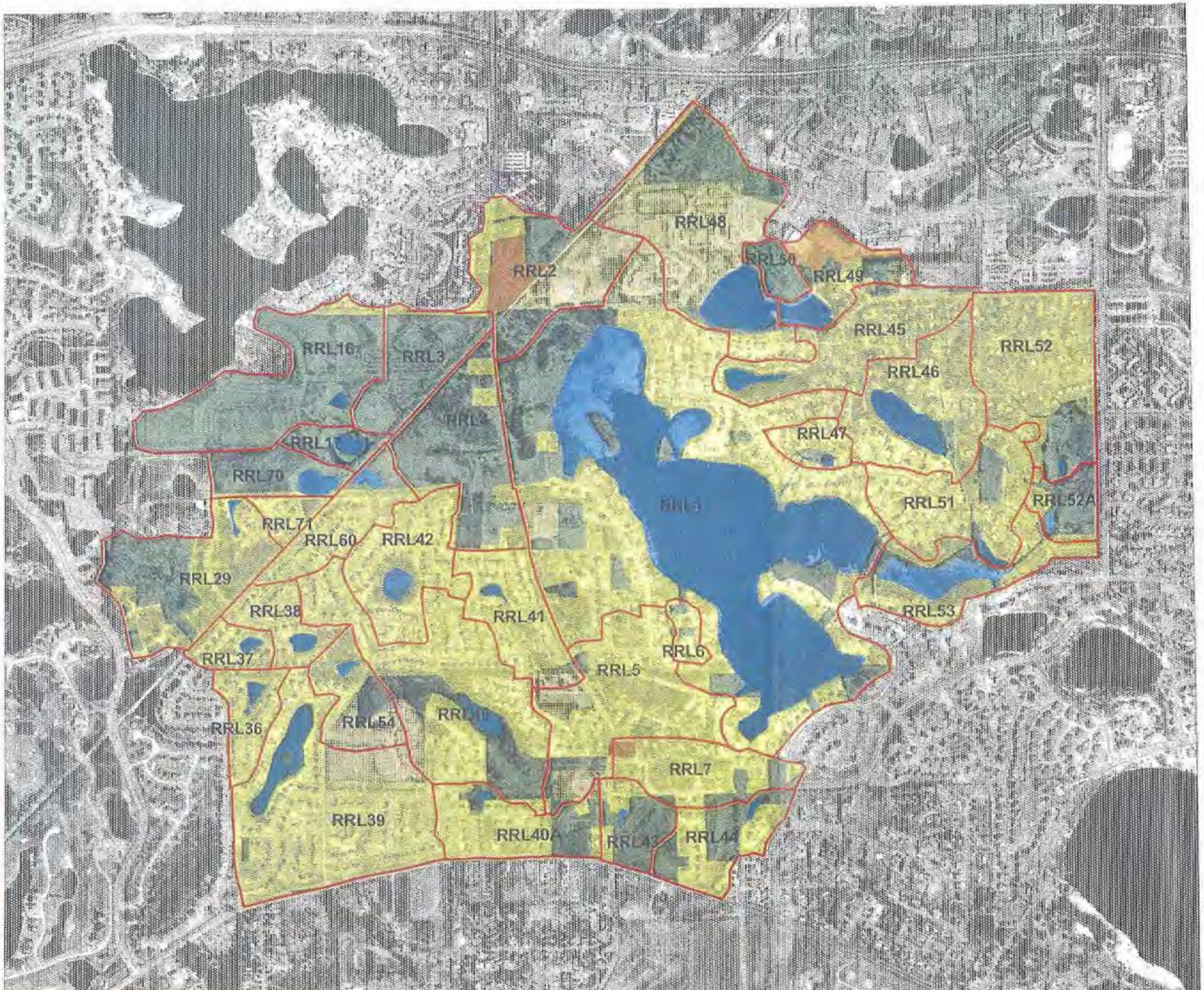


Figure 4

Red Rock Lake UAA
Existing (1997) Land Use

Riley Purgatory Bluff Creek
Watershed District

Legend

Existing Subwatersheds

Existing Land Use

Natural/Park/Open

Low Density Residential

Medium Density Residential

Institutional

Commercial

Industrial/Office

Open Water

N W E S

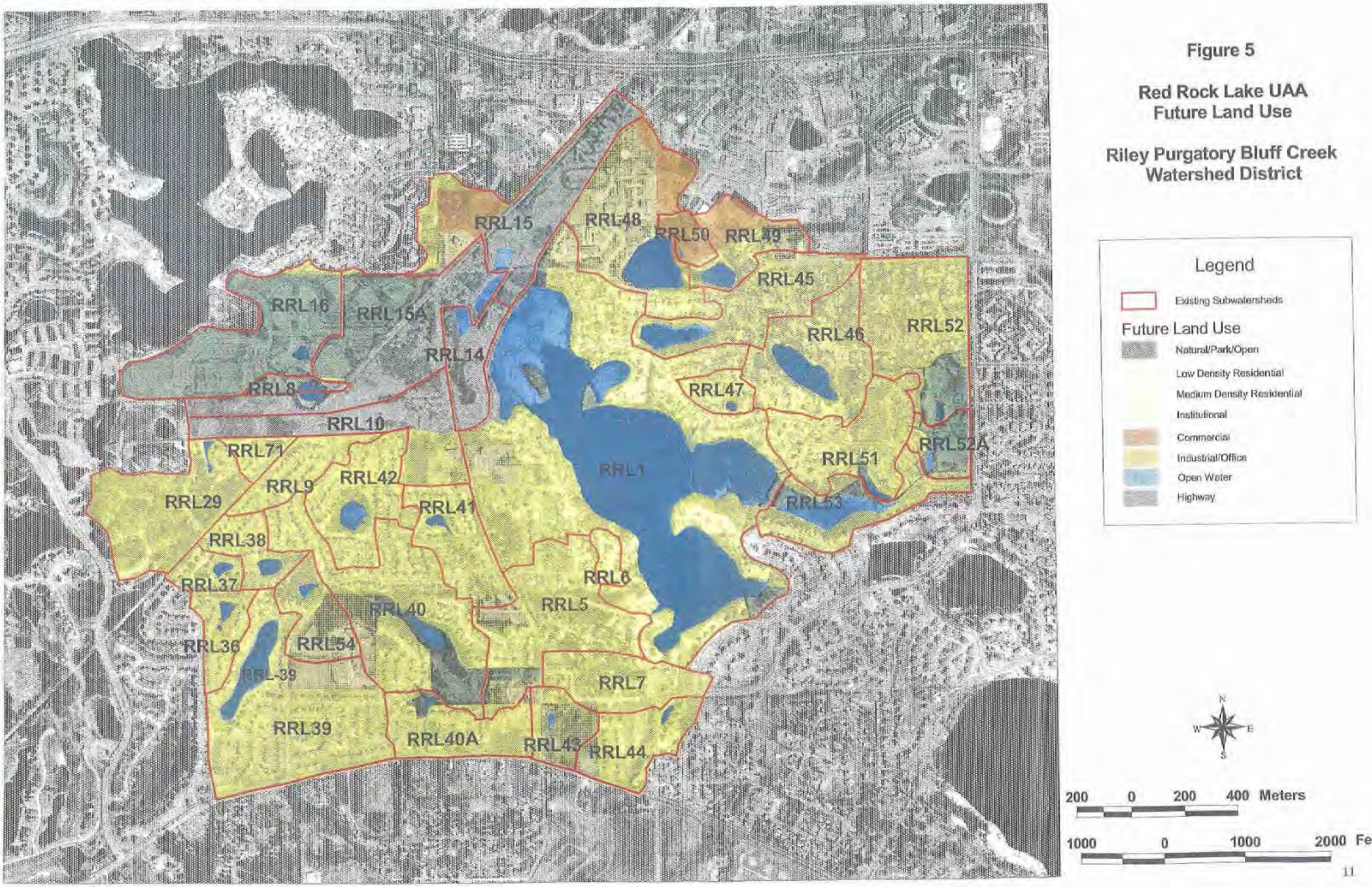
200 0 200 400 Meters

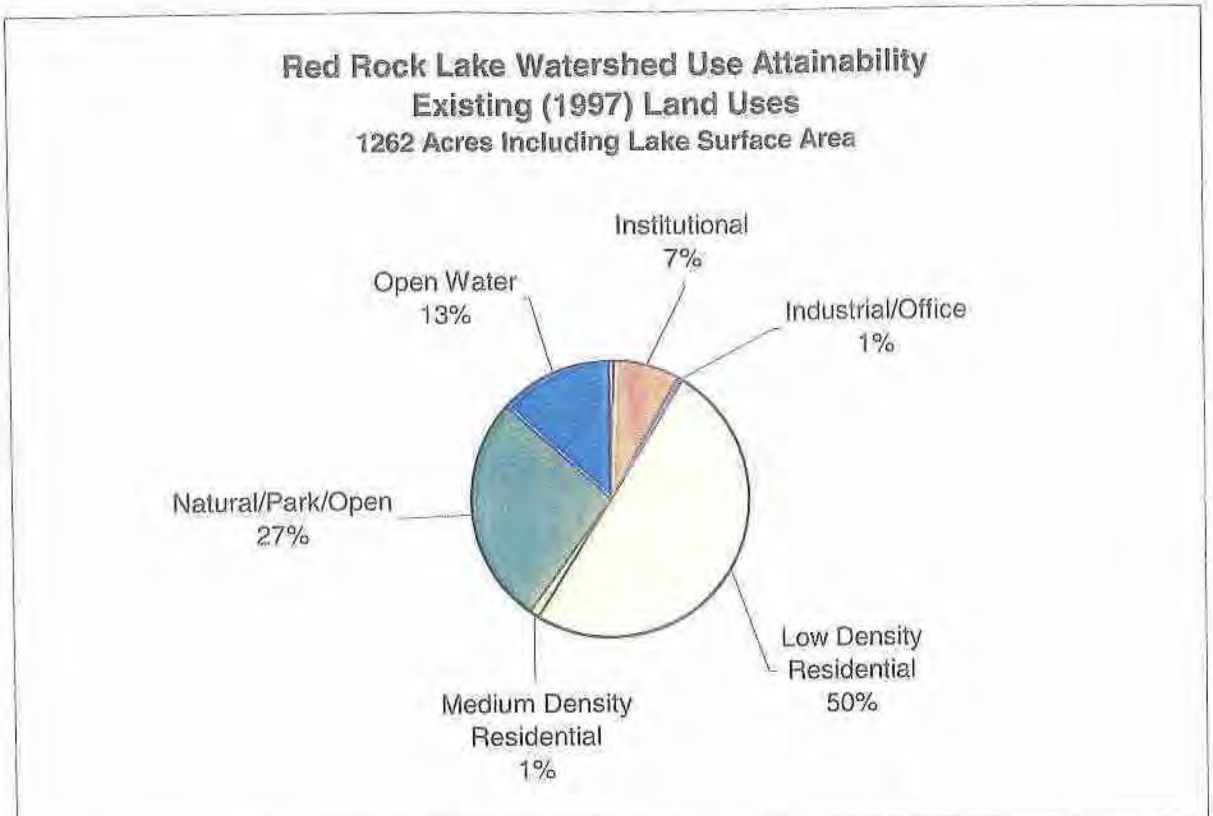
1000 0 1000 2000 Feet

Figure 5

Red Rock Lake UAA
Future Land Use

Riley Purgatory Bluff Creek Watershed District





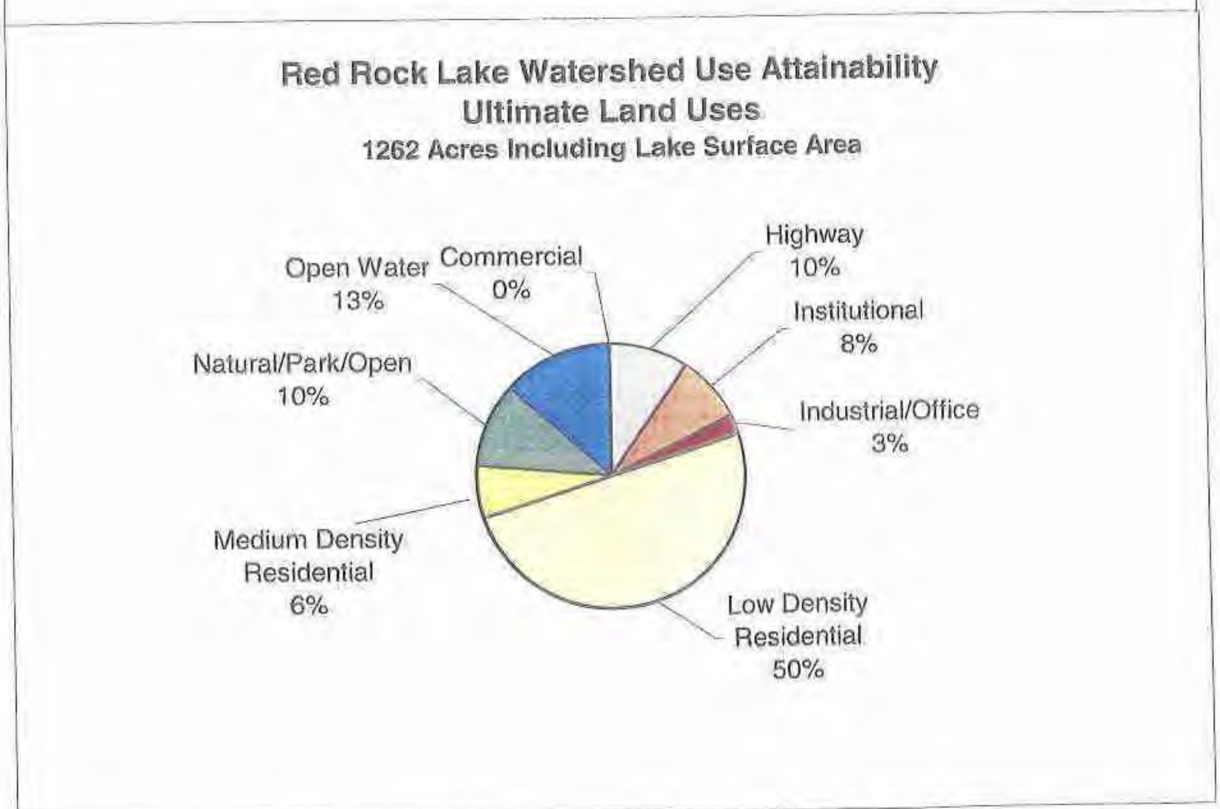


Figure 6
Red Rock Lake Watershed Land Uses

1.3 Water Quality

The water quality of a lake provides an indication of how a lake functions. A standardized lake rating system is often used to classify the ecological condition of a lake. The rating system uses phosphorus, chlorophyll *a*, and Secchi disc transparency values to classify a lake into four categories: Oligotrophic (clear, low productivity lakes with excellent water quality), Mesotrophic (intermediate productivity lakes with good water quality), Eutrophic (high productivity lakes with poor water quality) and Hypereutrophic (extremely productive lakes with poor water quality).

1.3.1 Data Collection

Water quality data were collected by the District for Red Rock Lake from 1972 to 1999 (for years 1972, 1975, 1978, 1981, 1984, 1988, 1991, 1993, 1996, and 1999).

From April through September, 1999, a water quality monitoring program was completed for Red Rock Lake to calibrate a water quality model for the lake. Water sampling and analytical methods used in this study are provided in Appendix C.

1.3.2 Baseline/Current Water Quality

A comparison of baseline and current water quality (total phosphorus, chlorophyll *a*, and Secchi disc transparency) was completed to determine whether changes in the lake's water quality occurred during the 1972 to 1999 monitoring period. Baseline water quality is defined as the average summer water quality for the years 1972 through 1987, while current water quality is defined as the average summer water quality for years 1988 through 1999.

For the baseline and current period, Red Rock Lake can be classified as eutrophic (poor water quality) to hypereutrophic (very poor water quality) (see Figure 7). Despite the lake's poor water quality throughout the period of record, it appears that the lake's water quality has degraded over time. The lake's baseline average total phosphorus and chlorophyll values were lower than the lake's current average total phosphorus and chlorophyll values. The lake's baseline average Secchi disc transparency was higher than the lake's current average Secchi disc transparency. Hence, it appears that the lake's water quality is poorer during the current period than the baseline period.

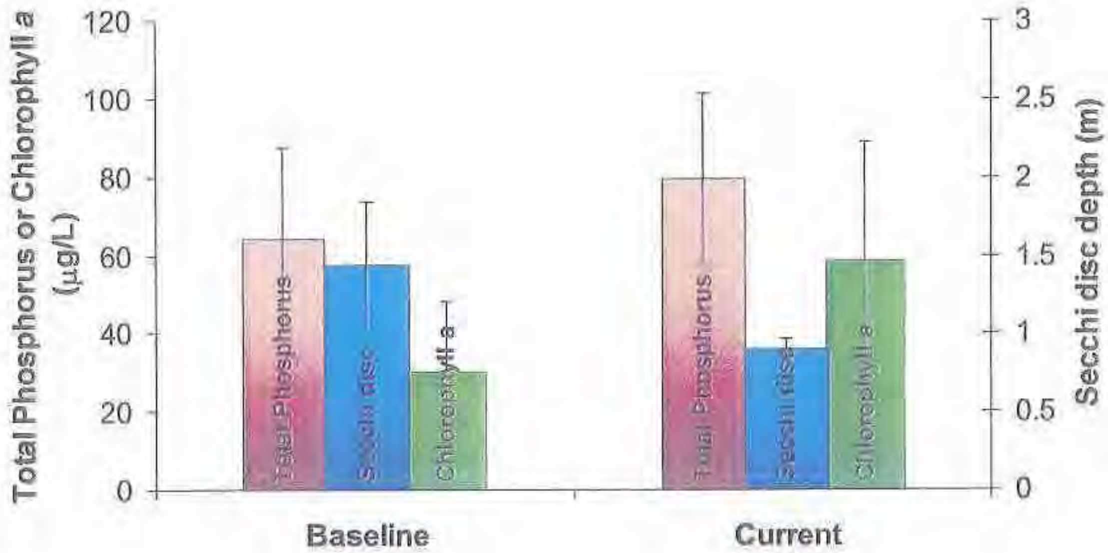


Figure 7 A Comparison of Baseline Water Quality of Red Rock Lake with Current Conditions Based on Summer (June through August) Averages)

1.3.2.1 Present Water Quality

An evaluation of water quality data for Red Rock Lake in 1999 was completed to examine the lake's present water quality. The evaluation was based upon a standardized lake rating system. The rating system uses the lake's total phosphorus, chlorophyll *a*, and Secchi disc transparency as the key water quality indicators to determine the lake's present water quality for the following reasons.

Phosphorus generally controls the growth of algae in lake systems. Of all the substances needed for biological growth, phosphorus is generally the one present in limited quantity. Consequently, when phosphorus is added to a system, it enhances algal growth. Chlorophyll *a* is the main pigment in algae; therefore, the concentration of chlorophyll *a* in the water indicates the amount of algae present in the lake. Secchi disc transparency is a measure of water clarity, and is inversely related to algal abundance. Water clarity determines recreational use-impairment. Figure 8 summarizes the seasonal changes in concentrations of total phosphorus and chlorophyll *a*, and Secchi disc transparencies for Red Rock Lake in 1999. The data are compared with a standardized lake rating system.

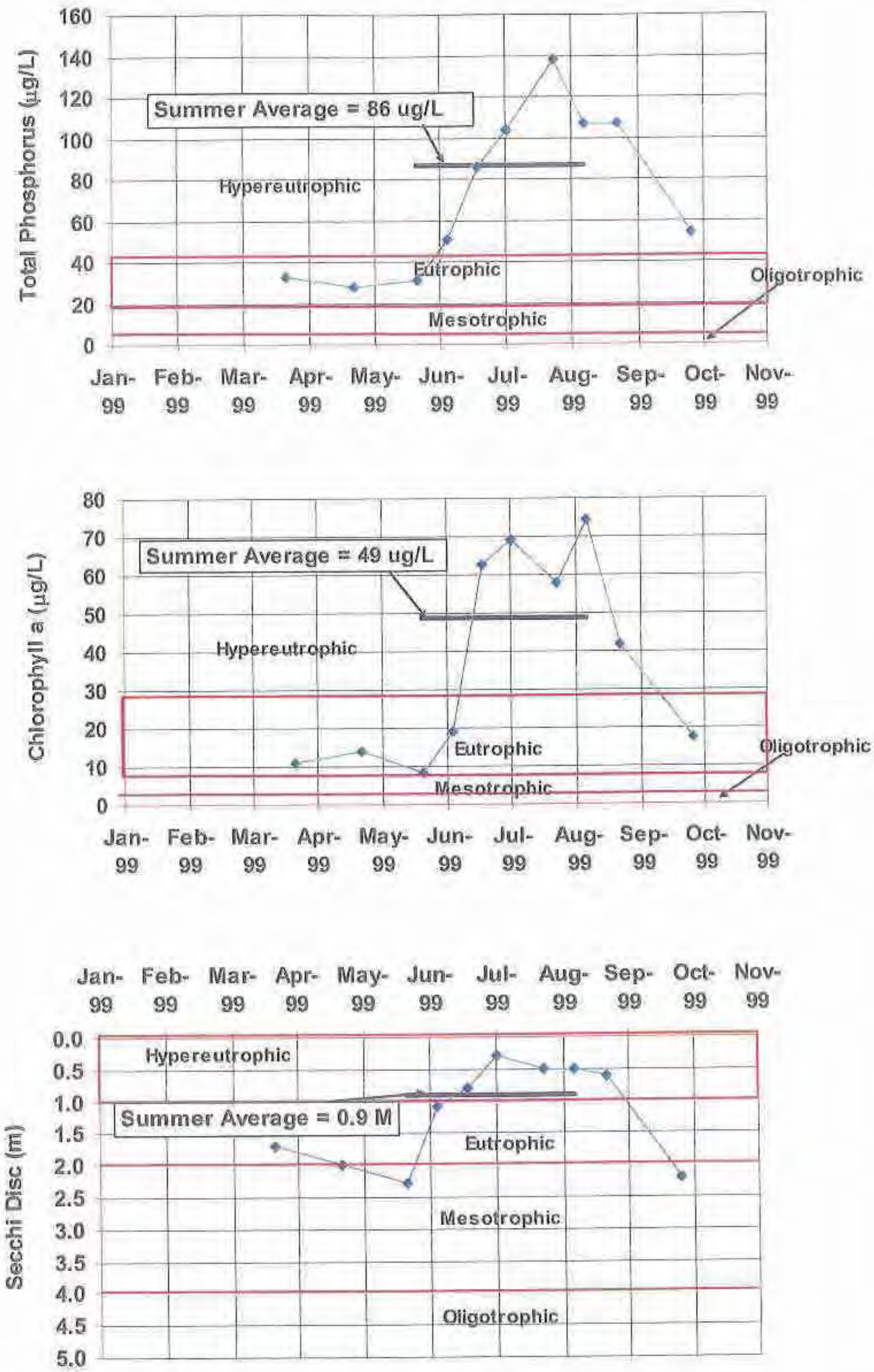


Figure 8 Seasonal Changes in the Concentration of Total Phosphorus and Chlorophyll a, and Secchi disc transparency in Red Rock Lake for 1999.

The water quality in Red Rock Lake was poor throughout the 1999 growing season. Nonetheless, the lake followed a very distinctive seasonal pattern of water quality degradation during the summer. In the spring, the concentrations of phosphorus and chlorophyll *a* were relatively high and the lake's water quality was poor (eutrophic). Although phosphorus concentrations remained relatively stable during April through early June, a reduction in chlorophyll concentration and improved water transparency resulted in good water quality during early June (i.e., borderline mesotrophic/eutrophic chlorophyll and mesotrophic Secchi disc water transparency). Phosphorus and chlorophyll increases and declining Secchi disc water transparency during late June through August resulted in very poor water quality (hypereutrophic). Phosphorus and chlorophyll levels declined and Secchi disc water transparency increased during September through October (see Figure 8).

Modeling results under existing land use and average climatic conditions, sediment sampling, and aquatic plant data (see Figure EX-2) suggest that the sources of phosphorus causing the observed seasonal changes in Red Rock Lake are stormwater runoff (44 percent), outflow from upstream Mitchell Lake (13 percent), atmospheric deposition (13 percent), release of phosphorus from the bottom sediments (20 percent), and decaying aquatic plants (10 percent).

1.4 Ecosystem Data

1.4.1 Aquatic Ecosystem

The interactions of the physical, chemical, and biological components of the Red Rock Lake aquatic ecosystem have a large effect on the capacity of Red Rock Lake to achieve the recreation, aquatic communities, and water quality goals that have been established for the lake. Hence, this use attainability analysis includes an evaluation of Red Rock Lake's aquatic ecosystem.

The aquatic ecosystem of Red Rock Lake is a good example of how the biological community of a lake (i.e., zooplankton, algae, and aquatic plants) can affect the chemical environment of a lake (i.e., pH, phosphorus levels, and dissolved oxygen) which can then also affect the biological community. Data collected for each component of the aquatic ecosystem is reviewed below and then in Section 1.9. A discussion is provided to interpret how these different components function in Red Rock Lake.

1.4.2 Phytoplankton

The population of phytoplankton in Red Rock Lake goes through a seasonal transformation where green algae and cryptomonads are dominant in the spring but decline in the summer, while blue-green algae populations are low in spring and dominate in the summer (Figures 9, 10, and 11).

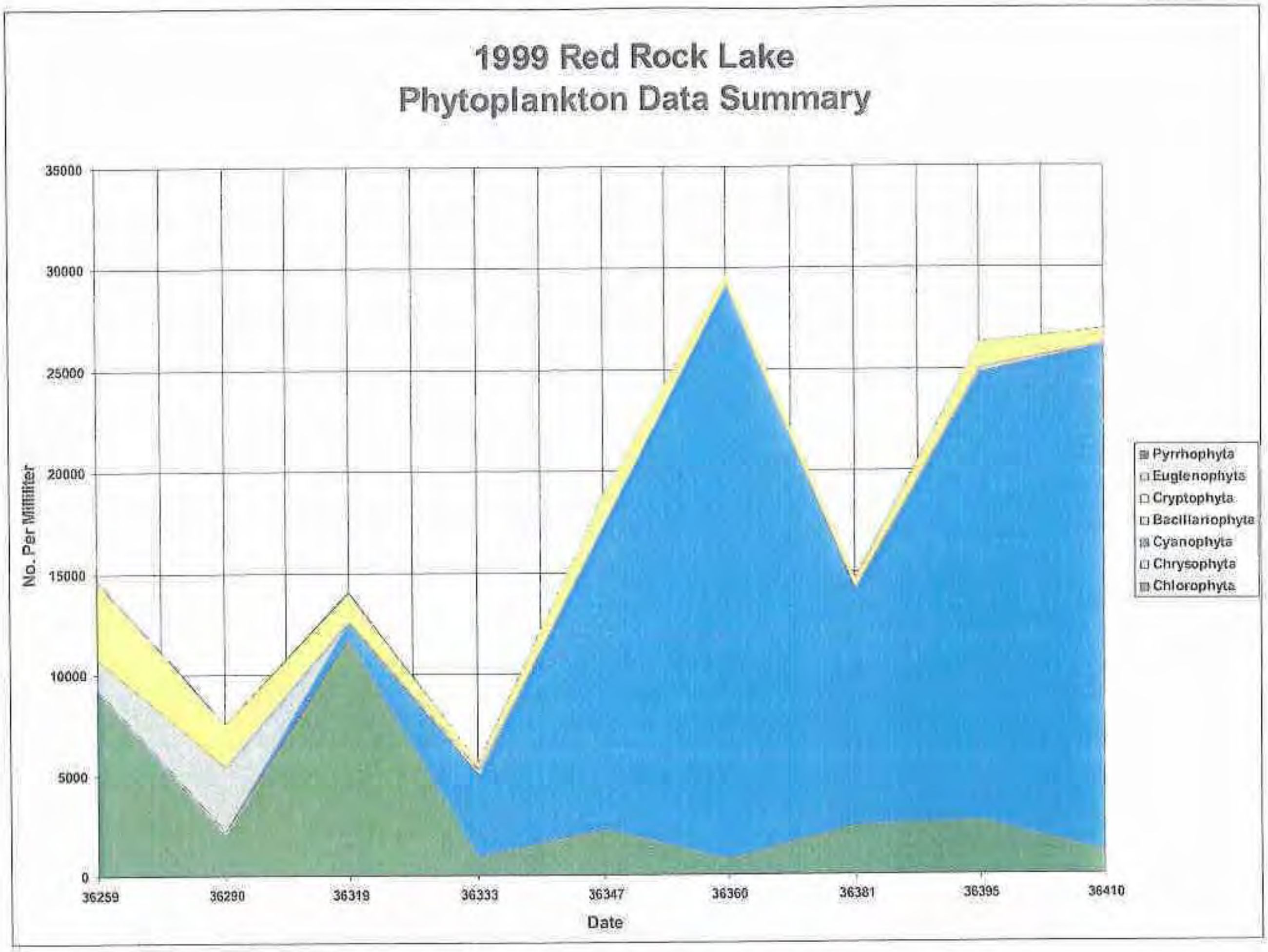


Figure 9 Phytoplankton Abundance and Diversity in Red Rock Lake

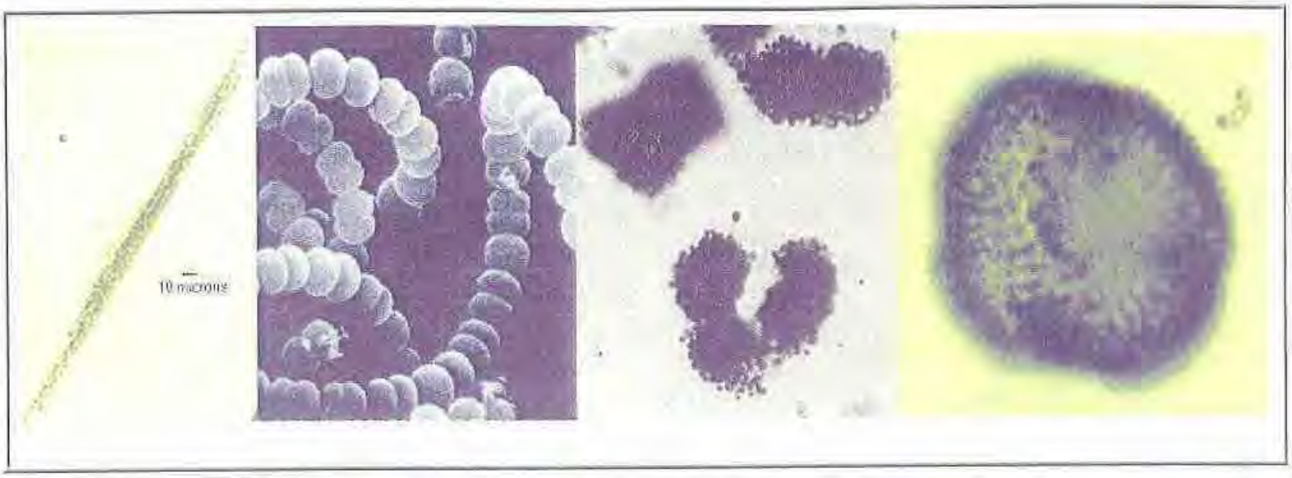
Cryptomonas

Chlamydomonas

Ankistrodesmus

Schroederia

Figure 10 Smaller Phytoplankton (Dominant in Spring of 1999)



Aphanizomenon *Anabaena* *Microcystis* *Coelosphaerium*

Figure 11 Larger Phytoplankton (Dominant in Summer of 1999)

Algal blooms are observed in Red Rock Lake from July through September. The blooms primarily consist of blue-green algae which are large and visible and are often noted to be floating on the surface during periods of severe blooms.

There are several reasons why dominance of blue-green algae during summer is unfavorable for Red Rock Lake:

- Blue-green algae are not a preferred food source for zooplankton,
- Blue-green algae can float at the lake surface causing highly visible algal blooms,
- Certain blue-green algae can be toxic to animals, and
- Blue-green algae disrupt lake recreation during the summer.

Large populations of blue-green algae are most often associated with high levels of phosphorus. Blue-green algae have a competitive advantage (i.e. grow more quickly) over other algal species when phosphorus levels are high. Hence, phosphorus levels will need to be reduced to reduce blue-green algae populations in Red Rock Lake.

1.4.3 Zooplankton

Zooplankton are an important component of the aquatic ecosystem of Red Rock Lake. They are particularly important for the lake's fishery and for the biological control of algae. Healthy zooplankton communities are characterized by balanced densities (number per meter squared) of the three major groups of zooplankton: Cladocera, Copepods, and Rotifers. Fish predation, however, may alter community structure and reduce the numbers of larger-bodied Cladocera.

All three groups of zooplankton were well represented in Red Rock Lake during 1999 (Figure 12). The community structure changed, however, during June through July when larger-bodied Cladocera (see Figure 13) decreased significantly and small bodied Cladocera (see Figure 14) increased. This observed drop in the large-bodied Cladocera population is typically caused by predation by newly hatched fish, called young-of-the-year.

Changes in numbers of large-bodied Cladocera affect a lake's water quality because large-bodied Cladocera have the capacity to biologically control algal growth through daily grazing. Daily zooplankton grazing rates of Red Rock Lake were estimated to range from 2 to 91 percent in 1999. Grazing rates decreased from 91 percent during late June to 10 percent during late July (see Figure 15). During late June through late July, a decline in large bodied Cladocera occurred. Small-bodied Cladocera increased from late June through October.

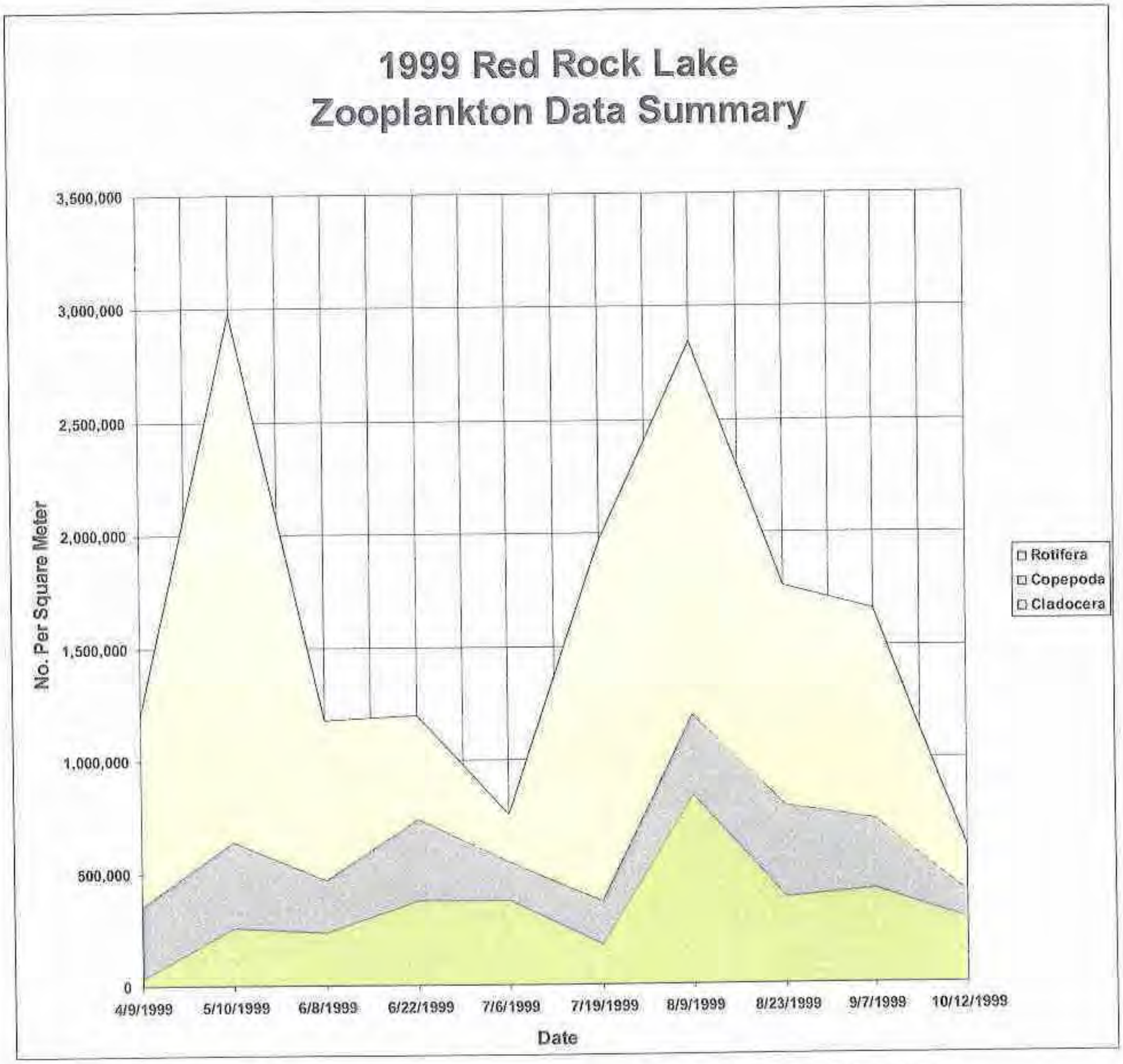
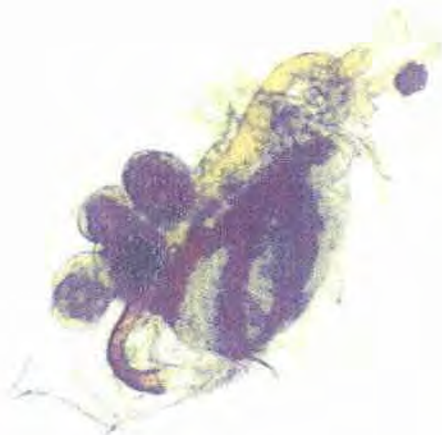
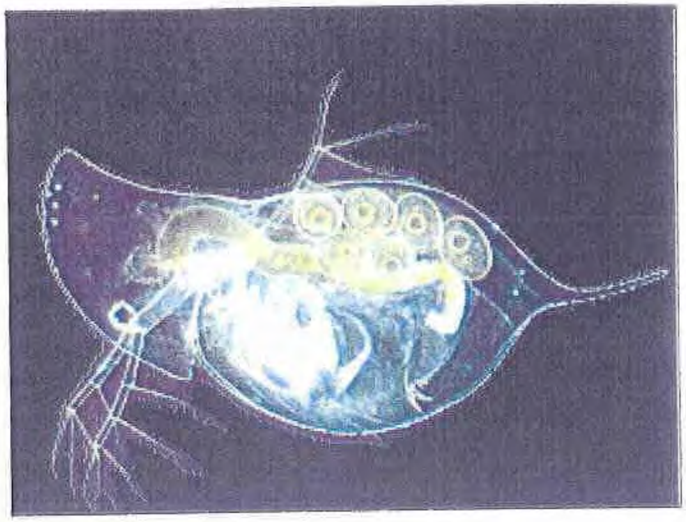


Figure 12 Zooplankton Abundance and Diversity in Red Rock Lake



Daphnia galeata mendotae



Daphnia retrocurva

Diaphanosoma

Figure 13 Large Bodied Cladocera

Bosmina longirostris

Ceriodaphnia sp.

Chydorus sphaericus

Figure 14 Small Bodied Cladocera

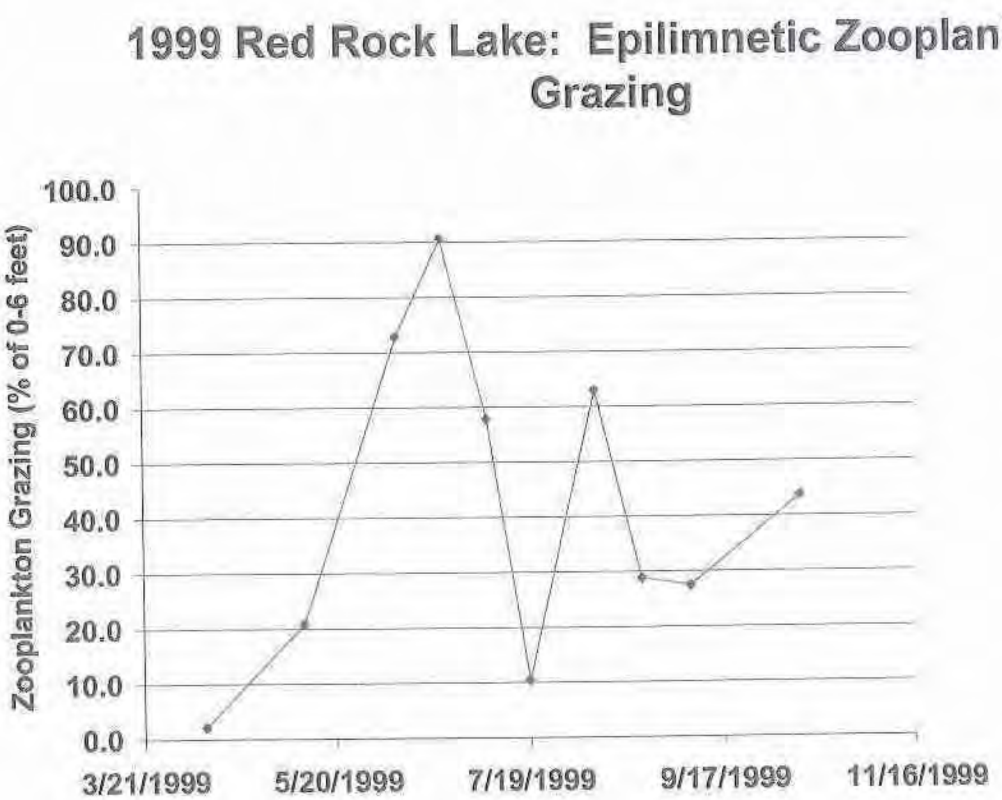


Figure 15 Percent of Red Rock Lake Waters Grazed by Zooplankton Each Day

During June, the phytoplankton (algae) community was comprised of small-bodied algae that are easily eaten by zooplankters (see Figure 10). However, during June through July small-bodied algae were replaced by large-bodied blue-green algae (see Figure 11). Blue-green algae dominated the lake's phytoplankton community through September (see Figure 9). The concurrent changes in the phytoplankton and zooplankton communities (i.e., increase in size of phytoplankton and decrease in size of zooplankton) prevented biological control of the lake's algal community during July through August. Although numbers of large-bodied cladocera increased in August, the large blue-green algal filaments and colonies were inedible. Hence, zooplankters were unable to exert control over the algae during August through September, despite increased numbers.

1.4.4 Macrophytes

Aquatic plants are a natural part of most lake communities and provide many benefits to fish, wildlife, and people. Typical functions of a lake's macrophyte community include:

- Provide habitat for fish, insects, and small invertebrates
- Provide food for waterfowl, fish, and wildlife
- Produce oxygen
- Provide spawning areas for fish in early-spring
- Help stabilize bottom sediments, marshy borders, and protect shorelines from wave erosion
- Provide nesting sites for waterfowl and marsh birds

Macrophytes (aquatic plants) are an important component of the lake ecosystem (Ozimek, Gulati, and van Donk, 1990). However, the introduction of exotic (nonnative) aquatic plants into a lake may cause undesirable changes to the plant community and to the lake ecosystem. Dense stands of some mat-forming plant species reduce oxygen exchange, deplete available dissolved oxygen, increase water temperatures, and increase internal loading rates of nutrients (Frodge, Thomas, and Pauley, 1991; Frodge et al., 1995; Seki, Takahashi, and Ichimura, 1979). Dense canopies formed by some nonnative species (e.g., curlyleaf pondweed) reduce native plant diversity and abundance (Madsen, et al., 1994), thereby reducing habitat complexity. This reduction in habitat complexity results in reduced macroinvertebrate diversity and abundance (Krull, 1970; Keast, 1984) and also reduces growth of fishes (Lillie and Budd, 1992). The introduction of a nonnative plant species to a lake is not only deleterious to human use of aquatic systems, but is also detrimental to the native ecosystem.

Submersed aquatic macrophytes can play an important role in the phosphorus budget of a lake. In particular, macrophytes can directly recycle phosphorus from the sediment via root uptake, incorporation into tissue, and subsequent senescence (Barko and Smart, 1980; Carpenter, 1980; Landers, 1982; Smith and Adams, 1986; Barko and James, 1998). They can also indirectly recycle phosphorus from the sediment by increasing pH in the water column through photosynthetic activities. Phosphorus release from the sediments can be enhanced at high pH as a result of ligand exchange on iron hydroxides contained in the sediment (Drake and Heaney, 1987).

Red Rock Lake's macrophytes were surveyed on June 25 (Figure 16) and August 27, 1999 (Figure 17) to identify the conditions of plant growth throughout the lake. Aquatic plants were found in water depths less than six feet. A total of nine submerged species, seven floating leaf species, and four emergent species were observed in Red Rock Lake (see Figure 18). These species are common to Minnesota lakes and most provide good habitat for the fish and aquatic animals living within the lake. Although the lake's plant community was primarily comprised of native species, the community included one non-native submerged species, curlyleaf pondweed (*Potamogeton crispus*), and one non-native emergent species, purple loosestrife (*Lythrum salicaria*).

1.4.4.1 Curlyleaf Pondweed

The growth of the exotic (nonnative) species, curlyleaf pondweed (*Potamogeton crispus*), in Red Rock Lake is of concern. Curlyleaf pondweed (see Figure 19) was found throughout the lake during June. Densities of this plant ranged from light to moderate. Moderate growth was found in the east and south littoral areas and lighter growth was found in the west and north littoral areas.

Figure 19 ***Potamogeton crispus* (Curlyleaf pondweed)**

* No Macrophytes Found in Water >5.0' - 6.0'
* *Potamogeton crispus* (Curlyleaf pondweed) has Matured and is Dying
* Floating Algal Mats Present
* Areas of Shoreline Have Been Treated
* Macrophyte Densities Estimated as Follows: 1 = light; 2 = moderate; 3 = heavy

	Common Name	Scientific Name
Submerged Aquatic Plants:	Leafy/Narrowleaf pondweed	*Potamogeton spp. (narrowleaf)*
	Bladderwort	*Utricularia spp.*
	Curlyleaf pondweed	*Potamogeton crispus*
	Flatstem pondweed	*Potamogeton zosteriformis*
	Sago pondweed	*Potamogeton pectinatus*
	Elodea	*Elodea canadensis*
	Coontail	*Ceratophyllum demersum*
	Water stargrass	*Zosterella dubia*
	Northern watermilfoil	*Myriophyllum sibiricum*
Floating Leaf Plants:	White waterlily	*Nymphaea tuberosa*
	Yellow waterlily	*Nuphar variegata*
	American lotus	*Nelumbo lutea*
	Star duckweed	*Lemna trisulca*
	Lesser duckweed	*Lemna minor*
	Greater duckweed	*Spirodela polyrhiza*
	Common watermeal	*Wolffia columbiana*
Emergent Plants:	Cattail	*Typha sp.*
	Water smartweed	*Polygonum spp.*
	Bulrush	*Scirpus sp.*
	Purple loosestrife	*Lythrum salicaria*
No Aquatic Vegetation Found:		

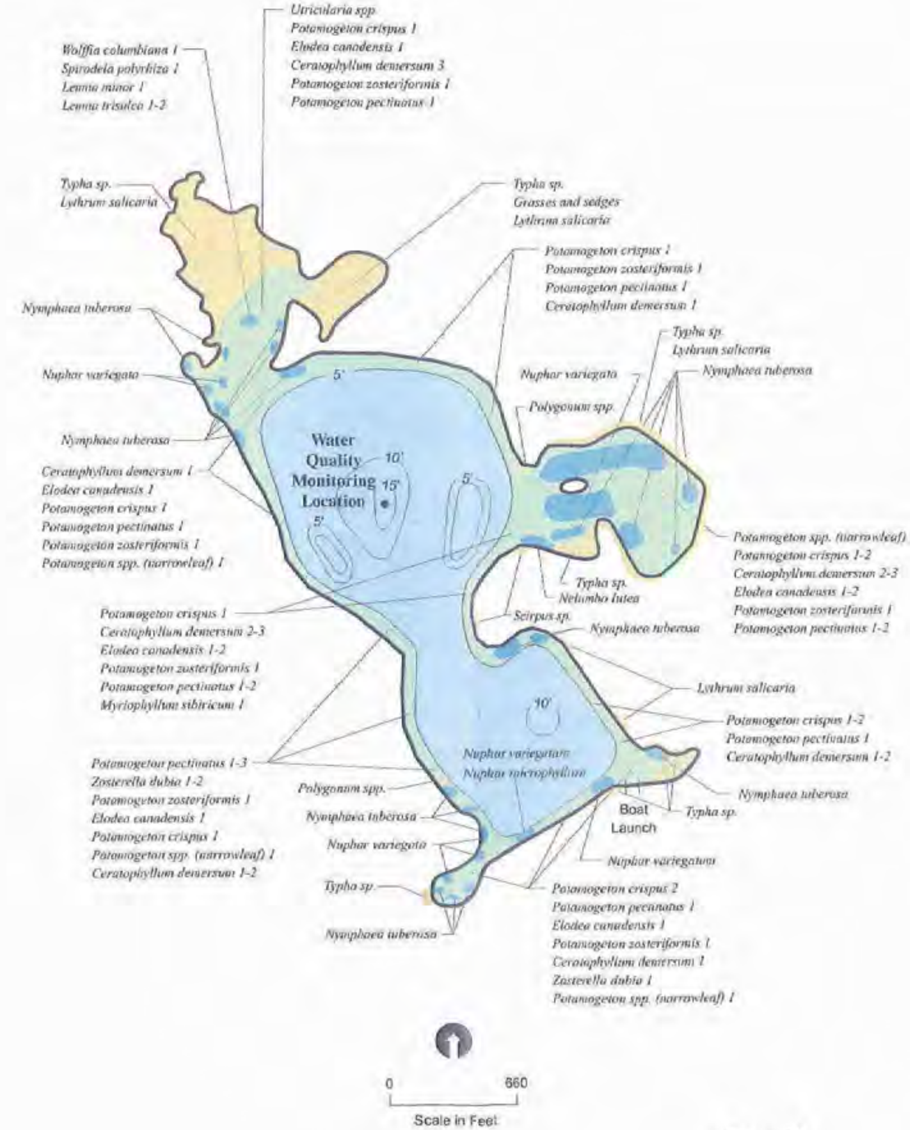


Figure 16

RED ROCK LAKE
MACROPHYTE SURVEY
JUNE 25, 1999

* No Macrophytes Found in Water >5.0' - 6.0'
* *Lythrum salicaria* (Purple Loosestrife) Along most of Shoreline, Heavier Areas Shown on Map
* Floating Algal Mats Present
* Areas of Shoreline Have Been Treated
* Macrophyte Densities Estimated as Follows: 1 = light; 2 = moderate; 3 = heavy

	Common Name	Scientific Name
Submerged Aquatic Plants:	Leafy/Narrowleaf pondweed	*Potamogeton spp. (narrowleaf)*
	Bladderwort	*Utricularia spp.*
	Flatstem pondweed	*Potamogeton zosteriformis*
	Sago pondweed	*Potamogeton pectinatus*
	Elodea	*Elodea canadensis*
	Coontail	*Ceratophyllum demersum*
	Water stargrass	*Zosterella dubia*
	Northern watermilfoil	*Myriophyllum sibiricum*
Floating Leaf Plants:	White waterlily	*Nymphaea tuberosa*
	Yellow waterlily	*Nuphar variegata*
	American lotus	*Nelumbo lutea*
	Star duckweed	*Lemna trisulca*
	Lesser duckweed	*Lemna minor*
	Greater duckweed	*Spirodela polyrhiza*
	Common watermeal	*Wolffia columbiana*
Emergent Plants:	Cattail	*Typha spp.*
	Water smartweed	*Polygonum spp.*
	Bulrush	*Scirpus spp.*
	Purple loosestrife	*Lythrum salicaria*
No Aquatic Vegetation Found:		

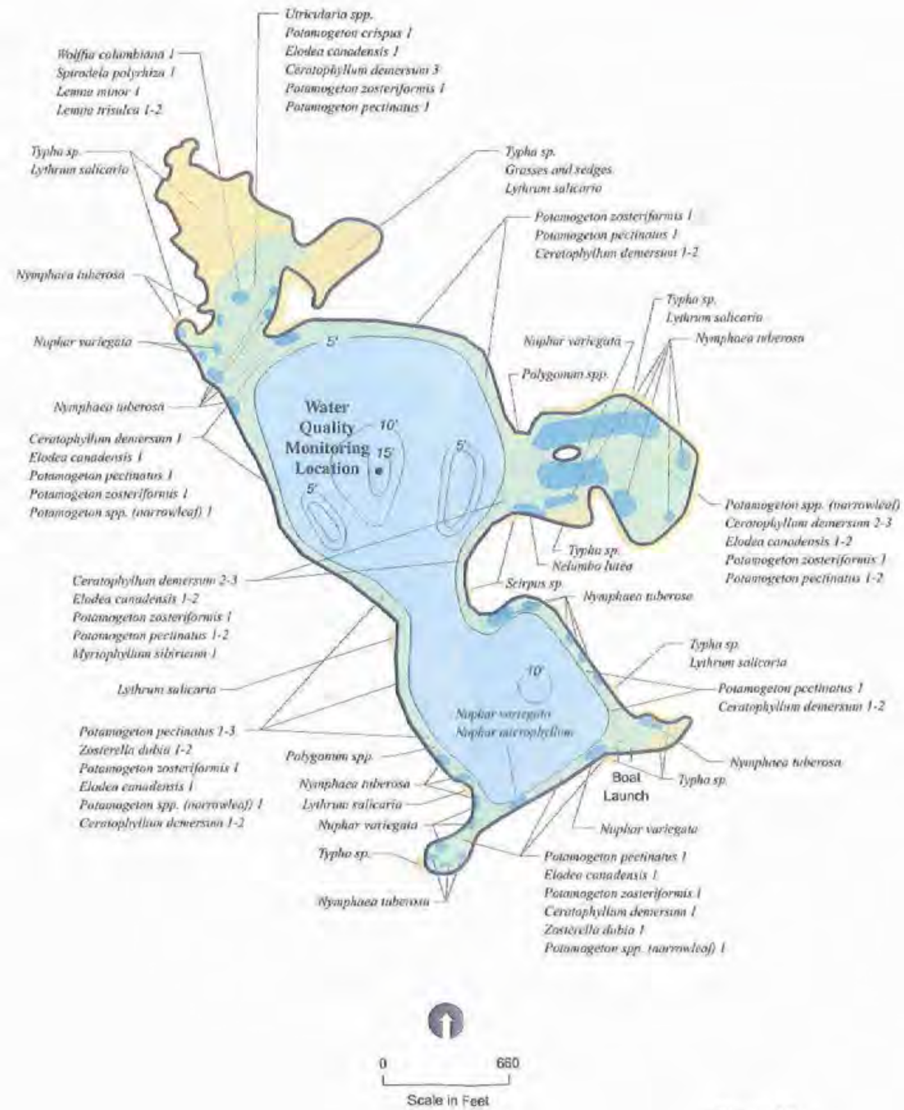


Figure 17

RED ROCK LAKE
MACROPHYTE SURVEY
AUGUST 27, 1999

Figure 18 1999 Red Rock Lake Aquatic Plants

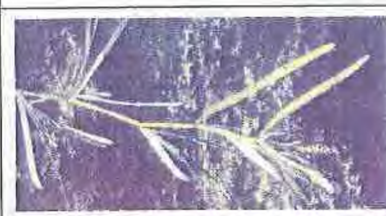
Common Name	Scientific Name	1999 Density	Picture
Submerged Aquatics			
Curlyleaf pondweed	*P. crispus*	1-2	
Flatstem pondweed	*P. zosteriformis*	1	
Sago pondweed	*P. pectinatus*	1-3	
Leafy/Narrowleaf pondweed	*P.spp.* (pictured is *P. foliosus*)	1	
Bladderwort	*Utricularia spp.*	--	
Coontail	*Ceratophyllum demersum*	1-3	

Figure 18 1999 Red Rock Lake Aquatic Plants (Continued)

Common Name	Scientific Name	1999 Density	Picture
Submerged Aquatics			
Elodea	*Elodea canadensis*	1-2	
Water stargrass	*Zosterella dubia.*	1-2	
Northern watermilfoil	*Myriophyllum sibiricum.*	1	
Floating Leaf Plants			
Greater Duckweed	*Spirodela polyrhiza*	--	
Lesser Duckweed	*Lemna minor*	--	

Figure 18 1999 Red Rock Lake Aquatic Plants (Continued)

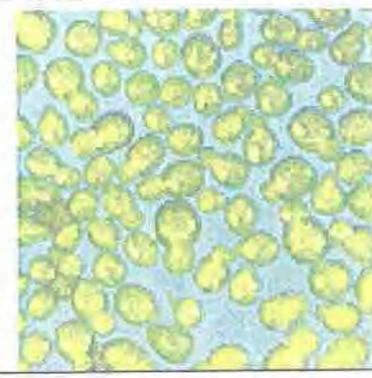
Common Name	Scientific Name	1999 Density	Picture
Submerged Aquatics			
Star Duckweed	*Lemna trisulca*	--	
Common Watermeal	*Wolffia columbiana*	--	

Figure 18 1999 Red Rock Lake Aquatic Plants (Continued)

Common Name	Scientific Name	1999 Density	Picture
Floating Leaf Plants			
American lotus	*Nelumbo lutea*	--	
White waterlily	*Nymphaea tuberosa*	--	
Spadderdock	*Nuphar variegata*	--	
Emergent Plants			
Cattail	*Typha sp.* *Left: T. latifolia, broadleaf (native).* *Right: T. angustifolia, narrow-leaf (non-native)*	--	 

Figure 18 1999 Red Rock Lake Aquatic Plants (Continued)			
Common Name			
Emergent Plants			
Bulrush	*Scirpus sp.*	—	 
Purple Loosestrife	*Lythrum salicaria*	--	
Water smartweed	*Polygonum spp.*	--	

Data from 1993 through 1999 and 2005 indicate curlyleaf infestation of the lake has occurred for more than a decade (See Appendix E). Fluctuations in density have occurred, including density increases during the 1999 through 2005 period. As shown in Figure 20, curlyleaf density during June 2005 ranged from light to heavy. The density increases observed during 1999 through 2005 are likely due to the plant's unique life cycle which enables it to outcompete native vegetation. The curlyleaf pondweed life cycle starts with germination/initial growth in late-August, continued growth throughout the winter at a slow rate, rapid growth in the spring, and die-off in early-summer (Madsen, et al., 2002). Curlyleaf pondweed's life cycle typically enables the plant to outcompete native vegetation. Native plants that grow from seed in the spring are unable to grow in areas already occupied by curlyleaf pondweed, and are displaced by this plant. Curlyleaf pondweed die-off in early-summer releases phosphorus to the lake, thus supporting algal growth for the remainder of the summer.

In addition to density increases, increased curlyleaf pondweed coverage was observed in Red Rock Lake during 1999 through 2005. Prior to 2005, macrophyte coverage was found in the littoral area in areas less than 5 or 6 feet. Submersed aquatic plants covered a total area of 39.5 acres, 41 percent of the lake's surface area, in 1999 (See Figure 21). During 2005, submersed aquatic plants were found in areas less than 14 feet deep and covered a total area of 85.2 acres, 88 percent of the lake's surface area (See Figure 22). The primary concern of the increased coverage of curlyleaf pondweed in Red Rock Lake is the increased phosphorus loading from curlyleaf pondweed die-off in early-summer.

Management of curlyleaf pondweed is recommended to protect the lake's water quality and native plant community and to improve the lake's fishery. Reduction of the lake's phosphorus concentration is recommended to reduce algal growth and improve water clarity.

* No Macrophytes Found in Water >13.0' - 14.0'
* *Potamogeton crispus* (Curlyleaf pondweed) is Maturing, Dense Areas Throughout Lake, Except Near Deep Hole.
* Floating Algal Mats Present
* Dense Mats of Dead and Dying *Potamogeton crispus* (Curlyleaf pondweed)
* Macrophyte Densities Estimated as Follows: 1 = light; 2 = moderate; 3 = heavy

	Common Name	Scientific Name
Submerged Aquatic Plants:	Narrowleaf pondweed	*Potamogeton sp. (narrowleaf)*
	Curlyleaf pondweed	*Potamogeton crispus*
	Flatstem pondweed	*Potamogeton zosteriformis*
	Sago pondweed	*Potamogeton pectinatus*
	Elodea	*Elodea canadensis*
	Coontail	*Ceratophyllum demersum*
	Water stargrass	*Zosterella dubia*
	Northern watermilfoil	*Myriophyllum sibiricum*
Floating Leaf Plants:	White waterlily	*Nymphaea tuberosa*
	Yellow waterlily	*Nuphar variegata*
	American lotus	*Nelumbo lutea*
	Star duckweed	*Lemna trisulca*
	Lesser duckweed	*Lemna minor*
	Greater duckweed	*Spirodela polyrhiza*
	Common watermeal	*Wolffia columbiana*
Emergent Plants:	Cattail	*Typha sp.*
	Bulrush	*Scirpus sp.*
	Purple loosestrife	*Lythrum salicaria*
No Aquatic Vegetation Found:		

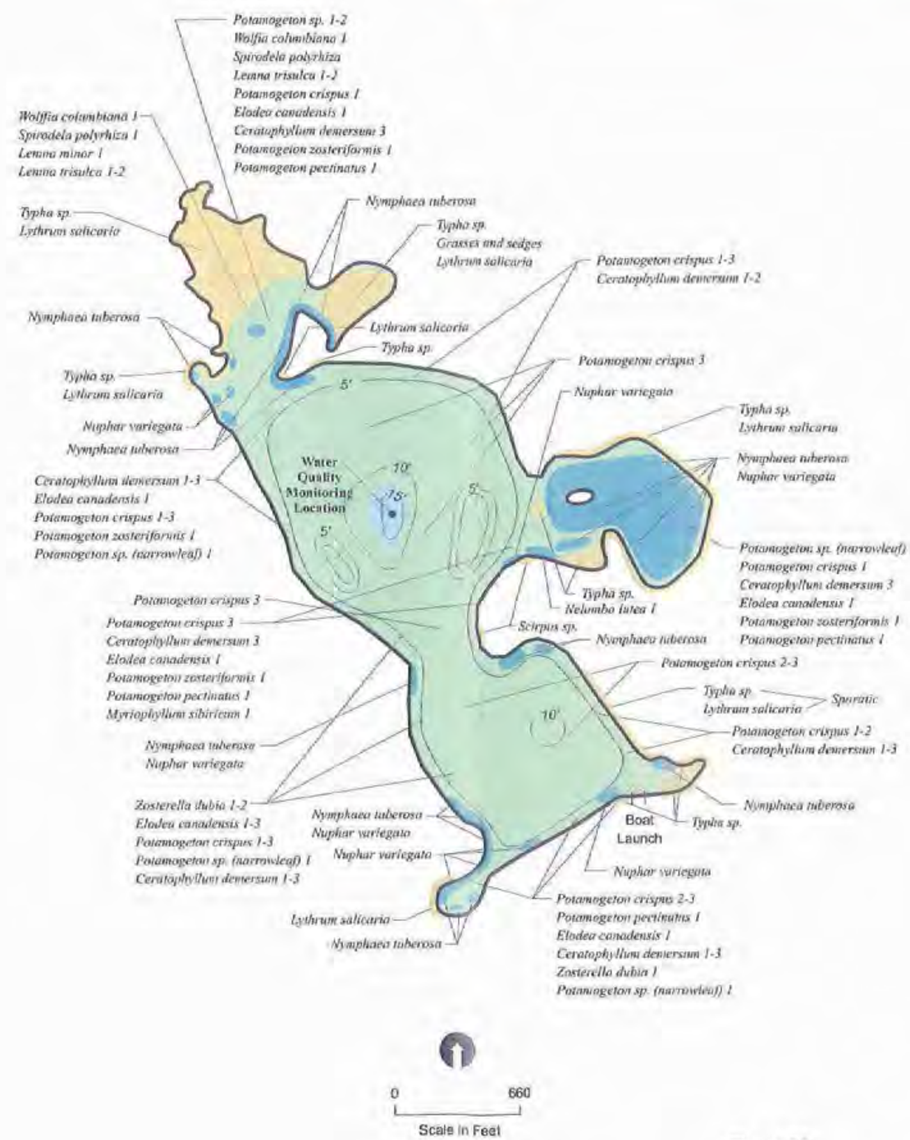


Figure 20

RED ROCK LAKE
MACROPHYTE SURVEY
JUNE 21, 2005

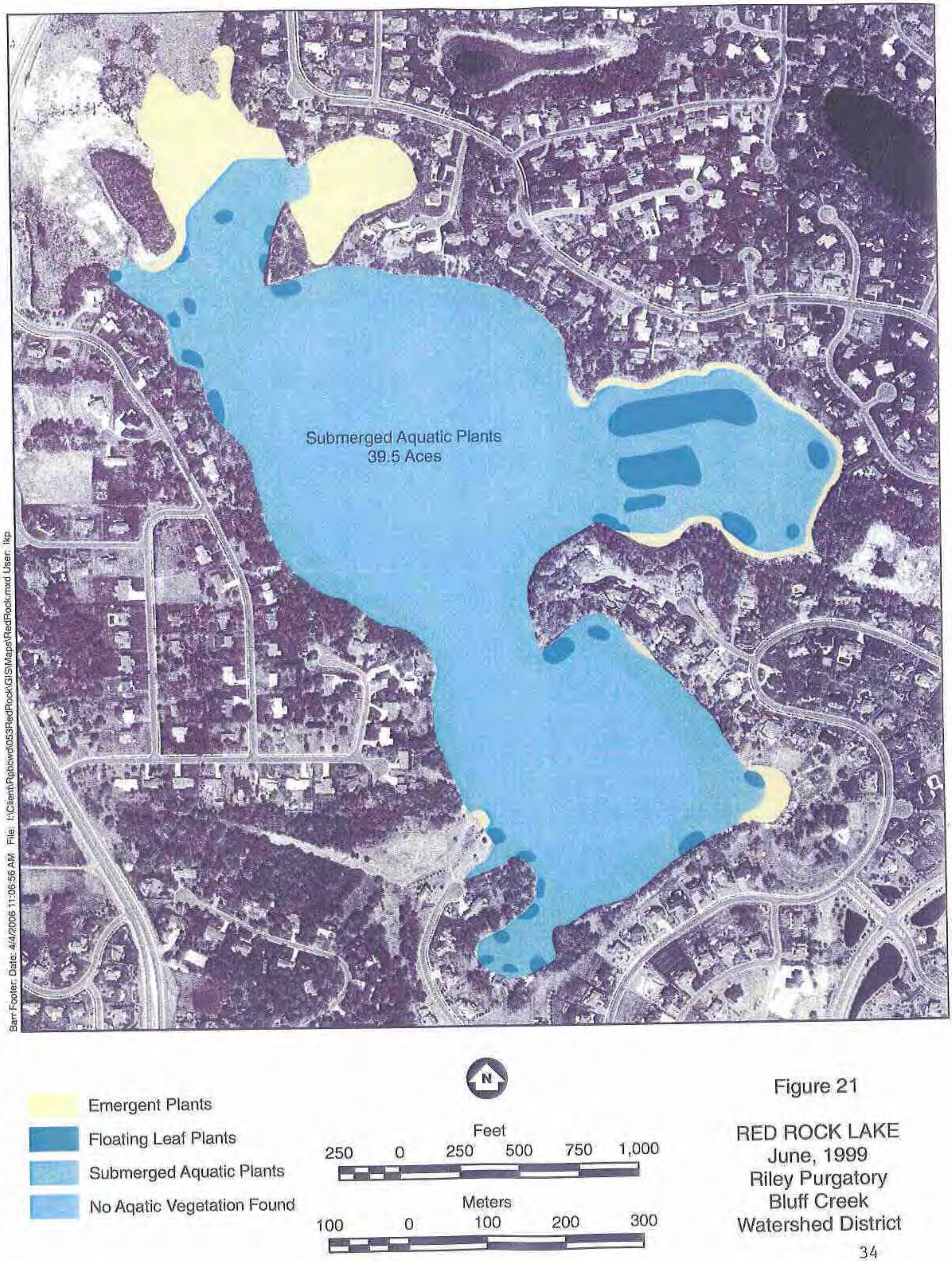
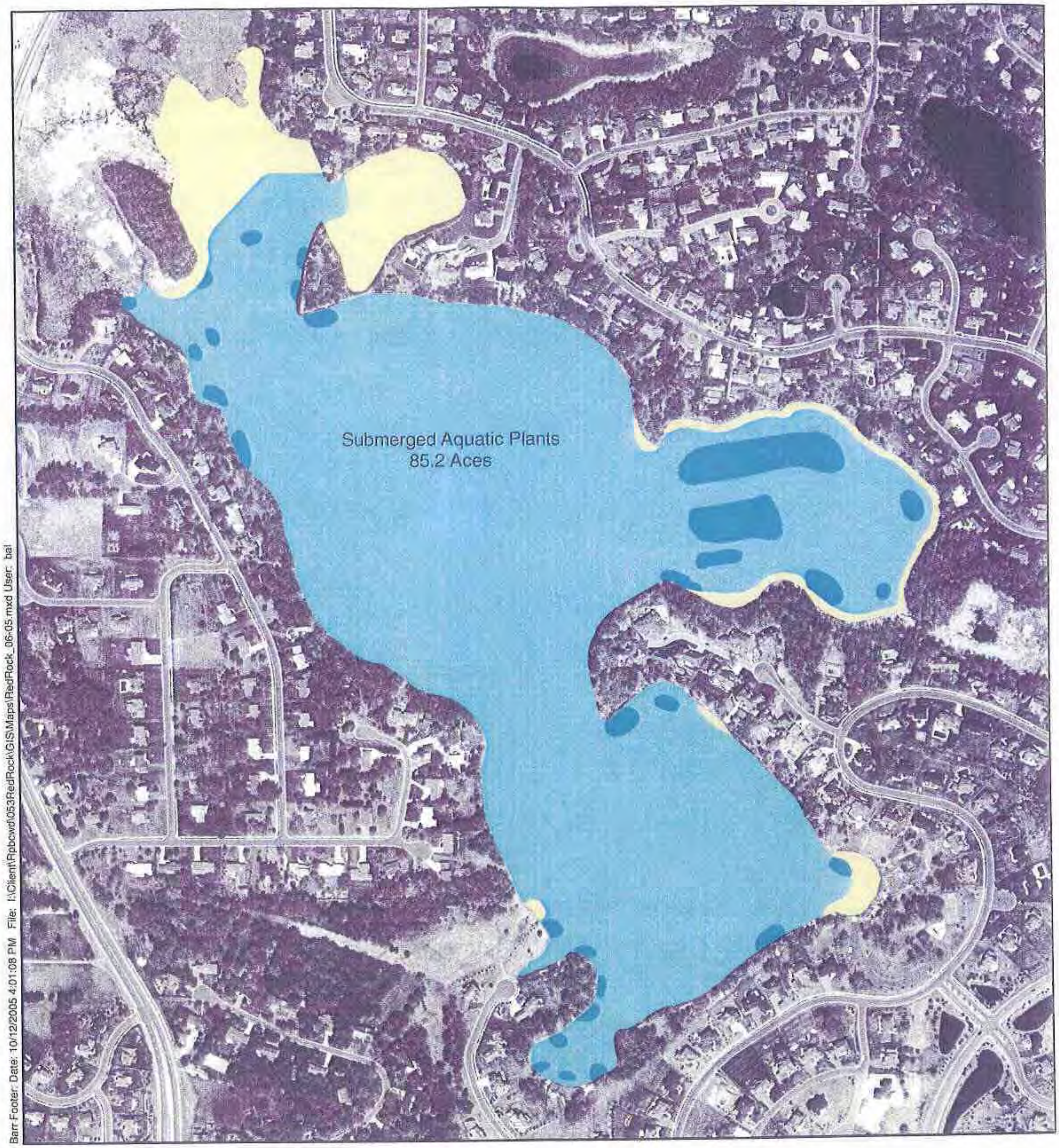


Figure 21

RED ROCK LAKE
June, 1999
Riley Purgatory
Bluff Creek
Watershed District



Emergent Plants

Floating Leaf Plants

Submerged Aquatic Plants

No Aqatic Vegetation Found

N

Feet

250 0 250 500 750 1,000

Meters

100 0 100 200 300

Figure 22

RED ROCK LAKE
June, 2005
Riley Purgatory
Bluff Creek
Watershed District

Barr Footer: Date: 10/12/2005 4:01:08 PM File: I:\Client\Rpbcwd\053RedRock\GIS\Maps\RedRock_06-05.mxd User: bal

1.4.4.2 Purple Loosestrife

During August of 1996, the non-native emergent plant, purple loosestrife (*Lythrum salicaria*), was observed for the first time in Red Rock Lake. The plant was observed along the lake's shoreline (sporadic) with heaviest growth observed in the lake's northeastern bay. In 1999, purple loosestrife was found along most of the shoreline and heavy growths were found throughout the northern bay and portions of the eastern, southern, and western shoreline. Purple loosestrife coverage continued its increase during the 1999 through 2005 period. Additional areas of heavy growth were observed along the southern and southeastern shoreline in 2005.

Purple loosestrife, an emergent plant, is native to Europe and the temperate regions of Asia (see Figure 23). Once introduced into an area, the plant typically replaces native vegetation and rapidly becomes the sole emergent species. Management of purple loosestrife is recommended to protect the quality of vegetation along the lake's shoreline.

Figure 23 Purple Loosestrife (*Lythrum salicaria*)

1.5 Water Based Recreation

Red Rock Lake is primarily used for boating, canoeing, fishing, and aesthetic viewing. A municipal boat launch was completed during the summer of 1989 in the southeast corner of the lake (MDNR, 1991).

1.6 Fish and Wildlife Habitat

The MDNR has developed a classification system for Minnesota lakes relative to the chemical and physical properties of each lake class and the fishery that is supported by each lake (Schupp, 1992). According to its ecological classification, Red Rock Lake is a Class 42 lake. Class 42 lakes are typically shallow and productive lakes with fish assemblages that include white sucker, yellow perch, bluegills, pumpkinseeds, black crappie, black bullhead, and northern pike (Schupp, 1992). Class 42 lakes are considered marginal fish lakes because they may winterkill frequently. The MDNR has indicated that the average water quality for the ecological class of Red Rock Lake is a TSI_{SD} (Trophic State Index in terms of Secchi disc transparency) of approximately 59 or lower (i.e., a summer average Secchi disc transparency of about 3.6 feet or greater). The recommendation is based upon the water quality needs of the fishery found in a Class 42 lake. Red Rock Lake's water quality does not meet this recommendation based upon the 1999 data. The lake's current water quality (monitoring year 1999) corresponds to a TSI_{SD} of 62 (a summer average Secchi disc of approximately 3 feet). Red Rock Lake did not meet the TSI_{SD} goal during the 1988 through 1999 monitoring period (TSI_{SD} ranged from 60 through 63). During 1972 through 1984, Red Rock Lake generally met the TSI_{SD} goal (TSI_{SD} ranged from 50 through 60).

An aeration system was installed in Red Rock Lake in 1991 and has been in operation during the winter period from 1991 through the present. Low oxygen levels were observed during 1996 despite the aeration system. Dissolved oxygen levels were less than 2 mg/L in the open water at the baffle and near 0 mg/L in most of the lake. The population assessment in May 1996 documented that the fishery carried over apparently at a refuge other than the aeration system.

Red Rock Lake's fishery currently (1999) consists of panfish, gamefish, and rough fish. The 1999 MDNR fish survey showed that the following species are present in Red Rock Lake:

- **Panfish**—black crappie, bluegill, green sunfish, and hybrid sunfish


photo by Konrad Schmidt

Black Crappie


photo by Konrad Schmidt

Bluegill


photo by Konrad Schmidt

Green Sunfish

- **Gamefish**—largemouth bass, northern pike, and yellow perch


photo by Konrad Schmidt

Largemouth Bass


photo by Konrad Schmidt

Northern Pike


photo by Konrad Schmidt

Yellow Perch

- **Rough fish**—black bullhead


photo by Konrad Schmidt

Black Bullhead

According to the 1999 survey (MDNR, 2000):

"Bluegills are very abundant in Red Rock Lake. The average length sampled was over 6 inches and 22 percent of the bluegills exceeded 7 inches. The black crappie population is average for this type of lake, but has improved since the last survey. Individuals up to 11.2 inches were sampled. Northern pike were captured in the nets for the first time during this survey. These fish were most likely stocked illegally in the early 1990's. Northern pike over 30 inches in length were sampled. The largemouth bass population is also increasing, as shown by their presence in the trapnets for the first time. Their average length was approximately 11 inches, with individuals over 15 inches also present. The yellow perch population has decreased dramatically since the 1991 survey. This may be a result of the introduction of northern pike and the increased largemouth bass population. Although less abundant, the yellow perch presently provide a fairly good quality fishery for the Metro area with individuals up to 11 inches present. Black bullheads are abundant enough to frustrate bluegill fishermen, but are large enough to provide a good meal for someone so inclined. Green sunfish and hybrid sunfish are present in low abundance."

Changes in the lake's fishery since 1991 indicate improvement in the lake's fishery. The improvements are likely due to the lake's aeration system. Prior to 1991, the lake's fishery was dominated by black bullhead. Also present were sunfish and crappies. In 1999, largemouth bass, northern pike, and yellow perch were present and bluegills were dominant.

The MDNR has prepared a fisheries management plan for Red Rock Lake. According to the plan, the MDNR will:

1. Work with the Eden Prairie Parks and Recreation Department to monitor winter oxygen levels and the aeration system.

2. Complete an annual winter fish house count.

3. Stock adult largemouth bass and bluegill in spring if winterkill occurs or if the community is favorable to a reclamation.

The mid-range objective of the plan is to establish a fish population that is capable of supporting 100 angler hours per acre.

A potential plan for the lake is to install a fishing pier at the city park, complete a creel survey, and reclamation of the lake.

1.7 Discharges

1.7.1 Natural Conveyance Systems

The natural inflow to Red Rock Lake consists of direct runoff from the land surrounding the lake and groundwater inflows. All other discharges to the lake are through piped inlets.

1.7.2 Stormwater Conveyance Systems

Stormwater is conveyed to the lake from the lake's watershed. Figure 1 shows the stormwater conveyance systems. Most stormwater runoff is treated by a pond or by an upstream lake (i.e., Mitchell Lake or Round Lake) before entering Red Rock Lake.

1.7.3 Public Ditch Systems

There are no public ditch systems that affect Red Rock Lake.

1.8 Appropriations

There are no known water appropriations from Red Rock Lake.

1.9 Summary of Surface Water Resource Data

The current water quality and ecological status of Red Rock Lake is largely the result of phosphorus loading from the lake's watershed and from internal lake processes, including decay of curlyleaf pondweed and the release of phosphorus from the lake's sediments.

Today's internal loading processes result from the addition of nutrient rich sediments to Red Rock Lake over a period of time. A historical aerial photo of the lake (Figure 3) shows that the watershed of the lake in 1947 primarily consisted of agricultural lands that drained to the lake. Agricultural sediment can be high in nutrients.

The concentration of phosphorus in the lake sediments that can release into the water column (i.e. mobile phosphorus) of Red Rock Lake is relatively high (Figure 24) and corresponds to a potential phosphorus release rate of approximately 8.54 mg per square meter of lake surface per day in deeper areas of the lake. The lake wide average release rate was determined to be 3.1 mg per square meter of lake surface per day. The lake wide average includes shallower areas of the lake water body with sediment not generally exposed to anoxic conditions which can result in higher release rates of phosphorus. Also, the shallow areas of the lake have sediment that is more transitional in nature meaning that the less dense, generally higher phosphorus content portions of the sediment move towards the deeper areas of the lake where they accumulate over time (See Figure 25). Both of these factors lead to lower phosphorus release rates in the shallower portions of the lake.

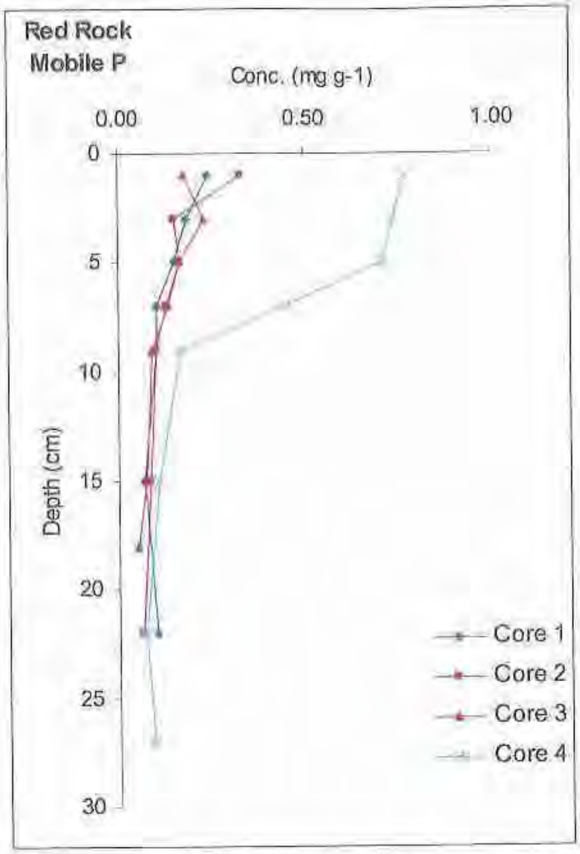


Figure 24 Distribution of Potentially Releasable Mobile Phosphorus in Red Rock Lake Sediment

Although the lake's current internal loading from sediments is due to mobile phosphorus, it is important to also characterize the organic content of the sediment. This is because much of the phosphorus bound in organic material will eventually be loaded to the lake and become available through sediment diagenesis or degradation. Organic material in the sediment of Red Rock Lake was higher in the shallower areas of the lake and indicates a substantial pool of phosphorus that will eventually become mobile phosphorus over time. Organic phosphorus concentration of the sediment in shallower areas of the lake reached 0.65 mg phosphorus per gram of lake sediment, nearly double that found in the deep hole of the lake (0.39 mg phosphorus per gram of lake sediment).

Under future watershed land use conditions, increased volumes of stormwater runoff reduce the proportion of the internal phosphorus load by an estimated 2 percent under wet climatic conditions, 4 percent under model calibration climatic conditions, and 6 percent under average and dry climatic conditions.

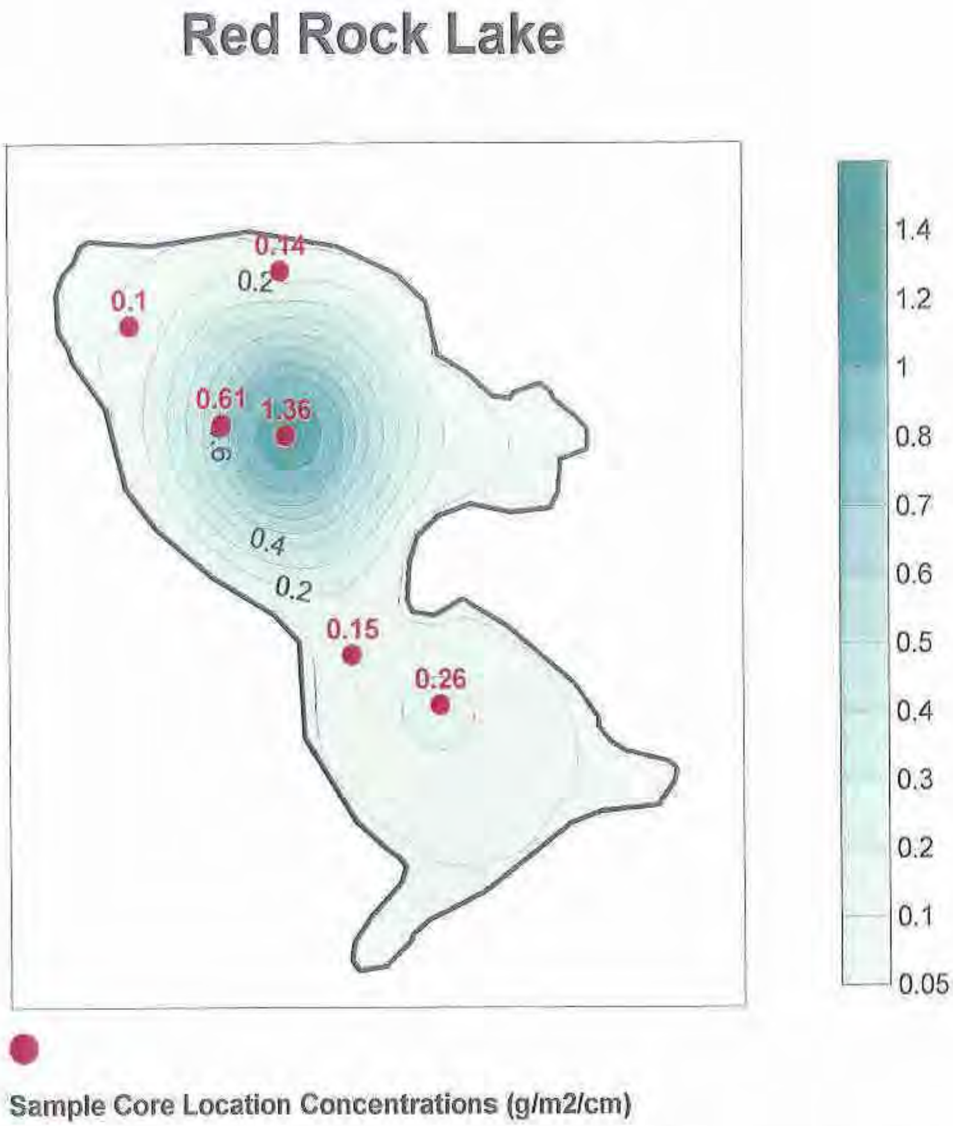


Figure 25 2005 Spatial Distribution of Mobile Phosphorus in Red Rock Lake

Currently, the ecology of Red Rock Lake is being driven by phosphorus loading from the lake's watershed and internal phosphorus loading. In mid- to late-summer there is a significant increase in phosphorus in the lake that is due to curlyleaf pondweed decay and the release of phosphorus from the lake's fertile sediments. Curlyleaf pondweed is found throughout the lake's littoral area in June and then dies off in early-summer. When curlyleaf pondweed dies off it releases phosphorus into the lake. Anoxic conditions at the lake's sediment water interface facilitate the release of phosphorus that is stored in lake sediments into the water column (anoxic release of phosphorus). In mid-to late-summer there is a significant increase in phosphorus in the lake that can be attributed to the release of phosphorus from lake sediments and the decay of curlyleaf pondweed. This increase in phosphorus is associated with mid-to late-summer algal blooms (Figure 26).

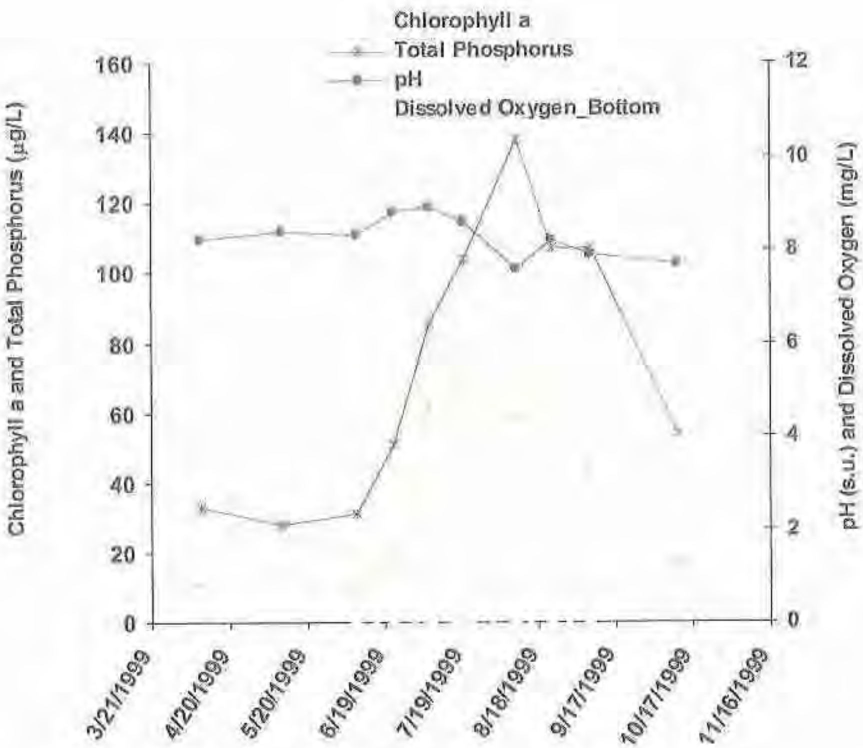


Figure 26 Seasonal Pattern of pH, Total Phosphorus, Temperature, and Chlorophyll *a* in Red Rock Lake

Figure 27 depicts the sources of the lake's phosphorus concentrations measured during 1999 (calibration year) as determined from in-lake modeling of Red Rock Lake. The lake's phosphorus content during spring was the primary source of phosphorus through mid-May. From mid-May through mid-June, stormwater runoff from the lake's watershed and flow from Mitchell Lake were the primary sources of phosphorus. For the remainder of June, sources of phosphorus included curlyleaf pondweed and decay from the lake's fertile sediments in addition to stormwater runoff and flow from Mitchell Lake. During July through October, curlyleaf pondweed decay and the lake's fertile sediments were the primary sources of phosphorus. During this period, stormwater runoff from the lake's watershed contributed to the lake's phosphorus content (from 15 to 29 percent), but played a lesser role than the lake's internal processes. Internal processes began contributing phosphorus to the lake during May and apparently were the source of approximately 62 to 76 percent of the lake's phosphorus concentration during July through October. During this period, sediment phosphorus release was the source of from 11 to 47 percent of the lake's phosphorus concentration and curlyleaf pondweed decay was the source of from 20 to 51 percent of the lake's phosphorus concentration.

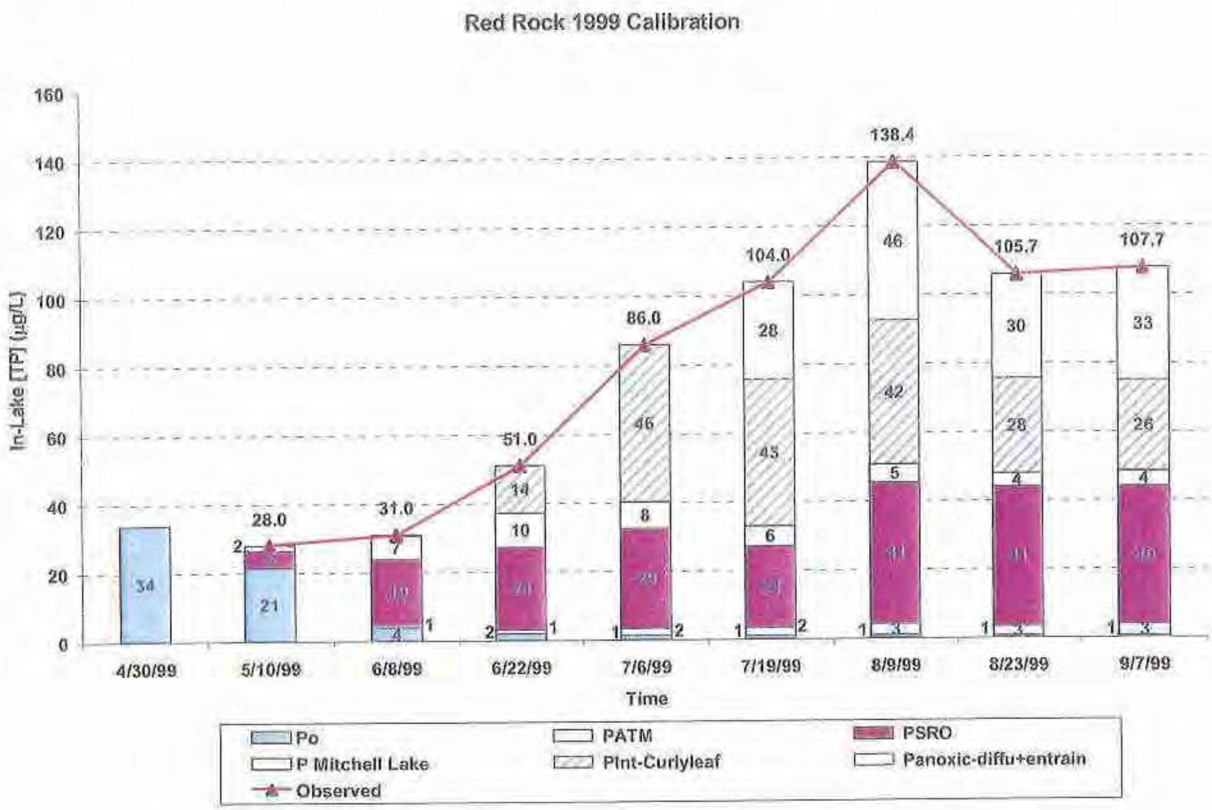


Figure 27 1999 Red Rock Lake Phosphorus Sources

During a wet climatic year (1997), flow from Mitchell Lake comprised a greater fraction of the lake's epilimnetic phosphorus concentration than during average or dry climatic conditions. As shown in Figure 28, flow from Mitchell Lake was the source of at least 9 percent and as much as 63 percent of the lake's epilimnetic phosphorus concentration during the July through October period.

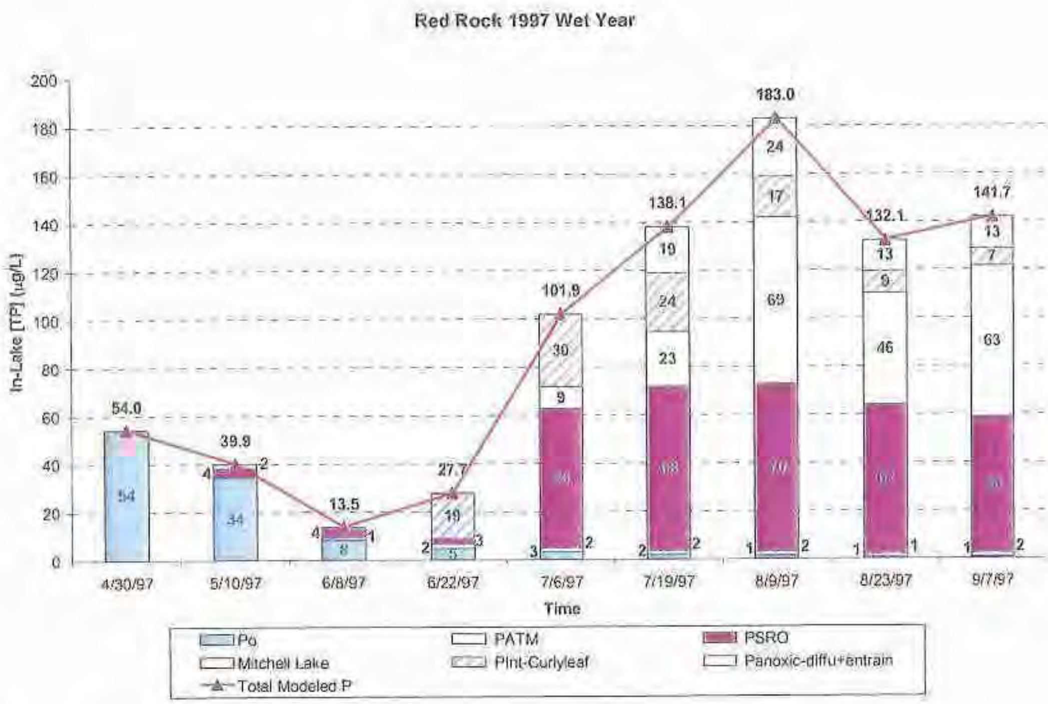


Figure 28 Red Rock Lake Wet Year (1997) Phosphorus Sources

Key to Figures 27 and 28 Legends:

P_0 = The lake's epilimnetic phosphorus concentration following ice-out in April is the starting phosphorus concentration. Most of the phosphorus present in April left the lake through its outlet during the growing season.

PATM = The fraction of the lake's epilimnetic phosphorus concentration resulting from atmospheric deposition. A portion of this phosphorus load left the lake through its outlet during the growing season.

PSRO = The fraction of the lake's epilimnetic phosphorus concentration resulting from stormwater runoff from the lake's direct watershed (the watershed draining to Red Rock Lake, excluding the watershed draining to upstream lakes Mitchell and Round). A portion of this phosphorus load left the lake through its outlet during the growing season.

Mitchell Lake = The fraction of the lake's epilimnetic phosphorus concentration resulting from Mitchell Lake outflow. A portion of this phosphorus load left the lake through its outlet during the growing season.

Plnt-Curlyleaf = The fraction of the lake's epilimnetic phosphorus concentration resulting from decay of curlyleaf pondweed plants. A portion of this phosphorus load left the lake through its outlet during the growing season.

Panoxic-diffu+entr = The fraction of the lake's epilimnetic phosphorus concentration resulting from sediment release of phosphorus under anoxic conditions. This fraction includes phosphorus entering the epilimnion via diffusion and entrainment. A portion of this phosphorus load left the lake through its outlet during the growing season.

Observed = epilimnetic total phosphorus concentrations measured during 1999

Total Modeled P = Epilimnetic total phosphorus concentrations estimated for water year 1997.

2.0 Assessment of Red Rock Lake Problems

2.1 Appropriations

There are no known water appropriations from Red Rock Lake.

2.2 Discharges

The model P8 (IEP Inc., 1990) was used to determine the water and phosphorus loading to Red Rock Lake from the land surrounding the lake and from conveyed stormwater discharges to the lake (parameters used in the P8 model are presented in Appendix D). Although the discharge of stormwater from the Red Rock Lake watershed conveys phosphorus to the lake and contributes to the level of phosphorus in the lake, these discharges are not the cause of high phosphorus levels that are observed in Red Rock Lake. Details of the phosphorus discharges to the lake are provided below.

2.2.1 Natural Conveyance Systems

Natural conveyance systems contribute stormwater to Red Rock Lake from the land that surrounds the lake. There are no other natural conveyances to Red Rock Lake such as streams.

2.2.1.1 Direct Watershed

The Red Rock Lake direct watershed is the land that surrounds the lake. There is no treatment of this runoff. Phosphorus loading from this watershed area was modeled using three climatic conditions:

- **Wet Year**: annual precipitation of 38 inches, the amount of precipitation that occurred during the 1997 water year.
- **Average Year**: annual precipitation of 35 inches, the amount of precipitation that occurred during the 1999 water year
- **Calibration Year**: annual precipitation of 33 inches, the amount of precipitation that occurred during the period May 1998 through April 1999.
- **Dry Year**: annual precipitation of 24 inches, the amount of precipitation that occurred during the 2000 water year

Loading from the direct watershed to Red Rock Lake is expected to range from 53 to 100 pounds per year under existing land uses and from 52 to 93 pounds per year for future land uses (Table 4). Currently loading from the direct watershed represents approximately 13 to 16 percent of the total annual phosphorus load to Red Rock Lake. The lake's total annual phosphorus load includes both external and internal phosphorus loads. Under future land use, loading from the direct watershed is estimated to represent approximately 9 to 11 percent of the total annual phosphorus load to Red Rock Lake.

Table 4 Estimated Annual Total Phosphorus Loads from the Red Rock Lake Direct Watershed for Existing and Future Land Uses

Climate Condition (Inches of Precipitation)	Annual Total Phosphorus Load From Direct Watershed (Pounds)	% of Total Annual Red Rock Lake Total Phosphorus Load
Existing Land Use		
Wet (38")	100	13
Model Calibration (33")	71	15
Average (35")	57	15
Dry (24")	53	16
Future Land Use		
Wet (38")	93	9
Model Calibration (33")	69	11
Average (35")	59	11
Dry (24")	52	11

2.2.2 Stormwater Conveyance Systems

The annual phosphorus load from all stormwater conveyance systems to Red Rock Lake (Table 5) is estimated to range from 122 to 507 pounds under existing land use conditions and from 250 to 752 pounds for future land uses. Currently loading from all stormwater conveyance systems represents approximately 37 to 66 percent of the of the total annual phosphorus load to Red Rock Lake. Under future land use conditions, loading from all stormwater conveyance systems will increase and represent approximately 54 to 75 percent of the lake's total phosphorus load.

Table 5 Estimated Total Phosphorus Loads from All Red Rock Lake Stormwater Conveyance Systems Under Varying Climatic Conditions—Existing and Future Land Use

Climate Condition (inches of precipitation)	Annual Total Phosphorus Load From All Conveyance Systems (Pounds)	% of Annual Red Rock Lake Total Phosphorus Load
Existing Land Use		
Wet (38")	507	66
Model Calibration (33")	253	52
Average (35")	157	42

Climate Condition (inches of precipitation)	Annual Total Phosphorus Load From All Conveyance Systems (Pounds)	% of Annual Red Rock Lake Total Phosphorus Load
Dry (24")	122	37
Future Land Use		
Wet (38")	752	75
Model Calibration (33")	429	65
Average (35")	314	59
Dry (24")	250	54

Currently, phosphorus loading to the lake from storm water runoff is primarily coming from the outflow from Mitchell Lake and from storm sewer outlets RRL-40, RRL-53, and RRL-45 (Table 6, locations shown on Figure 1). Collectively, these four outlets currently contribute from 81 to 88 percent of the annual total phosphorus load from storm sewer conveyance systems. Under existing watershed land use conditions, Mitchell Lake's outflow contributes about one fourth to one half of Red Rock Lake's current conveyance system annual phosphorus load. Collectively, three storm sewer outlets (RRL-40, RRL-53, and RRL-45) currently contribute approximately one third to one half of the lake's current conveyance system annual phosphorus load. Under future land use conditions, two additional ponds will be added, RRL-15A and MN DOT-3 (See Figure 2). Collectively the two outlets are expected to contribute from 19 to 30 percent of the lake's conveyance system annual phosphorus load. The addition of new conveyance systems will reduce the proportionate contribution of existing conveyance systems. The collective contributions from RRL-40, RRL-53, and RRL-45 are expected to range from 16 to 31 percent of the lake's conveyance system annual phosphorus load under future land use conditions. Mitchell Lake outflow is expected to contribute a relatively similar proportion in the future, ranging from 23 to 45 percent.

Table 6 **Estimated Total Phosphorus Loading From Each Stormwater Conveyance System to Red Rock Lake**

Stormwater Conveyance System	Annual Total Phosphorus Load in Pounds			
	Wet (38")	Model Calibration (33")	Average (35")	Dry (24")
Existing Land Use				
Mitchell Lake	272	113	48	32
RRL-16	15	9	4	5
RRL-17	14	8	6	5
RRL-40	80	49	40	31
RRL-40A	19	8	6	6
RRL-43	2	1	1	1
RRL-44	5	3	3	2
RRL-45	37	23	22	16
RRL-47	3	2	1	1
RRL-53	54	33	23	21
RRL-60	6	4	3	2
Total Annual Load From Stormwater Conveyance Systems	507	253	157	122
Total Annual Load from Watershed	607	324	214	175
Total Annual Load to Red Rock Lake (Includes Atmospheric Deposition, Watershed, and Internal Loads	765	482	372	333
Future Land Use				
Mitchell Lake	339	151	82	58
MNDOT-1	2	1	1	1
MNDOT-2	8	6	5	4
MNDOT-3	48	33	28	23
RRL-14	11	8	7	5
RRL-15A	99	72	63	53
RRL-16	15	9	4	5
RRL-29	18	11	8	8
RRL-40	85	53	45	35
RRL-40A	14	10	8	7
RRL-43	5	4	4	3
RRL-44	7	5	4	4
RRL-45	40	28	27	19
RRL-47	3	2	1	1
RRL-53	57	35	26	23
RRL-71	1	1	1	1
Total Annual Load From Stormwater Conveyance Systems	752	429	314	250
Total Annual Load from Watershed	845	498	373	302
Total Annual Load to Red Rock Lake (Includes Atmospheric Deposition, Watershed, and Internal Loads	1,003	656	531	460

Stormwater runoff from 87 percent of Red Rock Lake's watershed is currently treated before entering the lake. When Mitchell Lake and its upstream watershed are excluded and only the watershed draining directly to Red Rock Lake is considered, a total of 76 percent of Red Rock Lake's watershed is currently treated before entering the lake. Treatment effectiveness of the detention ponds and wetlands that lie within the Red Rock Lake watershed was determined for wet, model calibration, average, and dry conditions. As shown in Table 7, annual treatment efficiency of approximately half of the 27 ponds in the lake's watershed is near or above 50 percent. In general, larger ponds note a higher removal rate than smaller ponds. Overall, removal in downstream ponds was reduced because the ponds upstream (See Figure 1) had removed most of the phosphorus that could easily settle out. For example, phosphorus removal in Pond RRL-37, an upstream pond, ranged from 63 to 73 percent under varying climatic conditions and existing watershed land use. Pond RRL-40, the most downstream pond in the conveyance system, removed only 25 to 38 percent of its phosphorus load under the same conditions. Ponds RRL-37, RRL-38, and RRL-42 removed most of the phosphorus that could easily settle out. Hence, most of the phosphorus entering RRL-40 was associated with very small particles or was considered dissolved. An increase in the dead storage volume of these downstream ponds would not lead to measurable improvements in phosphorus removal.

Table 7 Estimated Total Phosphorus Removal Efficiency of Detention Ponds in the Red Rock Lake Watershed Under Existing Land Use Conditions and Varying Climatic Conditions

Stormwater Conveyance System	Pond Name	Total Phosphorus Removal Efficiency (%)			
		Wet (38")	Model Calibration (33")	Average (35")	Dry (24")
RRL-16	RRL-16	22	30	46	37
RRL-17	RRL-29	36	45	54	52
	RRL-71	59	67	67	71
	RRL-70	35	41	31	45
	RRL-17	14	16	11	19
RRL-40	RRL-37	63	68	63	73
	RRL-38	41	50	50	57
	RRL-41	51	59	62	64
	RRL-42	47	54	51	59
	RRL-36	48	57	60	63
	RRL-39	49	57	59	63

Stormwater Conveyance System	Total Phosphorus Removal Efficiency (%)				
	Pond Name	Wet (38")	Model Calibration (33")	Average (35")	Dry (24")
RRL-40	RRL-54	11	15	17	
	RRL-40	25	32	33	38
RRL-40A	RRL-40A	18	22	29	24
RRL-43	RRL-43	49	60	64	66
RRL-44	RRL-44	46	56	61	61
RRL-45	RRL-50	35	44	54	51
	RRL-48	56	64	64	68
	RRL-49	23	40	31	36
	RRL-45	29	32	33	39
RRL-47	RRL-47	45	54	59	61
RRL-53	RRL-46	59	67	65	72
	RRL-52	14	18	26	21
	RRL-52A	7	2	11	9
	RRL-51	15	21	28	25
	RRL-53	28	35	36	39
RRL-60	RRL-60	44	53	59	59

2.2.3 Public Ditch Systems

There are no known ditch systems affecting Red Rock Lake.

2.3 Fish and Wildlife Habitat

The MDNR has established criteria for the support of Red Rock Lake's fishery, based upon Red Rock Lake's classification as a Class 42 lake. The current habitat for Red Rock Lake fails to meet MDNR criteria of a TSI_{SD} of 59 or lower (a summer average Secchi disc transparency of at least 3.6 feet). The lake's poor transparency is caused by algal blooms, which result from excessive phosphorus.

2.4 Water Based Recreation

The recreational uses of Red Rock Lake include fishing, canoeing, boating, and aesthetic viewing. These uses are currently being impaired by curlyleaf pondweed growth and algal blooms.

2.5 Ecosystem Data

Development of a more balanced ecosystem at Red Rock Lake is needed for the lake to achieve the recreation, aquatic communities, and water quality goals that have been set for the lake. There are two primary imbalances in Red Rock Lake: (1) problematic growths of curlyleaf pondweed (See Figure 22), and (2) high phosphorus levels that result in severe summer algal blooms.

It appears that Red Rock Lake's zooplankton population is generally well balanced. However, an imbalance in zooplankton sizes occurs each summer when numbers of large-bodied Cladocera (see Figure 13) decrease and numbers of small-bodied Cladocera (see Figure 14) increase. Fish predation causes the decrease in numbers of large-bodied Cladocera. The changes in the Cladocera community (decreased sizes) together with changes in the algal community (increased sizes) each summer prevent the zooplankton from exerting biological control on the lake's algal community. Although numbers of large-bodied cladocera increased in August of 1999, the large blue-green algal filaments and colonies were inedible. Hence, zooplankters were unable to exert control over the algae during August through September, despite increased numbers. The data indicate a reduction of phosphorus is necessary to reduce algal blooms and improve the lake's water quality.

According to a 1999 MDNR fish survey, the existing fish population of Red Rock Lake has improved since the installation of an aeration system in 1991. The fishery is generally balanced, although bluegills are very abundant. However, the lake's water quality fails to meet the habitat requirements of the lake's fishery. The MDNR has indicated that the average water quality for the ecological class of Red Rock Lake is a TSI_{SD} of approximately 59 or lower. The lake's current water quality (monitoring year 1999) corresponds to a TSI_{SD} of 62 (a summer average Secchi disc of approximately 3 feet). Reduction of the lake's phosphorus concentration is necessary to reduce algal blooms, improve the lake's water transparency, and meet the lake's fishery habitat requirements.

2.6 Water Quality

2.6.1 Baseline/Current Analysis

Evaluation of the baseline and current trophic state index (TSI) of Red Rock Lake shows that the lake met the MDNR-criteria ($TSI_{SD} \leq 59$) for the lake's fishery during the baseline period but not during the current period (Figure 29).

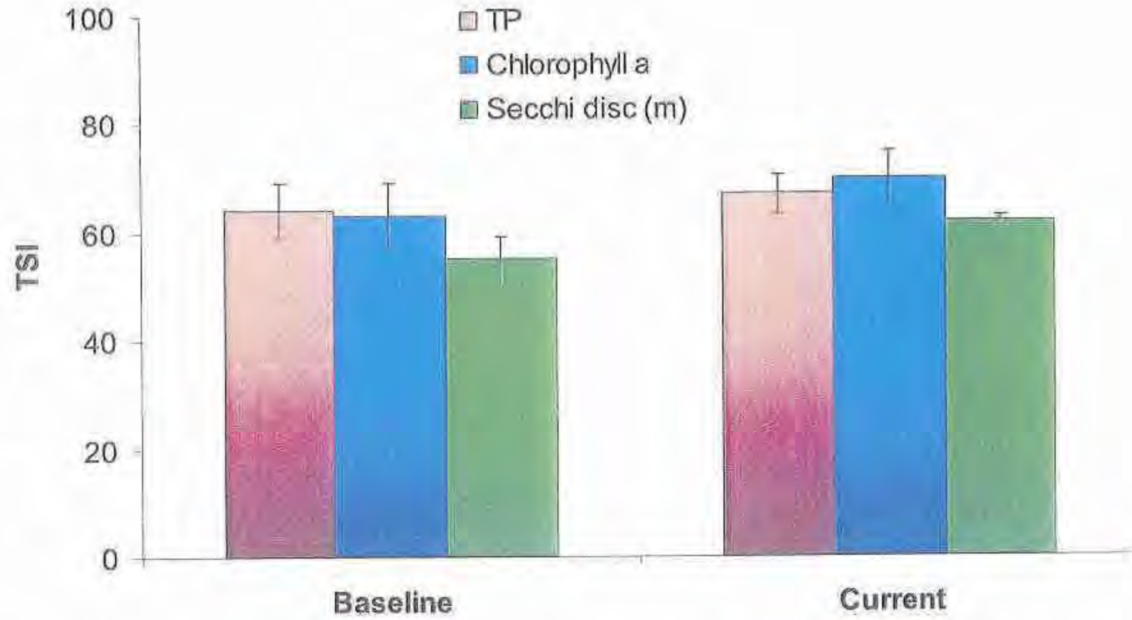
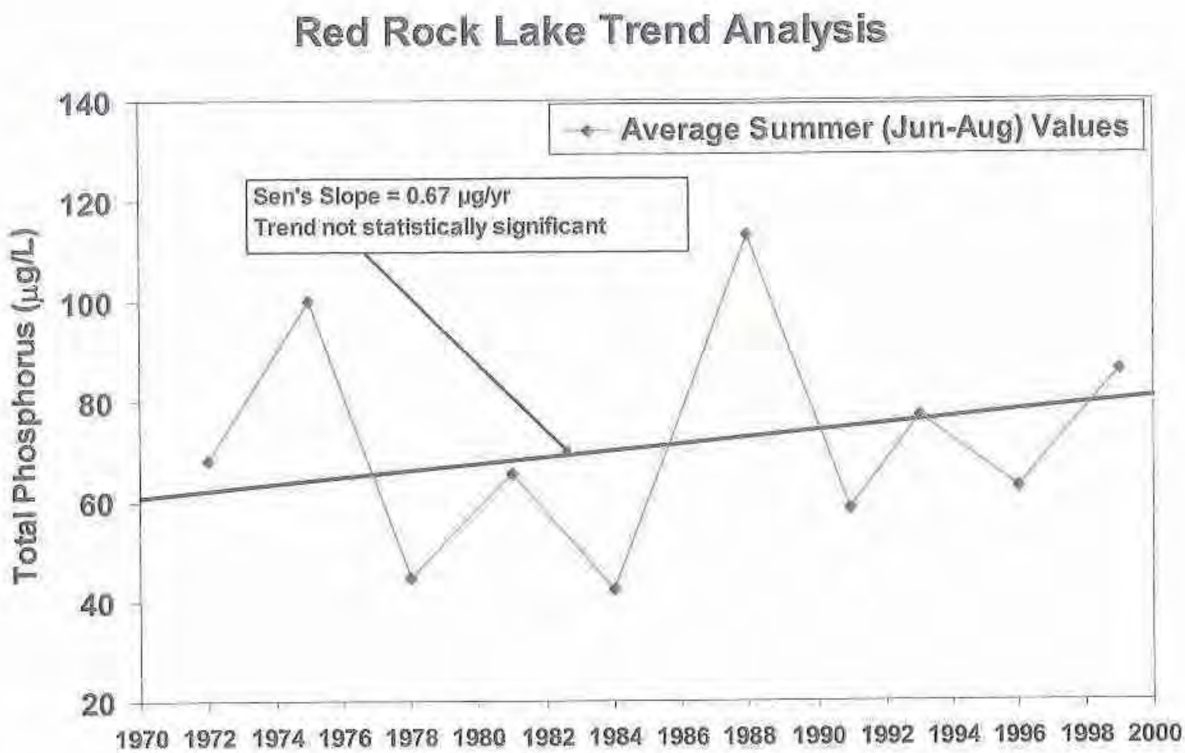


Figure 29 Baseline and Current Trophic State Index (TSI) for Red Rock Lake

2.6.2 Historical Water Quality-Trend Analysis

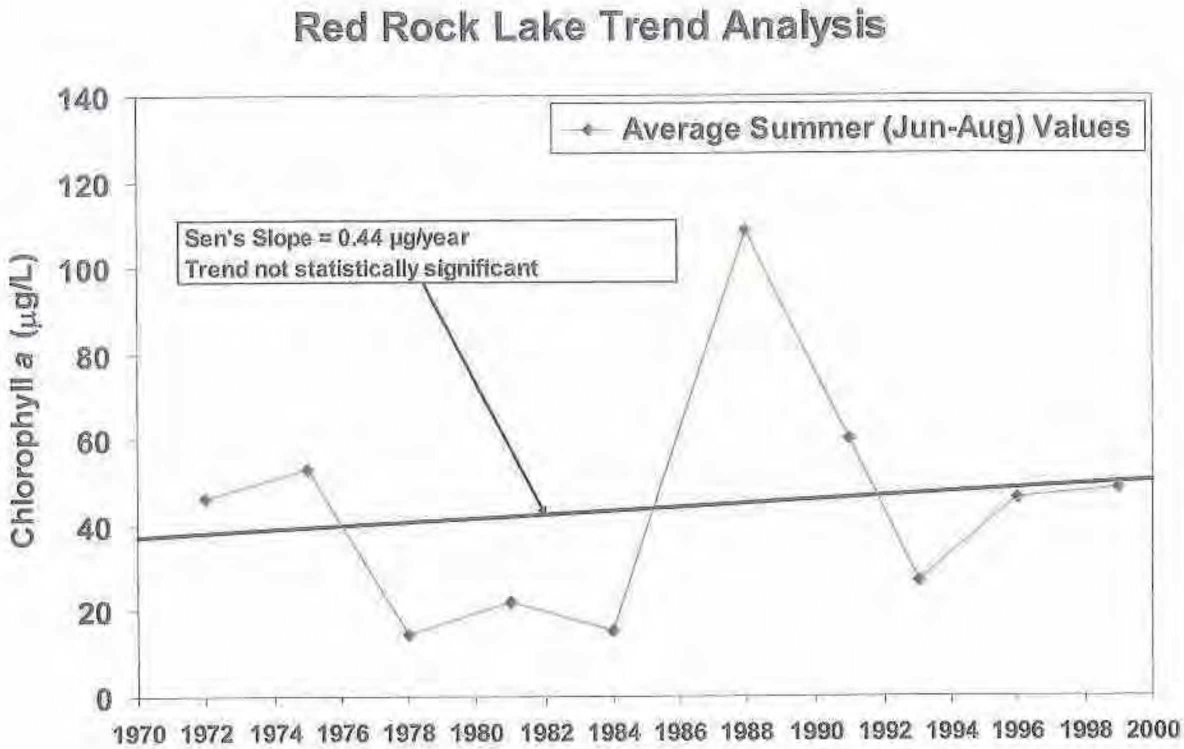
A trend analysis for Red Rock Lake was completed to identify any significant degradation or improvement during years in which water quality data were available. Although there have been fluctuations in phosphorus levels, chlorophyll *a* levels, and in lake clarity, it appears that over time the water quality of the lake has remained relatively stable and changes in phosphorus, chlorophyll *a*, and Secchi disc have not been statistically significant (see statistical analysis in Figures 30, 31, and 32).



Mann-Kendall/Sen's Slope Trend Test

Confidence Level	Test Statistic = 3	
	Test	Significance
99%	3 < 30	Not Significant
95%	3 < 23	Not Significant
90%	3 < 20	Not Significant
80%	3 < 16	Not Significant
Sen's Slope	0.67µg/year	

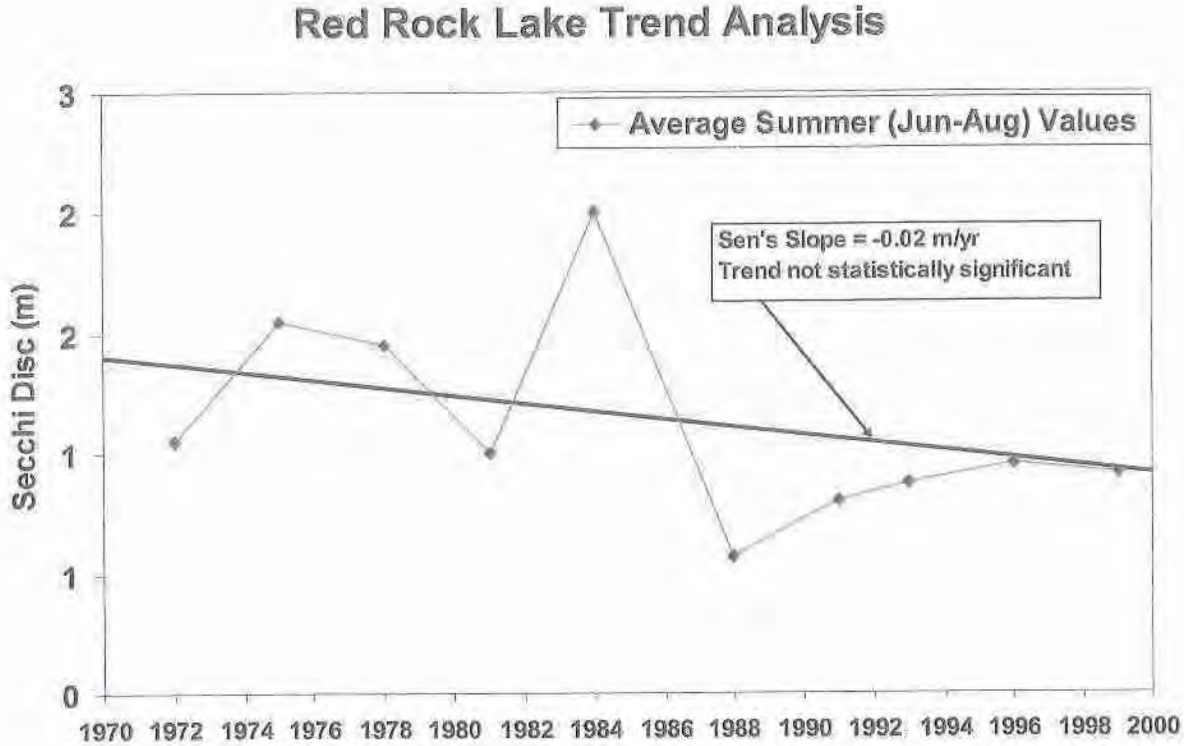
Figure 30 Mann-Kendall Trend Analysis of Total Phosphorus Concentration since 1972 for Red Rock Lake



Mann-Kendall/Sen's Slope Trend Test

Confidence Level	Test Statistic = 8	
	Test	**Significance**
99%	8 < 30	Not Significant
95%	8 < 23	Not Significant
90%	8 < 20	Not Significant
80%	8 < 16	Not Significant
Sen's Slope	0.44 µg/year	

Figure 31 Mann-Kendall Trend Analysis of Chlorophyll-*a* Concentration Since 1972 for Red Rock Lake



Mann-Kendall/Sen's Slope Trend Test

Confidence Level	Test Statistic = -15	
	Test	Significance
99%	-15 > -30	Not Significant
95%	-15 > -23	Not Significant
90%	-15 > -20	Not Significant
80%	-15 > -16	Not Significant
Sen's Slope	-0.02 meters/year	

Figure 32 Mann-Kendall Trend Analysis of Secchi Disc Transparency Depth Since 1972 for Red Rock Lake

2.6.3 Water Quality Modeling Analysis

Water quality modeling was performed to better understand the phosphorus dynamics in the Red Rock Lake watershed and in Red Rock Lake, and to understand how phosphorus loading is affecting algal growth in the lake. Watershed modeling, which includes both hydrologic and phosphorus loading, was performed using the P8 (IEP, Inc., 1990) model. In-lake models (Dillon and Rigler, 1974; WDNR, 1997; Thomann and Mueller, 1987; and Barr, 2004) were used to determine how external and internal phosphorus loading (loading within the lake) lead to the observed levels of phosphorus in Red Rock Lake. Internal loading was divided into two sources: aquatic plants (curlyleaf pondweed die-off) and sediment.

Modeling was performed for four climatic conditions (dry, average, model calibration, and wet year) and different management efforts to determine the potential effect of these management activities on phosphorus levels in Red Rock Lake. A regression between phosphorus levels and Secchi disc transparency was developed by the Minnesota Pollution Control Agency from Minnesota lake monitoring data and was used to predict expected lake clarity improvements (Secchi disc transparency) with different management activities (Heiskary and Wilson, 1990). A detailed description of model development and calibration is provided in Appendix B.

2.7 Major Hydrologic Characteristics

The major hydrologic characteristics of Red Rock Lake have changed as the watershed has changed from primarily agricultural to a mixture of park land, residential neighborhoods, and commercial, institutional, and industrial/office land use. Additional development will occur to attain proposed future watershed land use conditions. Approximately 200 acres of natural/park/open land use will be developed into highway, residential, institutional, and industrial/office land use. Following these land use changes, the lake's annual water load is expected to increase by about 20 to 54 percent under proposed future watershed land use conditions and varying climatic conditions.

2.8 Land Use Assessment

Land use in the watershed has changed from the predevelopment period. The watershed's land use changed from wooded to agriculture to urbanized. Additional development will occur to attain proposed future watershed land use conditions. The lake's annual phosphorus load is expected to increase by about 18 to 41 percent under proposed future watershed land use conditions. It is recommended that management practices be considered to minimize phosphorus loading increases to the greatest extent possible.

3.0 Red Rock Lake Goals

3.1 Water Quantity Goal

The water quantity goal for Red Rock Lake is to provide sufficient water storage during a regional flood. The water quantity goal has been achieved and no action is required.

3.2 Water Quality Goal

The water quality goal of Red Rock Lake is predicated on the lake's recreational goal. The goal is to achieve a water quality that will fully support the lake's use as a fishery. The District goal is a $TSI_{SD} \leq 59$. The District goal is similar to but slightly more stringent than the MPCA proposed water quality standard for Red Rock Lake. The MPCA proposed water quality standard for Red Rock Lake is a $TSI_{SD} \leq 60$, which is the proposed standard for a shallow lake in the North Central Hardwood Forest Ecoregion. The standard is expected to become finalized in 2006.

Table 8 shows that the water quality goal is currently not being achieved. Herbicide treatment of curlyleaf pondweed in Mitchell and Red Rock Lake and alum treatment of Mitchell and Red Rock Lake will attain the District goal during all but the future wet climatic condition. Under the future wet climatic condition, Mitchell Lake inputs to Red Rock Lake result in excess phosphorus loading to the lake. Treatment of Mitchell Lake inputs to Red Rock Lake with alum such that 60 percent of the phosphorus load is removed would prevent excess phosphorus loading to Red Rock Lake from Mitchell Lake. If treatment of Mitchell Lake inputs to Red Rock Lake were to occur concurrently with herbicide and alum treatments of both Mitchell and Red Rock Lake, the lake's goal would be attained under all climatic conditions. However, because an alum treatment facility to treat Mitchell Lake inputs to Red Rock Lake is expensive to build and operate, this alternative is not recommended at this time. If additional water quality improvement is needed to improve the lake's water quality under the future wet climatic condition, an alum treatment facility to treat Mitchell Lake's outflow waters may be considered.

The expected benefit of each management alternative is presented in Table 8. The expected cost of each alternative is presented in Figure 33. For each alternative to be successful, the prescribed management activities must follow a particular sequence. Herbicide treatment should be performed for a minimum of two years before the first alum treatment is completed. Evaluation of the results of the herbicide and alum treatments should occur following each year of treatment and for three consecutive years after completion of the treatments. The evaluation will determine warranted changes in the treatment program and whether goal attainment results from the treatments.

Table 8 Expected Water Quality with Water Quality Management Alternatives

Existing Land Use

	Trophic State Index (TSI_{SD}) Value					
Management Approach	**Current District Goal**	**Proposed MPCA Standard for Shallow Lakes***	**Wet Year (38")**	**Average Year (35")**	**Model Calibration Year (33")**	**Dry Year (24")**
1. No Action	≤59	≤60	64	62	62	63
2. Red Rock Lake: Herbicide Treatment of Curlyleaf Pondweed and Lake Alum Treatment	≤59	≤60	61	54	54	57
3. Mitchell and Red Rock Lakes: Herbicide Treatment of Curlyleaf Pondweed and Lake Alum Treatment	≤59	≤60	59	53	53	57
4. Mitchell and Red Rock Lakes: Herbicide Treatment of Curlyleaf Pondweed and Lake Alum Treatment; Alum Treat Mitchell Lake Inputs to Red Rock Lake	≤59	≤60	57	53	53	56

Future Land Use

	Trophic State Index (TSI_{SD}) Value					
	Current District Goal	**Proposed MPCA Standard for Shallow Lakes***	**Wet Year (38")**	**Average Year (35")**	**Model Calibration Year (33")**	**Dry Year (24")**
No Action	≤59	≤60	65	64	64	64
Red Rock Lake: Herbicide Treatment of Curlyleaf Pondweed and Lake Alum Treatment	≤59	≤60	62	57	57	59
Mitchell and Red Rock Lakes: Herbicide Treatment of Curlyleaf Pondweed and Lake Alum Treatment	≤59	≤60	63	56	56	57
Mitchell and Red Rock Lakes: Herbicide Treatment of Curlyleaf Pondweed and Lake Alum Treatment; Alum Treat Mitchell Lake Inputs to Red Rock Lake	≤59	≤60	58	55	55	56

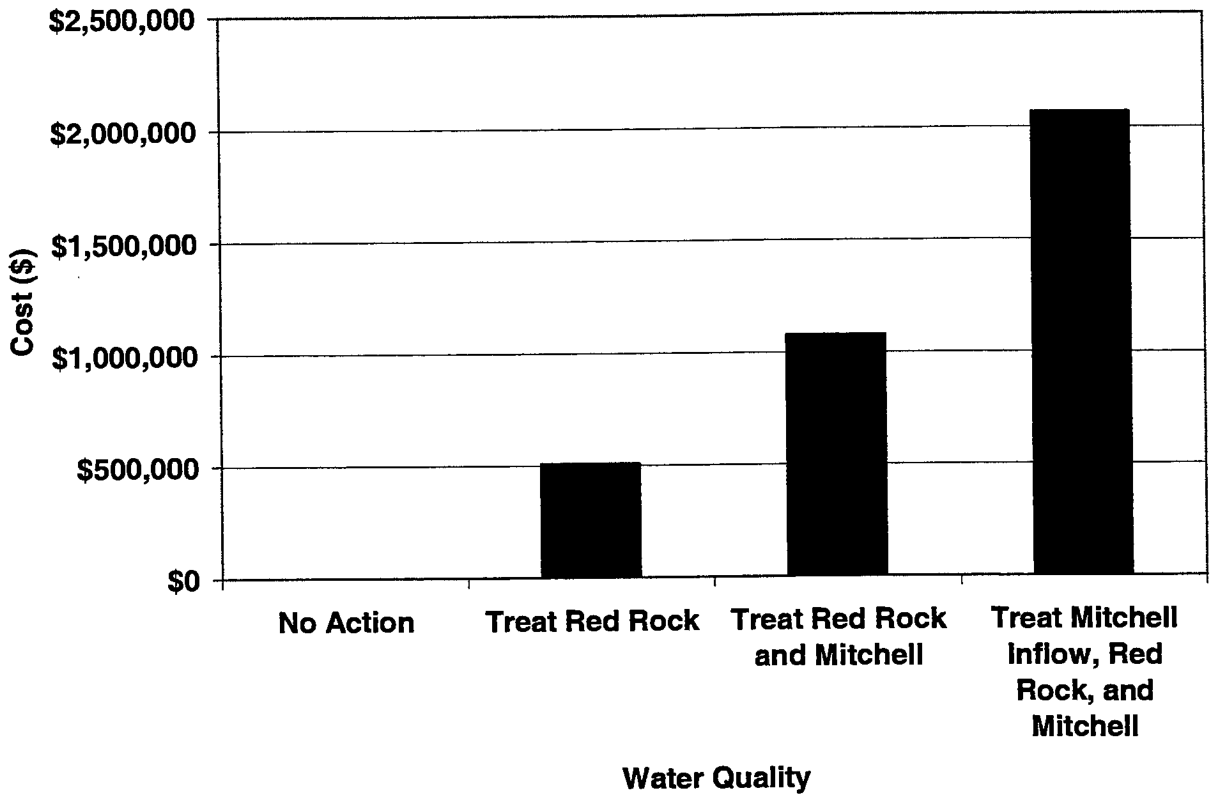


Figure 33 Costs of Water Quality Management Alternatives

3.3 Aquatic Communities Goal

The aquatic communities' goal for Red Rock Lake is the achievement and maintenance of a water quality that fully supports the lake's fisheries-use classification as determined by the MDNR (Schupp, 1992), displace non-native plant species with native plant species, and protect the lake's native plant community. The water quality goal to support the lake's fisheries is to maintain a $TSI_{SD} \leq 59$. From the perspective of the TSI_{SD} goal and the problems with excessive blue-green algae growth, the lake's current water quality does not provide the desired habitat for the lake's fishery.

Treatment of purple loosestrife with beetles, herbicide treatment of curlyleaf pondweed in Mitchell and Red Rock Lake, and alum treatment of Mitchell and Red Rock Lake will attain the District goal during all but the future wet climatic condition. Under the future wet climatic condition, Mitchell Lake inputs to Red Rock Lake result in excess phosphorus loading to the lake. Treatment of Mitchell Lake inputs to Red Rock Lake with alum such that 60 percent of the phosphorus load is removed would prevent excess phosphorus loading to Red Rock Lake from Mitchell Lake. If treatment of Mitchell Lake inputs to Red Rock Lake were to occur concurrently with herbicide and alum treatments of Mitchell and Red Rock Lake, the lake's goal would be attained under all climatic conditions. However, because an alum treatment facility to treat Mitchell Lake inputs to Red Rock Lake is expensive to build and operate, this alternative is not recommended at this time. If additional water quality improvement is needed to improve the lake's water quality under the future wet climatic condition, an alum treatment facility to treat Mitchell Lake's outflow waters may be considered.

The expected benefit of each management alternative is presented in Table 8 and the expected cost of each alternative is presented in Figure 34. For each alternative to be successful, the prescribed management activities must follow a particular sequence. Herbicide treatment should be performed for a minimum of two years before the first alum treatment is completed. Evaluation of the results of the herbicide and alum treatments should occur following each year of treatment and for three consecutive years after completion of the treatments. The evaluation will determine warranted changes in the treatment program and whether goal attainment results from the treatments.

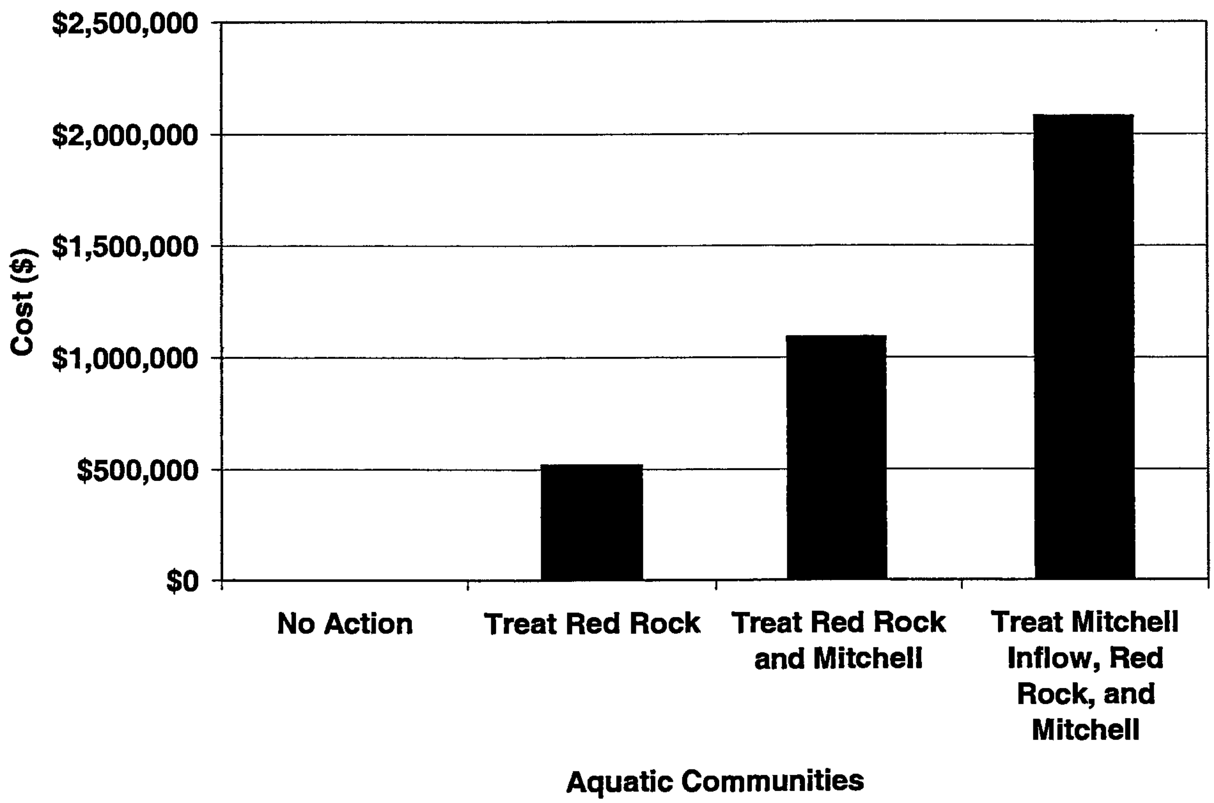


Figure 34 Costs of Aquatic Communities Management Alternatives

3.4 Recreation Goal

Because Red Rock Lake has not been designated a swimming lake by the Riley-Purgatory-Bluff Creek Watershed District, the recreational goal is to fully support the lake's fishery and maintain a $TSI_{SD} \leq 59$. From the perspective of the TSI_{SD} goal and the problems with excessive blue-green algae growth, the recreation goal is currently not being achieved.

Treatment of purple loosestrife with beetles, herbicide treatment of curlyleaf pondweed in Mitchell and Red Rock Lake, and alum treatment of Mitchell and Red Rock Lake will attain the District goal during all but the future wet climatic condition. Under the future wet climatic condition, Mitchell Lake inputs to Red Rock Lake result in excess phosphorus loading to the lake. Treatment of Mitchell Lake inputs to Red Rock Lake with alum such that 60 percent of the phosphorus load is removed would prevent excess phosphorus loading to Red Rock Lake from Mitchell Lake. If treatment of Mitchell Lake inputs to Red Rock Lake were to occur concurrently with herbicide and alum treatments of Mitchell and Red Rock Lake, the lake's goal would be attained under all climatic conditions. However, because an alum treatment facility to treat Mitchell Lake inputs to Red Rock Lake is expensive to build and operate, this alternative is not recommended at this time. If additional water quality improvement is needed to improve the lake's water quality under the future wet climatic condition, an alum treatment facility to treat Mitchell Lake's outflow waters may be considered.

The expected benefit of each management alternative is presented in Table 8 and the expected cost of each alternative is presented in Figure 35. For each alternative to be successful, the prescribed management activities must follow a particular sequence. Herbicide treatment should be performed for a minimum of two years before the first alum treatment is completed. Evaluation of the results of the herbicide and alum treatments should occur following each year of treatment and for three consecutive years after completion of the treatments. The evaluation will determine warranted changes in the treatment program and whether goal attainment results from the treatments.

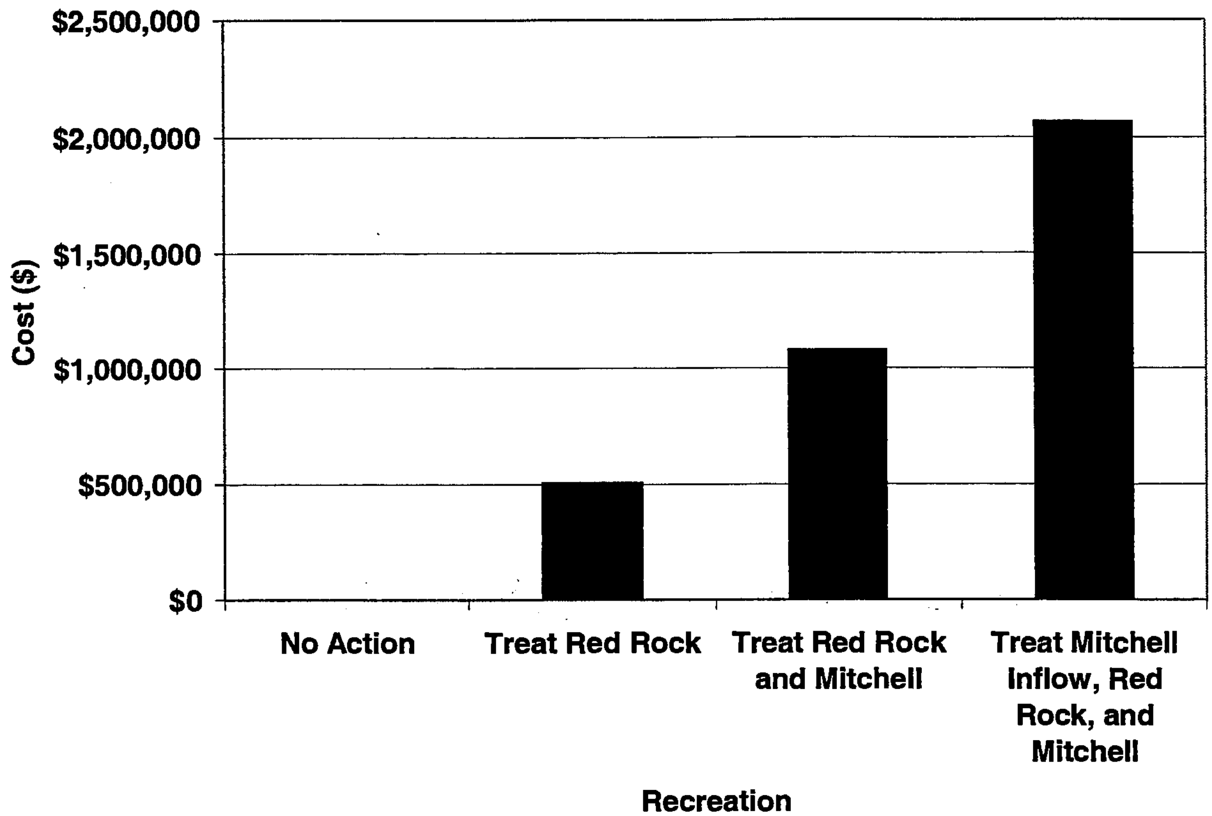


Figure 35 Costs of Recreation Management Alternatives

3.5 Wildlife Goal

The wildlife goal for Red Rock Lake is to protect existing, beneficial wildlife uses. The wildlife goal has been achieved.

3.6 Public Participation

The public participation goal is to encourage public participation as part of the use attainability analysis. This goal will be achieved through a public meeting to obtain comments on the use attainability analysis.

4.0 Selected Implementation Plan

4.1 Basis for Selected Implementation Plan

Red Rock Lake is a complex aquatic system. Any management action must be taken with consideration of how the different components of the ecosystem fit together. Monitoring data and modeling results have been used to better understand the ecology of Red Rock Lake and to estimate what the result may be from different management activities. The root of the imbalances that are observed at Red Rock Lake (excessive curlyleaf pondweed growth and blue-green algae blooms) is a high level of phosphorus. Although it may appear that the solution is to immediately reduce phosphorus levels, simply reducing phosphorus in a non-systematic manner may not lead to expected improvements and may have some unintended consequences.

The five sources of phosphorus inputs to Red Rock Lake are: release of phosphorus from lake curlyleaf pondweed senescence, release of phosphorus from lake sediments, inputs from Mitchell Lake, stormwater inputs from the lake's watershed, and atmospheric deposition.

Curlyleaf pondweed, a nuisance non-native species, is presently found in Red Rock Lake. Improvement in the lake's water clarity is expected to increase light availability to the plants and may promote additional growth of curlyleaf pondweed. Failure to effectively manage curlyleaf pondweed before improving the lake's water clarity could result in additional coverage or density of this species. This plant grows quickly in the spring, extracts phosphorus from the sediments, and dies off in June, thus releasing phosphorus stored in plant tissue. Increased coverage or density of curlyleaf pondweed would contribute additional phosphorus to the lake. Consideration of curlyleaf pondweed indicates management of this plant should occur before completion of a lake alum treatment to manage phosphorus loads from the lake's sediments. Failure to follow this order during the implementation program could have the unintended consequences of additional problematic plant growths and a failure to attain water quality improvement goals. Management of curlyleaf pondweed should involve removing the species from Red Rock Lake so that native plants can replace them.

Phosphorus from curlyleaf pondweed senescence currently comprises approximately 10 percent of the lake's annual total phosphorus load under average climatic conditions and existing watershed land use (see Figure EX-2). Hence, management of curlyleaf pondweed is expected to reduce the lake's average summer total phosphorus concentration. In addition, curlyleaf pondweed management will prevent increases in the lake's phosphorus concentration that would result from increased coverage or density of curlyleaf pondweed.

Research has shown that the appropriate herbicide for curlyleaf pondweed control is Endothall, and that this herbicide should be applied in the spring (when the water temperature is approximately 55 to 60° F) and at a dose of 1 to 1.5 mg/L (Poovey, et al. 2002, Skogerboe, 2004 – personal communication). Preliminary results from studies in Eagan Minnesota by John Skogerboe of the U.S. Army Engineer Research and Development Center have shown that four consecutive years of Endothall treatment have essentially eliminated curlyleaf pondweed from two of the study lakes and that after the 4th year of treatment no viable turions (pondweed seeds) remained in the sediment (John Skogerboe, 2004 -- personal communication). To remove curlyleaf pondweed, treatment will need to continue until curlyleaf pondweed is no longer observed in Red Rock Lake and no viable turions are found. Treatment is expected to occur for four years.

Current research is evaluating the effectiveness of lime to control curlyleaf pondweed. In a pilot study at Big Lake, Wisconsin, curlyleaf pondweed did not grow in 1-acre plots treated with lime, even though the plant continued to grow throughout the lake (Barr, 2001). In whole lake studies, curlyleaf pondweed was not observed where lime had been applied in Clifford Lake and Faille Lake, located near Osakis in central Minnesota. The U.S. Army Engineer Research and Development Center is currently conducting a lime slurry research project at the Eau Galle Aquatic Ecology Laboratory near Spring Valley, Wisconsin. Should the project results indicate lime would be the most effective tool to control curlyleaf pondweed in Red Rock Lake, lime will be used rather than Endothall to manage this plant.

Purple loosestrife along the lake's shoreline threatens to displace native vegetation and reduce the habitat quality of the lake's shoreline area. Introducing a natural predator will control purple loosestrife along the shore. Two beetle species, *Galerucella pusilla* and *Galerucella calmariensis*, effectively prey upon purple loosestrife, inhibit purple loosestrife growth, and greatly reduce flowering seed output. Introducing the beetles to the infested area along the shoreline of Red Rock Lake will control purple loosestrife growth and promote the growth of native species.

Phosphorus stored in sediment, together with phosphorus from decaying curlyleaf pondweed plants, are the most treatable sources of phosphorus in the water column of Red Rock Lake. The concentration of phosphorus in Red Rock Lake sediments that can release into the water column (i.e., mobile phosphorus) is high (see Figure 24) and corresponds to a potential phosphorus release rate of approximately 8.54 mg per square meter of lake surface per day in deeper areas of the lake. The lake wide average release rate was determined to be 3.1 mg per square meter of lake surface per day.

The lake wide average includes shallower areas of the lake water body with sediment not generally exposed to anoxic conditions that can lead to higher release rates of phosphorus seen in deeper areas of the lake. Also, the shallow areas of the lake have sediment that is more transitional in nature meaning that the less dense, generally higher phosphorus content portions of the sediment move towards the deeper areas of the lake where they accumulate over time. Both of these factors lead to lower phosphorus release rates in shallower portions of the lake.

Although shallower areas of the lake noted lower concentrations of mobile phosphorus, higher concentrations of organic phosphorus were observed in shallower areas. Organic material in the sediment of Red Rock Lake was higher in the shallower areas of the lake and indicates a substantial pool of phosphorus that will eventually become mobile phosphorus over time. Organic phosphorus concentration of the sediment in shallower areas of the lake reached 0.65 mg phosphorus per gram of lake sediment, nearly double that found in the deep hole of the lake (0.39 mg phosphorus per gram of lake sediment). Because of the elevated organic bound phosphorus in the sediment of Red Rock Lake, management options for controlling internal phosphorus loading from the sediment should control both mobile and organic phosphorus in the lake's sediments.

Phosphorus released from the lake's sediments currently comprises approximately 20 percent of the lake's annual total phosphorus load under average climatic conditions and existing watershed land use (see Figure EX-2). Alum treatment of the lake and management of the lake's curlyleaf pondweed are expected to reduce the lake's average summer total phosphorus concentration by approximately 17 to 49 percent under existing land use and varying climatic conditions.

Inputs from Mitchell Lake outflow comprise approximately 13 percent of the lake's annual total phosphorus load under average climatic conditions and existing watershed land use (See Figure EX-2). Alum treatment of Mitchell Lake and management of the lake's curlyleaf pondweed are expected to reduce phosphorus loading to Red Rock Lake by reducing inputs from Mitchell Lake. Management of curlyleaf pondweed and alum treatment to reduce internal loading in both Mitchell Lake and Red Rock Lake is expected to reduce Red Rock Lake's average summer total phosphorus concentration by approximately 41 to 60 percent under existing land use and varying climatic conditions.

Implementation of the recommended water quality improvement plan is expected to attain the District goal and the proposed MPCA standard for shallow lakes in the North Central Hardwood

Forests Ecoregion during all but the future wet climatic condition. However, it should be noted that water quality improvement estimates in this UAA are conservative. Hence, it is possible that the actual water quality improvement to Red Rock Lake following plan implementation may exceed expectations. Monitoring the lake during and following implementation of the lake's water quality improvement plan will ascertain changes in the lake's water quality

4.2 Manage Curlyleaf Pondweed in Red Rock Lake and Mitchell Lake

The recommended treatment program for curlyleaf pondweed consists of annual spring herbicide treatment until this species is removed from Red Rock Lake and Mitchell Lake. Treatment will occur in late-April or early-May when the water temperature is approximately 55 to 60° F. Curlyleaf pondweed will be treated with the herbicide Endothall at a dose of approximately 1 to 1.5 mg/L. To remove the species from the lakes, treatment will need to continue annually until no curlyleaf pondweed and no viable turions remain. Treatment is expected to continue for four years.

Current research to determine the effectiveness of lime to manage aquatic plants, including curlyleaf pondweed, could potentially conclude that lime is a better management tool than herbicide for control of curlyleaf pondweed. Should lime prove to be a better tool, lime treatment will replace herbicide treatment.

4.3 Manage Purple Loosestrife

The recommended purple loosestrife treatment program includes introduction of beetles, natural predators, into Red Rock Lake's shoreline area. The MDNR will provide beetles to the District at no cost. However, introducing the beetles into the purple loosestrife infested area along Red Rock Lake's west shoreline is the District's responsibility. Management of purple loosestrife generally spans several years (4 years estimated). During the treatment period, annual field surveys will measure beetle population establishment and persistence. Survey results will determine whether the collection and release of additional beetles are warranted.

4.4 Alum Treatment of Red Rock Lake and Mitchell Lake

The recommended treatment program to reduce phosphorus loading from the Red Rock and Mitchell Lakes' sediments is an alum treatment of each lake. The recommended alum dose for Red Rock Lake is 63 g/m^2 by 1 centimeter deep or 1,167 gallons per acre to treat the top 6 centimeters of sediment in Red Rock Lake. The recommended dose for Mitchell Lake is 61 g/m^2 by 1 centimeter deep or 1,137 gallons per acre. If applied in one treatment, the large dose of alum that is required to treat Red Rock and Mitchell Lakes' sediments may be too heavy for the sediments to bear. The sediments have a limited weight bearing capacity because the water content of the upper

6 centimeters of the lakes' sediments is 91 to 98 percent. Hence, the weight of the alum may cause it to sink far below the sediment's surface.

Splitting the large dose into smaller doses (i.e., about 300 gallons per acre) applied annually for 4 consecutive years is recommended. The smaller annual doses are expected to remain in the upper 6 centimeters of the lake sediment and effectively treat the sediment's mobile phosphorus.

Unless buffering capacity is added during alum treatment (i.e., lime or sodium aluminate), the dose proposed will need to be divided due to pH concerns. Because Red Rock and Mitchell Lakes are shallow, the buffering capacity of the lakes will be low in relation to the amount of alum needed to neutralize excess mobile P. It is likely that the dose will need to be split into approximately four treatments (with no added buffering) to prevent pH depression during treatment based on the alkalinity of similar lakes in the area.

If current research determines that lime is a better plant management tool than Endothall, 4 years of lime treatment will be substituted for 4 years of Endothall treatment. If this option is selected, then four years of alum–lime treatment will concurrently manage phosphorus loading from curlyleaf pondweed and sediment. Monitoring of the lake and sediments before and after treatment will measure treatment effectiveness and the mobile phosphorus remaining in the lake's sediments. Dose adjustments will be made as warranted.

A letter of support must be obtained from the MPCA and MDNR prior to treating Red Rock and Mitchell lakes with alum. If lime treatment is selected, a letter of support from the MPCA and MDNR must be obtained prior to Red Rock and Mitchell Lakes with lime.

4.6 Expected Sequence of Implementation Plan

Below is the expected sequence of the lake management activities.

Years 1-2	Herbicide (Endothall) treatment of curlyleaf pondweed in the spring; beetle treatment of purple loosestrife in the spring; monitoring and evaluation of aquatic plants, including purple loosestrife; monitoring and evaluation will determine changes in herbicide treatment and whether additional beetles need to be introduced into the purple loosestrife infested area.

Year 3	Herbicide (Endothall) treatment of curlyleaf pondweed in the spring, beetle treatment of purple loosestrife in the spring, monitoring and evaluation of aquatic plants, including purple loosestrife; monitoring and evaluation will determine changes in herbicide treatment and whether additional beetles need to be introduced into the purple loosestrife infested area; Pre-treatment monitoring and evaluation of lake water quality and sediments; Alum treatment of Mitchell and Red Rock Lakes in the fall (first one fourth of alum dose applied);
Year 4	Herbicide (Endothall) treatment of curlyleaf pondweed in the spring, beetle treatment of purple loosestrife in the spring, monitoring and evaluation of aquatic plants, including purple loosestrife; monitoring and evaluation will determine changes in herbicide treatment and whether additional beetles need to be introduced into the purple loosestrife infested area; Monitoring and evaluation of lake water quality and sediments to determine results from application of first one fourth of alum dose; alum treatment of Mitchell and Red Rock Lakes in the fall (second fourth of alum dose).
Years 5-6	Monitoring and evaluation of lake water quality and sediments to determine results from application of second and third fourths of alum dose; alum treatment of Mitchell and Red Rock Lakes in the fall (third and fourth fourths of alum dose). Monitoring and evaluation of aquatic plants to determine effectiveness of herbicide and beetle management programs.
Years 7-9	Monitoring and evaluation of sediments, lake water quality, and aquatic plants to determine effectiveness of alum treatments, herbicide treatments, and beetle management of purple loosestrife. Data will be used to determine whether goal attainment occurred.
Year 10	Monitoring and evaluation of sediments, lake water quality, and aquatic plants to determine effectiveness of alum treatments, herbicide treatments, and beetle management of purple loosestrife. Completion of Final Report.

The annual costs of the lake management activities for the 10 year period are shown in Figure 36 The expected lake average summer total phosphorus concentrations under varying climatic conditions following completion of the implementation plan are summarized in Figure 37.

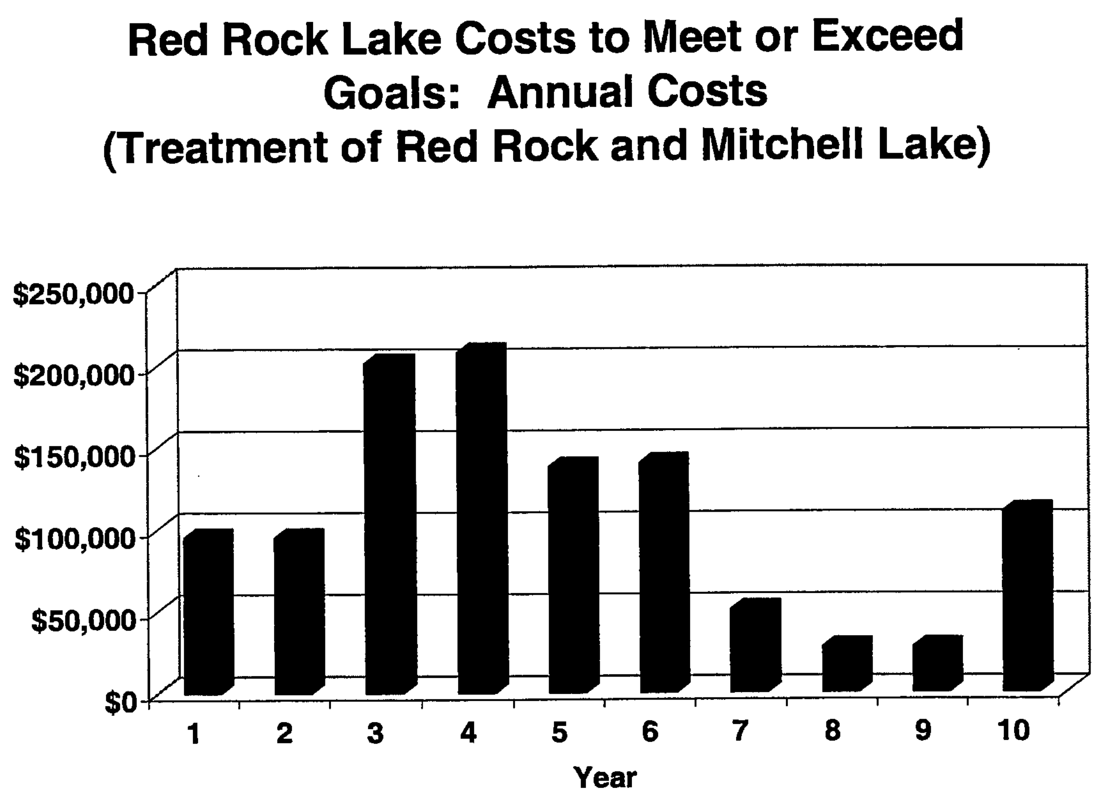


Figure 36 Annual Costs of Red Rock Lake Implementation Plan

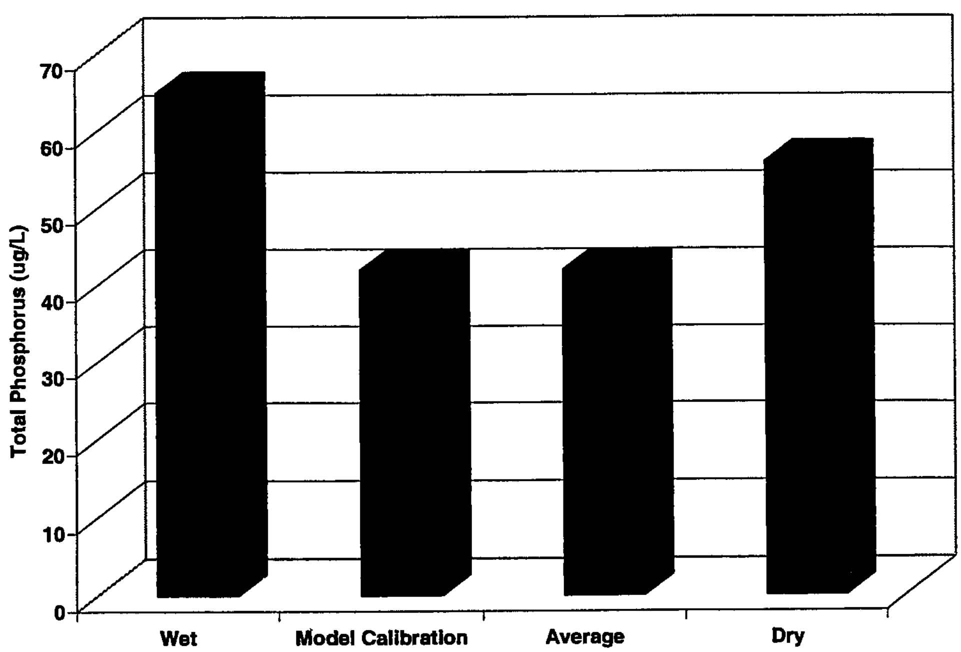


Figure 37 Estimated Red Rock Lake Average Summer Total Phosphorus Concentrations With Implementation Plan (Varying Climatic Conditions and Existing Watershed Land Use)

4.7 Monitoring and Evaluation

An important part of this plan is monitoring and evaluation, including aquatic plant monitoring, purple loosestrife and beetle monitoring, water quality monitoring, and sediment monitoring.

4.7.1 Aquatic Plant Monitoring

During each treatment year, Red Rock Lake and Mitchell Lake aquatic plant surveys should be completed on three occasions: pre-treatment survey, late-spring survey, and late-summer survey. The three surveys will determine the locations and density of plants in the lakes, including curlyleaf pondweed. Because treatment is expected to occur in late-April or early-May, the pre-treatment survey should be completed in either April or May, but before treatment occurs. The late-spring survey should be completed by late-June. The late summer survey should be completed by late-August. During the late-spring survey, turions (curlyleaf pondweed "seeds") should be collected from 10 percent of sample locations.

For at least four years following treatment, aquatic plant surveys should be completed during June and August. The surveys will determine whether curlyleaf pondweed has been eradicated from the lake. If any curlyleaf pondweed plants are found, the spring herbicide treatment program will resume until no curlyleaf pondweed plants are collected

Annual monitoring will be used to assess plant community changes and to determine treatment changes. It is anticipated that reduced curlyleaf pondweed (and turions) will occur annually during the treatment period. The treatment area is expected to decrease with decreased coverage. The treatment program will be adjusted annually based upon monitoring results and will be terminated when no curlyleaf pondweed plants and no viable turions are collected.

4.7.2 Purple Loosestrife/Beetle Monitoring

Annual field surveys should determine purple loosestrife coverage or eradication and measure beetle population establishment and persistence.

4.7.3 Water Quality Monitoring

Water quality parameters (total phosphorus, chlorophyll *a*, Secchi disc transparency, dissolved oxygen, and pH) should be monitored every 2 weeks from April through September prior to application of the first fourth of the alum dose, following application of each of the four fourths of the alum dose, and for 3 years following completion of the alum treatment. Hence, monitoring will occur for 8 years. Monitoring data will determine whether the District goal is attained.

4.7.4 Sediment Monitoring

Sediment monitoring should occur before alum treatment, following application of each of the four fourths of the alum dose, and for 3 years following completion of the alum treatment. The monitoring will evaluate changes in the mobile and organic phosphorus content of the lakes' sediments. The monitoring following application of each of the four fourths of the alum dose will also evaluate the location of the alum layer. If the layer is below the sediment's surface, the distance from the surface will be measured to ascertain the alum layer is within the top 6 centimeters of lake sediment. If the layer is found deeper than 6 cm, the remaining portion of the alum dose will be divided into smaller aliquots to prevent the alum floc from sinking deeper than 6 cm. Additional alum applications as warranted will occur to administer the lakes' alum doses.

5.0 Proposed 7050 Rules For Lakes

The 1972 amendments to the federal Clean Water Act require the MPCA to assess the water quality of rivers, streams, and lakes in Minnesota (Code of Federal Regulations, title 40, part 130). Waters determined to be not meeting water quality standards and not supporting assigned beneficial uses are defined as "impaired." Impaired waters are listed and reported to the citizens of Minnesota and to the Environmental Protection Agency (EPA) in the 305(b) report and the 303(d) list. Both listings are named after the relevant sections of the Clean Water Act. The beneficial uses assessed in this context are aquatic life and recreation (swimming) and aesthetics.

Impaired water or impaired condition is defined in Minn. R. pt. 7050.0150 as follows:

> *... a water body that does not meet applicable water quality standards or fully support applicable beneficial uses, due in whole or in part to water pollution from point or nonpoint sources, or any combination thereof.*

The listing of a waterbody on the 303(d) list triggers a regulatory response on the part of the MPCA to address the causes and sources of the impairment. This process is called a Total Maximum Daily Load (TMDL) analysis. The purpose of the TMDL analysis is to focus attention and resources on impaired waters and ultimately bring them back into compliance with water quality standards. Current rules require that a TMDL analysis be completed after a water body is listed on the 303(d) impaired waters list to determine a water quality improvement program to bring the water body in compliance with MPCA standards. The rules also require implementation of the water quality improvement program to bring the water body in compliance with MPCA standards.

The MPCA has developed lake criteria to determine impaired waters. The criteria are found in *Guidance Manual for Assessing the Quality of Minnesota Surface Waters For Determination of Impairment. 305(b) Report and 303(d) List (MPCA, 2004.* Red Rock Lake has been assessed by the MPCA and its water quality failed to meet these criteria (see Table 9). Hence, Red Rock Lake is listed on the 303(d) List as an impaired waters of the state.

Table 9 Eutrophication Criteria Used to List Lakes on the 303(d) List for 2004: Lakes in the North Central Hardwood Forests (NCHF) Ecoregion

Parameter	Criteria
Total Phosphorus (μg/L)	<40
Chlorophyll *a* (μg/L)	<15
Secchi Disc (m)	>1.2

*Lakes meeting the criteria are not listed on the 303(d) list.

The criteria found in Table 9 were modified during the 2004 through 2005 revision of Minnesota's 7050 Water Quality Standards. The 7050 Standards' revisions include the addition of eutrophication standards for lakes (i.e., total phosphorus, chlorophyll *a*, and Secchi disc standards) on a regional basis. Within each region, separate criteria were established for deeper lakes (depths greater than 15 feet) and shallow lakes (depth of 15 feet or less and/or 80 percent or more of the lake is littoral). Red Rock Lake is located within the North Central Hardwood forests region and, because the lake's depth is less than 15 feet and 100 percent of the lake is littoral, it is a shallow lake. The proposed 7050 standards for Red Rock Lake are shown in Table 10.

Table 10 Proposed 7050 Standards Under Consideration for North Central Hardwood Forests (NCHF) Shallow Lakes, including Red Rock Lake

Parameter	Criteria
Total Phosphorus (μg/L)	≤60
Chlorophyll *a* (μg/L)	≤20
Secchi Disc (m)	≥1.0

*Lakes meeting the proposed criteria will not be listed on the 303(d) list.

The proposed changes to the 7050 Standards are expected to be finalized during 2006. Once finalized, the 7050 standards will be used to assess lakes to determine lake impairment. Lakes not meeting the standards will be placed on Minnesota's 303(d) Impaired Waters List (List). Lakes, such as Red Rock Lake, currently on the List must attain the water quality of the 7050 standards to be removed from the List.

Red Rock Lake's historical water quality has generally failed to meet the proposed 7050 Standards (Standards). During the 1972 through 1999 monitoring period, the lake's water quality failed to meet the proposed Standards for total phosphorus, chlorophyll *a*, and Secchi disc at a frequency of 80, 80, and 40 percent, respectively. During the current period (i.e., 1988 through 1999), the lake's water quality failed to meet the proposed Standards for total phosphorus, chlorophyll *a*, and Secchi disc at a frequency of 80, 100, and 75 percent.

Following implementation of the recommended lake improvement plan, Red Rock Lake's water quality is expected to meet the proposed phosphorus and Secchi disc transparency standards (see Table 11) during average and dry climatic conditions under both existing and future land use conditions. The lake's water quality during wet conditions is not expected to meet the proposed standards.

Table 11 Comparison of Proposed 7050 Standards for Red Rock Lake With Expected Water Quality Following Implementation of Recommended Plan

Parameter	Proposed 7050 Standard Goal	Wet Year (38")	Average Year (35")	Model Calibration Year (33")	Dry Year (24")
Existing Land Use					
Total Phosphorus (µg/L)	≤ 60	65	42	42	56
Secchi Disc (m)	≥1.0	1.1	1.6	1.6	1.2
Future Land Use					
Total Phosphorus (µg/L)	≤ 60	90	53	53	57
Secchi Disc (m)	≥1.0	0.8	1.3	1.3	1.2

Implementation of one additional water quality improvement project would attain the proposed 7050 standards under all climatic conditions. Treatment of Mitchell Lake outflow waters, which flow into Red Rock Lake, with alum (60 percent removal of total phosphorus load assumed) would enable Red Rock Lake to attain the proposed 7050 standards under all climatic conditions (See Table 12). However, because an inflow alum treatment facility is both expensive to build and operate, this alternative is not recommended at this time. Since the water quality estimates in this UAA are conservative, it is possible that the actual water quality improvement to Red Rock Lake following plan implementation may exceed expectations. Monitoring the lake during and following implementation of the lake's water quality improvement plan will ascertain changes in the lake's water quality and will determine whether the lake's water quality meets 7050 standards under all climatic conditions. If additional water quality improvement is needed to improve the lake's water quality under the wet climatic condition, an alum treatment facility to treat Mitchell Lake's outflow waters may be considered.

Table 12 Comparison of Proposed 7050 Standards for Red Rock Lake With Expected Water Quality With Treatment of Mitchell Lake Outflow Waters

Parameter	Proposed 7050 Standard Goal	Wet Year (38")	Average Year (35")	Model Calibration Year (33")	Dry Year (24")
Existing Land Use					
Total Phosphorus (µg/L)	≤ 60	56	39	39	51
Secchi Disc (m)	≥1.0	1.2	1.7	1.7	1.3
Future Land Use					
Total Phosphorus (µg/L)	≤ 60	60	49	49	52
Secchi Disc (m)	≥1.0	1.2	1.4	1.4	1.3

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Appendix A

Red Rock Lake Watershed Pond Data

Red Rock Lake Watershed Ponds Summary

Pond ID	Outlet Size/Type	Primary Outlet Elev. (ft.)	Overflow Elev. (ft.)	Average Pond Slope (outlet to overflow)	Buffer (Overflow Height *Pond Slope)	Water Elev. (ft.)	DSS Surface Area (Acres)	DSS Volume (Acre/ Feet)	LSS Surface Area (Acres)	LSS Volume (Acre/ Feet)
RRL-50	12" PVC	100.0	103.0 (3.0)	3/1	9	0.05	0.071	0.17	0.136	0.308
RRL-49	None	N/A	100.0 (0.0)	5/1	0	-17.00	2.095	10.825	N/A	N/A
RRL-48	None	N/A	100.0 (0.0)	3/1	0	-1.50	7.251	13.325	N/A	N/A
RRL-45	12" Corrugated PVC	100.0	106.0 (6.0)	3/1	18	-7.00	1.488	6.633	2.529	12.024
RRL-47	18" RCP	100.0	111.5 (11.5)	3/1	34.5	-0.30	0.252	0.652	0.690	5.267
RRL-46	18" RCP	100.0	107.5 (7.5)	3/1	22.5	-0.50	3.366	10.199	6.693	37.666
RRL-51	10' Wide Channel to Pond 53	N/A	100.0 (0.0)	3/1	0	0.00	0.420	0.458	N/A	N/A
RRL-52	2 x 24" RCP	100.0	102.4 (2.4)	5/1	12	0.50	0.168	0.168	0.346	0.619
RRL-53	2 x 24" CMP	100.0	102.2 (2.2)	3/1	6.6	0.00	2.434	1.512	7.257	10.356
RRL-15A	44" CMP	100.0	107.5 (7.5)	3/1	22.5	0.00	0.622	0.527	1.975	9.818
RRL-15	30" RCP	100.0	102.5 (2.5)	3/1	7.5	0.00	0.851	2.071	1.182	2.554
RRL-14	24" RCP	100.0	103.6 (3.6)	3/1	10.8	0.00	0.838	2.77	1.371	3.948
RRL-44	18" RCP	100.0	105.0 (5.0)	3/1	15	-0.10	0.332	0.986	0.630	2.397
RRL-43	18" Corrigated PVC	100.0	108.5 (8.5)	3/1	25.5	-2.50	0.258	1.13	0.619	3.653
RRL-40	24" RCP	100	135.0 (35.0)	3/1	105	-1.50	1.969	10.368	5.642	132.244
RRL-41	33" RCP	100.0	111.0 (11.0)	3/1	33	-3.00	0.605	2.201	1.374	10.989
RRL-42	12" RCP	100.0	114.0 (14.0)	3/1	42	-2.10	2.077	9.047	3.266	37.502
RRL-38	12" RCP	100.0	112.5 (12.5)	3/1	37.5	-0.35	0.809	2.328	1.960	16.967
RRL-37	None	N/A	100.0 (0.0)	3/1	0	-3.50	0.675	3.016	N/A	N/A
RRL-36	15" RCP	100.0	113.0 (13.0)	3/1	39	-0.10	0.624	0.969	1.961	16.550
RRL-39	15" RCP	100	103.2 (3.2)	3/1	9.6	0.00	3.032	6.486	5.362	13.211
RRL-16	27" RCP	100.0	113.0 (13.0)	3/1	39	0.20	0.222	0.397	0.954	7.326
RRL-17	None	N/A	100.0 (0.0)	5/1	0	-1.50	1.102	2.671	N/A	N/A
RRL-29	27" RCP	100.0	107.0 (7.0)	3/1	21	-1.00	0.460	1.144	1.047	5.288

Red Rock Lake Watershed Ponds Summary

Pond ID	Outlet Size/Type	Primary Outlet Elev. (ft.)	Overflow Elev. (ft.)	Average Pond Slope (outlet to overflow)	Buffer (Overflow Height *Pond Slope)	Water Elev. (ft.)	DSS Surface Area (Acres)	DSS Volume (Acre/ Feet)	LSS Surface Area (Acres)	LSS Volume (Acre/ Feet)
RRL-52A	42" RCP	100.0	116.0 (16.0)	5/1	80	(+1.7)	0.023	0.009	1.635	110.540
RRL-40A	24" RCP	100.0	107.6 (7.6)	3/1	22.8	0.00	0.075	0.033	0.494	1.913
RRL-54	18" RCP	100.0	112.0 (12.0)	3/1	36	0.00	0.161	0.112	1.202	7.693
RRL-70	NONE	N/A	100.0 (0.0)	5/1	0	(-1.0)	2.208	6.685	N/A	N/A
RRL-60	18" UNKNOWN	100.0	110.0 (10.0)	5/1	50	(+1.5)	0.547	0.573	2.184	12.963

Red Rock Lake Watershed Ponds Summary

Pond ID	Comments
RRL-50	Flows to pond RRL-48 (field notes).
RRL-49	Flows to pond RRL-45 (field notes). No GPS points for depth but -17' depth at center in notes. I placed points with -17' at center and corresponding depths out from center.
RRL-48	Flows to pond RRL-49 (field notes).
RRL-45	Flows to SW (field notes). No GPS points for depth. Notes say 1.5' deep at center. I placed a 1.5' depth point at center and corresponding depths out from center.
RRL-47	Flows to South (field notes).
RRL-46	Flow to SW (field notes).
RRL-51	Water elev same as pond 53 (field notes).
RRL-52	Flow under walking path to South (field notes).
RRL-53	Flows to Red Rock Lake. No GPS data. Notes say to assume 2.0 in water hole on west and 1.0 in cattails. I placed points randomly as indicated above. Calculations re-done.
RRL-15A	Digitized pond from GPS edge data. Placed random points at 1.0 depth (as per field notes). 100% cattails. Flows to RRL.
RRL-15	No flow at this time (field notes).
RRL-14	24" RCP at outlet narrows to 12" RCP at control and flows south to Red Rock Lake (field notes).
RRL-44	
RRL-43	
RRL-40	Floating bog (field notes). When I placed buffer at 35 x 3 = 105, it comes to houses surrounding bog/pond.
RRL-41	
RRL-42	Bog in pond and many dead trees to SE (field notes).
RRL-38	Flows to NW (field notes).
RRL-37	Flows to east to Pond 38 (field notes).
RRL-36	Part of Pond 35 with cattails and depth of 0.5' between (field notes). Both pond 35 and 36 are combined in volume calculations.
RRL-39	Flows to SE (field notes).
RRL-16	Flow to SE (field notes).
RRL-17	Flows to North to pond 16 (field notes).
RRL-29	Flows to SE (field notes).

Red Rock Lake Watershed Ponds Summary

RRL-52A	1.7' WATER IN PIPE SLIGHT FLOW TO SOUTH, 0-1' WATER IN POND, 100% CATTAILSIN POND, OVERFLOW TO SOUTH, NO STORAGE, no gps data collected. Placed random points at 1.0' and 0.5'. Did not use depth in pipe (1.7')
RRL-40A	0.5' standing water in pond, no storage, no gps data collected. Placed some points of 0.5' to make calculations.
RRL-54	1.0' standing water in pond, trickle out, 90% grass in pond, no gps data collected. Placed some points of 1.0' and 0.5' to make calculations.
RRL-70	**1-1.5' standing water at pond edge--5.0' deep in center, 100% grass coverage, no gps data collected. Placed random points of 5' at center and decreasing to 1' at edge to make calculations.**
RRL-60	pond is 100% cattails with 1-1.5 'standing water, no gps data collected. Placed random points of 1.5' and 1.0' to make calculations.

Appendix B

Lake Modeling

B-1 Modeling Approach

The purpose of developing a watershed and in-lake model for Red Rock Lake was to determine how different phosphorus sources contribute to the observed levels of phosphorus in the lake. Modeling was performed for a range of climatic conditions (dry, average, and wet years). The in-lake model was calibrated using lake monitoring data from 1999 (average year). The calibration year model used phosphorus loading for the period May 1998 through April 1999 to calibrate the model's estimation of the lake's spring concentration. The calibrated in-lake model was then run for the 1999 water year (average year), a wet year (1997) and a dry year (2000) to determine the expected average summer total phosphorus concentration for years with average, wet, and dry precipitation levels.

One of the first steps in developing the in-lake model was the determination of water and phosphorus loads from different potential sources. The five phosphorus sources evaluated in this modeling study include: the Red Rock Lake watershed, inflow from Mitchell Lake, aquatic plant senescence, phosphorus release and migration from sediment, and atmospheric deposition.

The in-lake model was run under varying climatic conditions (dry, average, and wet year) to determine expected average summer phosphorus levels under a range of precipitation conditions. The model was also run under different management approaches to assess their benefits. From the predicted total phosphorus levels, average expected Secchi disc transparency was predicted from a relationship between total phosphorus and Secchi disc transparency. Data used to develop this relationship were from Minnesota lakes. The relationship was developed by the MPCA (Heiskary et al., 1990)

B-2 Watershed Modeling

Phosphorus loading from the Red Rock Lake watershed was determined using the P8 model (IEP, Inc., 1990). Water and phosphorus loading were estimated using input from land use maps, soils maps, aerial photos with elevation contours, and storm sewer maps . Phosphorus removal by detention basins was also calculated with the P8 model. Daily phosphorus and water loading outputs from this model were used as inputs to an in-lake model. P8 modeling parameters are detailed in Appendix D.

B-3 Lake Modeling

The first step in lake modeling was the identification and evaluation of different phosphorus sources. Both external phosphorus sources, i.e. watershed inputs, inflow from Mitchell Lake, and direct atmospheric deposition on the lake, and internal phosphorus sources, i.e., aquatic plant senescence and migration from sediment, were considered for this model. Because of the significant increases in phosphorus that are observed in the Red Rock Lake water column from July through August, and the fact that this increase was not associated with storm water inputs, internal phosphorus loading was identified early in this study as a significant source of phosphorus loading (see Figure B-1).

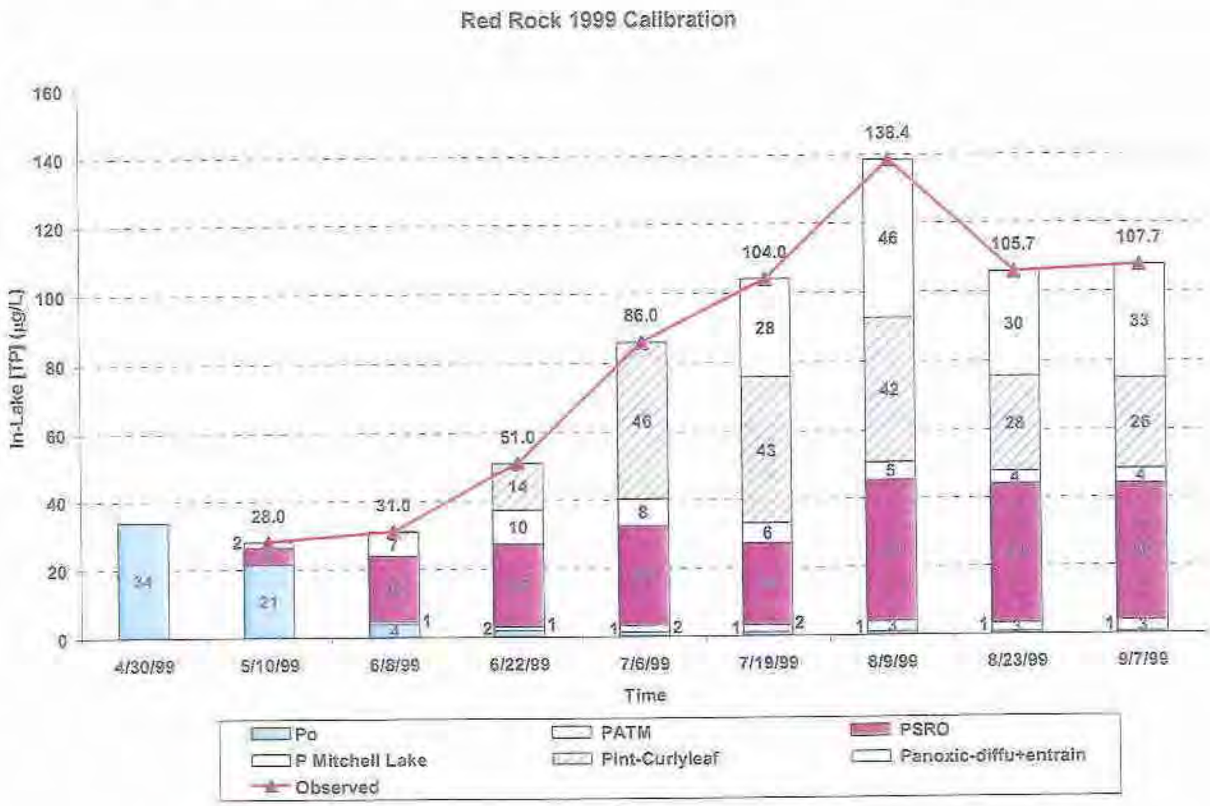


Figure B-1 Estimated 1999 Red Rock Lake Phosphorus Sources—Internal Sources Compared With Stormwater Inputs (See Page 45 of this report for the Legend)

Two types of internal loading were evaluated, aquatic plants and sediments. A macrophyte survey in 1999 showed that curlyleaf pondweed die-off occurred in early-summer (Pint-Curlyleaf in Figure B-1). Plant senescence nearly doubled the lake's phosphorus concentration during the late June through July period.

Sediment cores were collected in 2003 and 2005 and analyzed for total and potentially releasable (mobile and organic) phosphorus. Results of the sediment analysis indicated that sediment was also a potentially significant source of phosphorus loading to Red Rock Lake (Panoxic-diffu+entrain in Figure B-1).

B-3.1 Macrophytes

Because curlyleaf pondweed decomposition was identified as a potentially significant source of internal loading, the total phosphorus mass contributed to the Red Rock Lake water column by the die-off of curlyleaf pondweed was estimated. 1999 macrophyte densities were semi-quantitatively determined for Red Rock Lake. At several sampling locations in the lake (see Figures 16 and 17), macrophyte species were identified as light (1), typical (2), or heavy (3). Light approximately corresponds to 30 stems per square foot, typical to 41 stems per square foot, and heavy to 59 stems per square foot (Barr, 2001). Stem density from the typical category was used to estimate phosphorus loading from curlyleaf pondweed.

Data from a macrophyte study performed in Wisconsin was used to estimate the mass and phosphorus content of curlyleaf pondweed in Red Rock Lake (Barr, 2001). This study determined that the mass of each stem was 0.35 grams and the phosphorus content per gram of curlyleaf pondweed material was 2 mg. This corresponds to 226.8 mg of phosphorus per square meter or approximately 0.92 kg phosphorus per acre. Because this value represents the maximum potential phosphorus load by the curlyleaf pondweed this loading estimate was viewed as a starting point from which to calibrate the contribution of phosphorus loading by curlyleaf pondweed. Also, it should be noted that this estimate of phosphorus mass per square meter is comparable to a study on Half Moon Lake, Wisconsin (James et al. 2001) where a dense population of curlyleaf pondweed was estimated to contain between 103 to 216 mg of phosphorus per square meter of lake surface. A literature review by Bolduan et al., 1994 presented phosphorus content for curlyleaf pondweed that ranged from 1.15 mg to 8.0 mg per gram of plant material (0.115 to 0.8 percent). The density of curlyleaf pondweed (stems per square meter) was not presented in this study.

The contribution of phosphorus to the water column by curlyleaf pondweed is a two step process with die-off followed by decomposition and then release of phosphorus. James et al. 2001 estimated that this is a non-linear process with most of the phosphorus release occurring within 30 days of die-off. Because all of the curlyleaf pond weed at Red Rock Lake does not die-off at the same time, a mathematical model, which was derived from the chemical kinetics literature (Brezonik, 1994), was used to estimate die-off then phosphorus release. This kinetic equation consists of two first order equations called a two-set first order sequence. Figure B-2 shows how pondweed die-off and phosphorus inputs were modeled. It was assumed that phosphorus input from pondweed die-off begins in late June of each year.

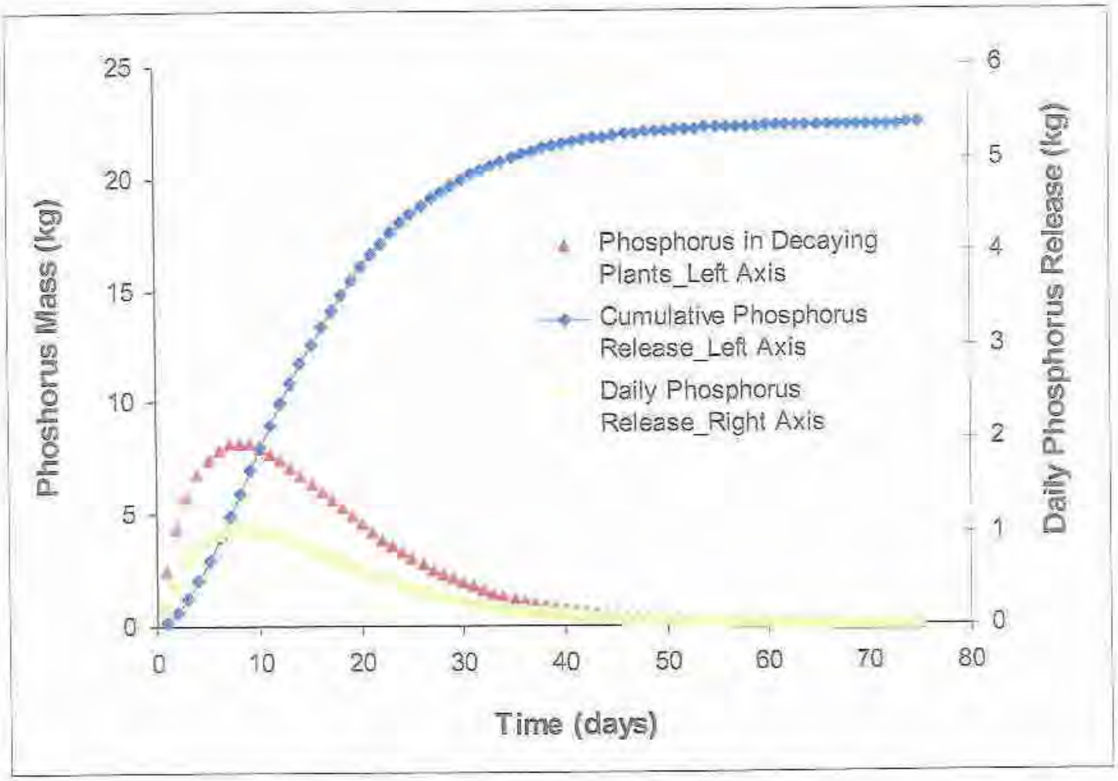


Figure B-2 Phosphorus Release to the Red Rock Lake Water Column by Curlyleaf Pondweed

B-3.2 Sediment

Total phosphorus monitoring data for Red Rock Lake (see Figure 8) show that the concentration of phosphorus in the water column can increase significantly in July through August. Red Rock Lake sediment is relatively high in phosphorus that can release into the lake column (see Figure 24). From the sediment phosphorus data it was estimated that the phosphorus release rate was approximately 8.54 mg per square meter of lake surface per day in deeper areas of the lake. The lake wide average release rate was determined to be 3.1 mg per square meter of lake surface per day. The lake wide average includes shallower areas of the lake water body with sediment not generally exposed to anoxic conditions which can result in higher release rates of phosphorus. Also, the shallower areas of the lake have sediment that is more transitional in nature meaning that the less dense, generally higher phosphorus content portions of the sediment move towards the deeper areas of the lake where they accumulate over time. Both of these factors lead to lower phosphorus release rates in the shallower portions of the lake.

Partitioning modeling results (see Figure B-1) indicate that phosphorus released from sediment increases the lake's phosphorus concentration by approximately 14 µg/L in June and from 42 to 48 µg/L in July through August under 1999 climatic conditions and existing watershed land uses. Hence, phosphorus released from sediments comprises from one quarter to one half of the lake's phosphorus concentration during the June through August period under 1999 climatic conditions and existing watershed land uses.

B-3.3 Calibration

Two parameters were used to calibrate the lake model: (1) phosphorus settling velocity, and (2) the rate of phosphorus release from curlyleaf pondweed. The phosphorus settling velocity was calculated using an equation from Dillon and Rigler (1974) and lake characteristics such as lake volume and mean depth, watershed phosphorus and water loading from the spring of one year to the spring of the next year (1 year of phosphorus loading), outflow discharge volume, and outflow concentration. The phosphorus settling velocity was calculated such that the model-predicted phosphorus concentration was equal to the concentration of phosphorus monitored in the spring (calibrated with 1999 monitoring data). The rate of phosphorus release from curlyleaf pondweed was used as an input to a second mass balance model (adapted from Thomann and Mueller, 1987) to develop a calibrated model. The phosphorus release rate from curlyleaf pondweed was adjusted to minimize the difference between model-predicted and monitored phosphorus concentrations.

The equations used in this study are presented below.

Curlyleaf Pondweed Die-Off

For the process: pondweed (A) $\xrightarrow[k_1]{}$ decaying pondweed (B) $\xrightarrow[k_2]{}$ released phosphorus (C), two equations apply,

$$[B]=\frac{k_1[A_o]}{k_2-k_1}\{\exp(-k_1 t)-\exp(-k_2 t)\ \}$$

$$[C]=\frac{[A_o]}{k_2-k_1}\{k_2(1-\exp(-k_1 t))-(1-\exp(-k_2 t))\ \}$$

where t is time in days.

Dillon and Rigler

There are two equations for the Dillon and Rigler model.

$$R_{\exp} = \frac{Vp}{q_a + Vp}$$

and

$$C = L\frac{(1 - R_{\exp})}{Zp}$$

where R_{exp} = retention coefficient, q_a = overflow rate, Vp = net apparent settling rate, C = lake concentration, L = phosphorus loading, z = average lake depth, and p = the fraction of the lake that is lost by discharge. The first equation was solved for net apparent settling rate variable, Vp. This variable was then input in the equation below. The second equation was used to estimate the concentration of phosphorus that will occur in the spring.

Adapted from Thomann and Mueller

$$\frac{\Delta C}{\Delta t} = \frac{Q_{in} * C_{in} - Q_{out} * C_{lake} - C_{lake} * A * Vp + SedPond}{V}$$

where: C = concentration of total phosphorus in the lake, t = time, Q_{in} = water flow into lake, Q_{out} = water flow out of lake, A = lake area, Vp = net total phosphorus settling "removal" rate, *SedPond* = sediment and pondweed loading, and V = lake volume. This model was used with a daily time step.

B-3.5 Management Estimates

The effect of different management actions on phosphorus loading to Red Rock Lake was estimated for herbicide treatment, alum treatment of Red Rock and Mitchell Lakes, alum treatment of Mitchell Lake outflow waters which flow into Red Rock Lake, NURP upgrade to ponds not currently meeting NURP criteria, and rainwater gardens. Because NURP upgrade to ponds and rainwater gardens resulted in a negligible improvement to the lake's water quality, these management options are not recommended for Red Rock Lake.

It was estimated that herbicide (Endothall) treatment can result in curlyleaf pondweed removal to 80 percent. This estimate was approximated from published literature (Poovey, et al 2002). Elimination of curlyleaf pondweed is expected to occur following several years of annual Endothall treatment because plant reproduction will be prevented by the annual early spring treatment.

However, a conservative estimate of 80 percent phosphorus removal from curlyleaf pondweed was used for management estimates. Lime treatment has resulted in pondweed growth inhibition from 50 to 80 percent (Reedyk, et al., 2001). For modeling purposes lime treatment was assumed to have the same effectiveness as Endothall.

The magnitude of phosphorus release inhibition from Red Rock Lake sediments is based upon the alum dose that is used. Alum dose can be applied that will reduce the sediment phosphorus release rate to 0 mg per square meter per day. However, a conservative 80 percent reduction in sediment phosphorus release was used for modeling. Hence, a release rate equal to 20 percent of the estimated current release rate was used as a model input to simulate the effect of sediment treatment on phosphorus levels in Red Rock Lake. The recommended alum dose is 63 g/m2 by 1 centimeter deep or 1,167 gallons per acre to treat the top 6 centimeters of sediment in Red Rock Lake.

B-3.5 Partitioning of Phosphorus Sources

Phosphorus sources to Red Rock Lake were partitioned to determine the relative contribution of each source to the lake's water quality. A mass balance spreadsheet model was used to proportion the lake's phosphorus sources during 1999. Sample dates were selected for the partitioning time step. Details follow.

- The lake's spring phosphorus concentration (P_0) was the starting phosphorus concentration during April.
- Stormwater runoff contributions (P_{SRO}) to the lake during April through September were determined from P8 modeling results. For each sample date, the P8 modeled stormwater runoff phosphorus load was divided by the lake's epilimnetic volume to estimate the lake phosphorus concentration resulting from stormwater runoff.
- Annual atmospheric deposition (P_{ATM}) was calculated within the Dillon and Rigler model. An atmospheric deposition rate of 0.56 kg/ha/yr. (Tetra Tech. 1982) was applied to the surface area of Red Rock Lake to determine annual phosphorus loading from atmospheric deposition. Stormwater inflow to Red Rock Lake from P8 modeling results was used to proportion atmospheric deposition to the individual days throughout the year. Then, the daily atmospheric deposition rate was used to estimate atmospheric deposition during each sample period. The atmospheric deposition load during each sample period was divided by the lake's epilimnetic volume to estimate the lake phosphorus concentration resulting from atmospheric deposition.
- The lake's phosphorus load from decaying plants (Pint-Curlyleaf) was comprised of the estimated phosphorus load from decaying curlyleaf pondweed. The load was computed using a mathematical model (see Figure B-2) used to estimate curlyleaf pondweed die-off and phosphorus release. The phosphorus load from decaying curlyleaf pondweed during each

sample period was divided by the lake's epilimnetic volume to estimate the lake phosphorus concentration resulting from decaying curlyleaf pondweed.

- The lake's phosphorus load from sediment (Panoxic-diffu+entrain) was estimated from mobile phosphorus measurements of the lake's sediment (see Figure 24). From the sediment phosphorus data it was estimated that the phosphorus release rate was 3.1 mg per square meter per day from mid-June through early-September (Pilgrim, 2002). Diffusion across the thermocline and entrainment were estimated to determine phosphorus loading from sediments. Diffusion was estimated from the temperature and phosphorus concentration difference between the epilimnion and hypolimnion. Entrainment was estimated from hypolimentic and epilimnetic changes in phosphorus mass. The estimated phosphorus load from decaying sediment during each sample period was divided by the lake's epilimnetic volume to estimate the lake phosphorus concentration from sediment.
- Losses from settling and outflow through the outlet were estimated. The losses were partitioned based upon the contribution of each phosphorus source. Hence, the percent contribution to the lake's losses on each sample date was the same as the percent contribution to the lake's sources. Phosphorus losses were subtracted from phosphorus sources on each sample date to estimate net contributions.

The partitioned total phosphorus concentrations for Red Rock Lake during April through September of 1999 are presented in Table B-3 and Figure 27 of this report. Partitioned total phosphorus concentrations for wet, dry, and average climatic conditions are presented in Appendix F of this report.

B-4 Results

A graphical presentation of the model calibration results are shown in Figure B-1.

The expected outcome of several alternative management actions was modeled using the calibrated model for dry, average, and wet years. The expected outcome of each management activity is presented as the average summer total phosphorus concentration (Table B-1), the expected Secchi disc transparency given the average total phosphorus concentration (Table B-2), and the TSI that corresponds to the Secchi disc transparency (Table B-3). The expected Secchi disc transparency presented in Table B-3 was calculated using a logarithmic relationship between measured summer phosphorus levels in Red Rock Lake and corresponding Secchi disc transparency (Figure B-3).

Table B-1 Expected Mean Summer Total Phosphorus Concentrations Under Varying Climatic Conditions and Management Approaches

Management Approach	Mean TP Concentration (µg/L)			
	Wet Year (38 inches)	Average Year (35 inches)	Calibration Year (33 inches)	Dry Year (24 inches)
Existing Watershed Land Use Conditions				
No Action	99	86	86	90
NURP Upgrade*	92	82	82	83
Rainwater Gardens	99	85	85	87
Red Rock Lake Curlyleaf Pondweed Management and Alum Treatment**	78	44	44	56
Red Rock Lake and Mitchell Lake Curlyleaf Pondweed Management and Alum Treatment**	65	42	42	56
Red Rock Lake and Mitchell Lake Curlyleaf Pondweed Management and Alum Treatment** and Alum Treat Mitchell Lake Inflow to Red Rock Lake	56	39	39	51
Future Watershed Land Use Conditions				
No Action	106	96	95	98
NURP Upgrade*	105	95	95	97
Rainwater Gardens	105	95	94	96
Red Rock Lake Curlyleaf Pondweed Management and Alum Treatment**	86	57	57	66
Red Rock Lake and Mitchell Lake Curlyleaf Pondweed Management and Alum Treatment**	90	53	53	57
Red Rock Lake and Mitchell Lake Curlyleaf Pondweed Management and Alum Treatment** and Alum Treat Mitchell Lake Inflow to Red Rock Lake (Assume 60% Removal)	60	49	49	52

*Upgrade Watershed Ponds to meet MPCA/Nurp Criteria

**Lake phosphorus concentration estimate is following the 4th consecutive year of alum treatment (i.e., after full dose has been administered)

Table B-2 Expected Mean Summer Secchi Disc Transparencies Under Varying Climatic Conditions and Management Approaches

Management Approach	Mean Summer Secchi Disc (m)			
	Wet Year (38 inches)	Average Year (35 inches)	Calibration Year (33 inches)	Dry Year (24 inches)
Existing Watershed Land Use Conditions				
No Action	0.8	0.9	0.9	0.8
NURP Upgrade*	0.8	0.9	0.9	0.9
Rainwater Gardens	0.8	0.9	0.9	0.8
Red Rock Lake Curlyleaf Pondweed Management and Alum Treatment**	0.9	1.5	1.5	1.2
Red Rock Lake and Mitchell Lake Curlyleaf Pondweed Management and Alum Treatment**	1.1	1.6	1.6	1.2
Red Rock Lake and Mitchell Lake Curlyleaf Pondweed Management and Alum Treatment** and Alum Treat Mitchell Lake Inflow to Red Rock Lake (Assume 60% Removal)	1.2	1.7	1.7	1.3
Future Watershed Land Use Conditions				
No Action	0.7	0.8	0.8	0.8
NURP Upgrade*	0.7	0.8	0.8	0.8
Rainwater Gardens	0.7	0.8	0.8	0.8
Red Rock Lake Curlyleaf Pondweed Management and Alum Treatment	0.9	1.2	1.2	1.1
Red Rock Lake and Mitchell Lake Curlyleaf Pondweed Management and Alum Treatment*	0.8	1.3	1.3	1.2
Red Rock Lake and Mitchell Lake Curlyleaf Pondweed Management and Alum Treatment** and Alum Treat Mitchell Lake Inflow to Red Rock Lake (Assume 60% Removal)	1.2	1.4	1.4	1.3

*Upgrade Watershed Ponds to meet MPCA/Nurp Criteria

**Lake Secchi disc transparency estimate is following the 4th consecutive year of alum treatment (i.e., after full dose has been administered)

Table B-3 Expected Trophic State Index Values Under Varying Climatic Conditions and Management Approaches

Management Approach	Trophic State Index (TSI_{SD}) Value				
	District Goal	Wet Year (38 inches)	Average Year (35 inches)	Calibration Year (33 inches)	Dry Year (24 inches)
Existing Watershed Land Use Conditions					
No Action	≤59	64	62	62	63
NURP Upgrade*	≤59	63	62	62	65
Rainwater Gardens	≤59	64	62	62	62
Red Rock Lake Curlyleaf Pondweed Management and Alum Treatment	≤59	61	54	54	57
Red Rock Lake and Mitchell Lake Curlyleaf Pondweed Management and Alum Treatment*	≤59	59	53	53	57
Red Rock Lake and Mitchell Lake Curlyleaf Pondweed Management and Alum Treatment** and Alum Treat Mitchell Lake Inflow to Red Rock Lake (Assume 60% Removal)	≤59	57	53	53	56
Future Watershed Land Use Conditions					
No Action	≤59	65	64	64	64
NURP Upgrade*	≤59	65	64	64	64
Rainwater Gardens	≤59	65	63	64	64
Red Rock Lake Curlyleaf Pondweed Management and Alum Treatment	≤59	62	57	57	59
Red Rock Lake and Mitchell Lake Curlyleaf Pondweed Management and Alum Treatment*	≤59	63	56	56	57
Red Rock Lake and Mitchell Lake Curlyleaf Pondweed Management and Alum Treatment** and Alum Treat Mitchell Lake Inflow to Red Rock Lake	≤59	58	55	55	56

*Upgrade Watershed Ponds to meet MPCA/Nurp Criteria **Lake TSI_{SD} estimate is following the 4th consecutive year of alum treatment (i.e., after full dose has been administered)

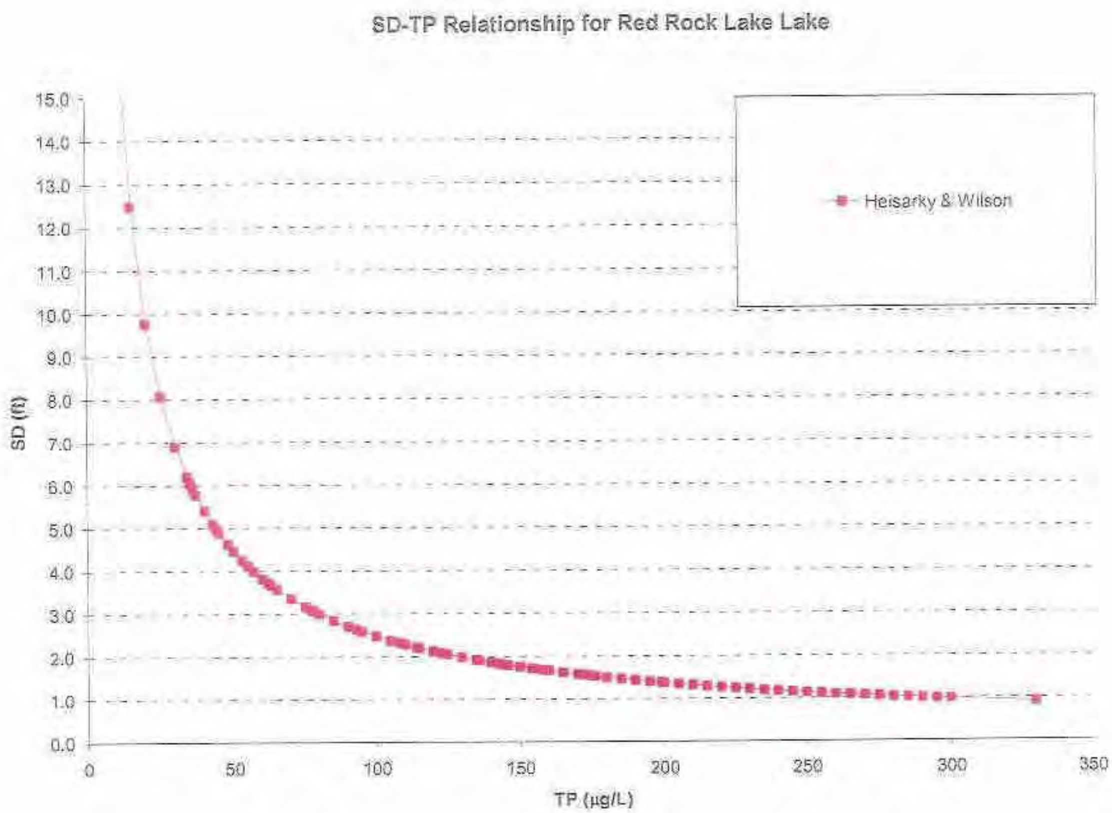


Figure B-3. Relationship Between Total Phosphorus and Secchi Disc (Heiskary and Wilson 1990)

B-5 WATBUD Modeling

WATBUD is a lake water balance model produced by the Minnesota Department of Natural Resources (MnDNR 1996, 1998). The model calculates daily lake level changes based on daily inputs of precipitation and temperature, optional daily inputs of runoff, evaporation or groundwater exchange and optional internal sub models which estimate runoff, evaporation or groundwater exchange. The model is capable of optimizing various water balance parameters using known lake level data as calibration targets.

For this project, the WATBUD model was used to evaluate the water load estimated for Red Rock Lake by a P8 model of the Red Rock Lake watershed, which includes the up gradient Mitchell Lake watershed. The P8 model calculates the water flux into the lake from watershed runoff, including both direct runoff and flow through storm sewers. The P8 model does not, however, take into account groundwater seepage, nor the direct precipitation to or evaporation from the lake surface. Because of this, the WATBUD model was needed to evaluate the lake's water budget.

B-5.1 Water Budget Components

The WATBUD model was run to simulate conditions for the 1997 through 2000 water years (October 1, 1996 to September 30, 2000).

B-5.1.1 Precipitation

The WATBUD model requires daily rainfall records. Data were obtained from the Minneapolis-St. Paul International Airport prior to 1998. During 1998 through 2000, precipitation for the Red Rock Lake watershed was calculated using monthly grids created from State Climatologist data. The monthly precipitation amounts were compared with hourly precipitation amounts recorded by a gage in Eden Prairie to determine the adjustment factor that would convert the Eden Prairie data to equal the monthly Red Rock Lake watershed data. Then the adjustment factor was applied to the hourly Eden Prairie rainfall amounts to adjust them so that the monthly Eden Prairie rainfall would equal the monthly Red Rock Lake watershed rainfall amounts.

B-5.1.2 Evaporation

Daily lake evaporation rates were calculated from monthly evaporation rates taken from a Meyer Model simulation of the Minneapolis Chain of Lakes. Evaporation rates for the Minneapolis' lakes are assumed to be applicable to lakes within the Riley-Purgatory-Bluff Creek Watershed District, which are at a similar latitude and experience similar climatic conditions. The Meyer Model was developed by Barr Engineering Company, based on work by Adolf Meyer (Meyer, 1947; Barr

Engineering, undated), as a tool to estimate watershed net yield. Within the Meyer Model, monthly evaporation is calculated using average monthly water temperature, relative humidity and wind speed, as well as a site specific water temperature adjustment parameter.

B-5.1.3 Runoff

Daily runoff rates (which include both overland flow and flow through storm sewers) from the P8 model of the Red Rock Lake watershed were modified and used as input in the WATBUD model. Because the P8 Model does not simulate groundwater seepage, it is not able to accurately predict surface water outflow from a lake in which there is significant groundwater interaction. This is true for both Red Rock Lake and the up-gradient lakes (Mitchell and Round). In order to account for this, a WATBUD model was run for both Mitchell and Round Lakes for the same period of interest in order to calculate lake outflow. The Round Lake and Mitchell Lake WATBUD models were constructed in a manner similar to the Red Rock Lake model described here. All of the WATBUD models were calibrated to measured lake stages. The calibration of the Red Rock Lake model is discussed in detail below.

B-5.1.4 Groundwater Exchange

A groundwater exchange sub model (Lake Level Dependence) was used to calculate groundwater seepage into the lake. This sub model can be used to calculate groundwater exchange using lake level data under the assumption that there is a direct relationship between lake level and seepage, independent of the groundwater heads. In this sub model, seepage is calculated using the following equation:

Seepage = a * (1+b*Llake), where

a (inches) and **b** are arbitrary constants, and

Llake is the level of the lake.

The constants **a** and **b** can be user specified or fit during calibration. It is worth noting that the WATBUD model is not able to estimate total groundwater inflow and outflow, just the net groundwater exchange.

B-5.2 Model Calibration

The WATBUD model was calibrated using 50 lake stage measurements (monthly) from Red Rock Lake as calibration targets. During the automated calibration process the groundwater seepage parameters **a** and **b** (discussed above) were allowed to vary until there was an acceptable match between simulated and measured lake levels. Figure B-3 shows the resulting lake stages. Overall, the

WATBUD model does a good job of matching lake levels. However, it is unclear whether the model over predicts high lake levels, as the highest observed lake level (840.72 ft MSL) is significantly lower than the highest simulated lake level (842.13 ft MSL).

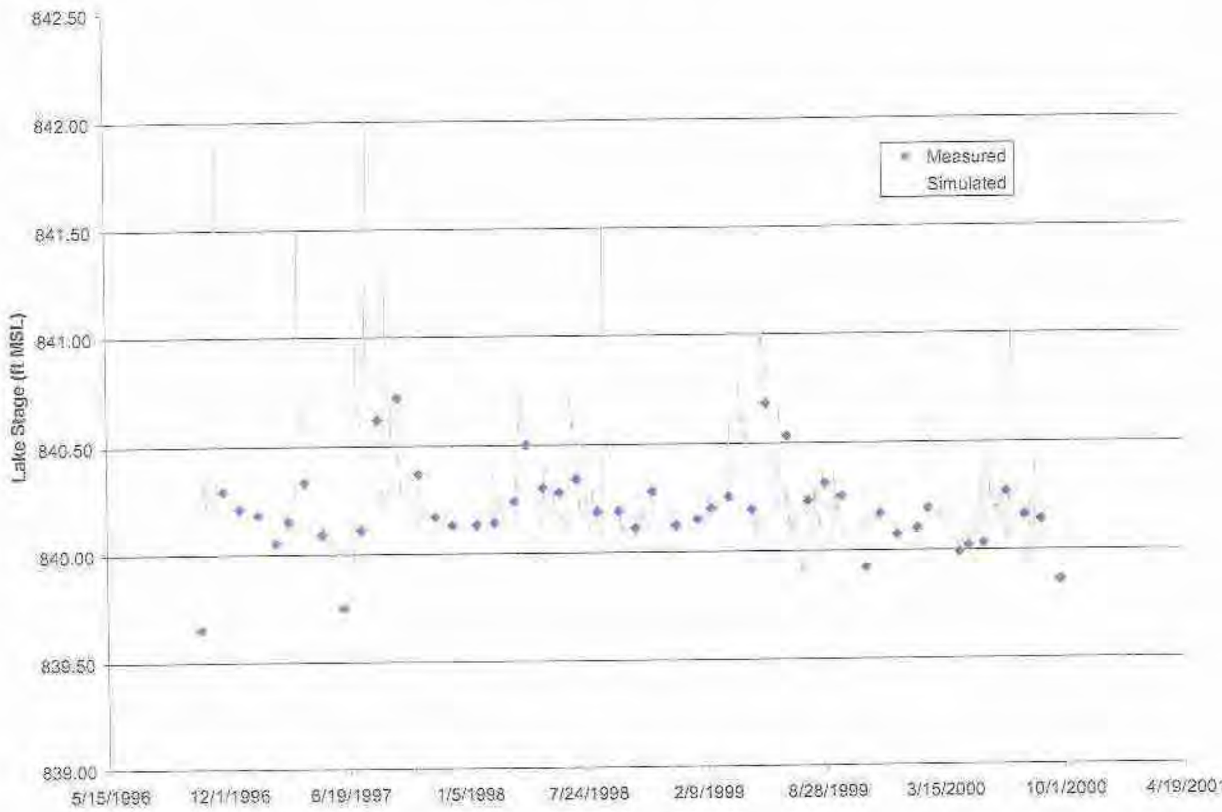


Figure B-4 Measured and Simulated Red Rock Stages

B-5.3 Results

The table below shows the simulated water balance for Red Rock Lake for water years 1997 through 2000:

Water Year	Average Lake Level (ft MSL)	Average Seepage (acre-ft)	Stream Outflow (acre-ft)	Precipitation (acre-ft)	Stream and Overland Inflow (acre-ft)	Evaporation (acre-ft)	Residence Time (years)
1997	840.30	395	-1,951	306	1,604	-307	0.16
1998	840.22	395	-1,143	235	813	-320	0.26
1999	840.22	395	-1,146	279	855	-385	0.25
2000	840.13	396	-675	192	456	-379	0.35

According to the WATBUD modeling results, there is a net groundwater flux (groundwater in minus groundwater out) into Red Rock Lake. For the simulated period, the hydraulic residence time for the lake varied between 0.16 and 0.35 years.

B-6 Conclusions

This lake model was used to estimate the relative phosphorus loading from watershed inputs, curlyleaf pondweed, and lake sediment, and how management of these different sources would affect phosphorus levels in Red Rock Lake.

The prescribed management activities should be completed according to the management plan presented in Sections 4.0 through 4.7 of this report. By following this management plan the relative contribution by curlyleaf pondweed to phosphorus levels in Red Rock Lake can be confirmed because herbicide treatment should eliminate phosphorus contributed by curlyleaf pondweed. Once curlyleaf pondweed is adequately controlled, alum treatments of Red Rock Lake and Mitchell Lake will occur to reduce the dense blue-green algal blooms at Red Rock Lake in the summer. Following control of phosphorus released from sediments, monitoring for three years should occur to determine whether the implementation program has resulted in attainment of the District goal.

Appendix C

Monitoring and Analysis Methods

Appendix C: Monitoring and Analysis Methods

The Red Rock Lake UAA included the collection of lake water quality data and ecosystem data.

C.1 Lake Water Quality Data Collection

In 1999, a representative Red Rock Lake sampling station was selected (i.e., located at the deepest location in the lake basin (see Figure 20 of this report). Samples were collected from April through October of 1999. A total of ten water quality parameters were measured at the Red Rock Lake sampling station. Table C-1 lists the water quality parameters and specifies at what depths the samples or measurements were collected. Dissolved oxygen, temperature, specific conductance, turbidity, pH, and Secchi disc transparency were measured in the field. Water samples were analyzed in the laboratory for total phosphorus, soluble reactive phosphorus, total nitrogen, and chlorophyll *a*. The procedures for chemical analyses of the water samples are shown in Table C-2. Generally, the methods can be found in Standard Methods for Water and Wastewater Analysis.

Table C-1 Red Rock Lake Water Quality Parameters

Parameters	Depth (Meters)	Sampled or Measured During Each Sample Event
Dissolved Oxygen	Surface to bottom profile	X
Temperature	Surface to bottom profile	X
Specific Conductance	Surface to bottom profile	X
Secchi Disc	—	X
Total Phosphorus	0 2 meter Composite Sample	X
Total Phosphorus	Samples at 3, 4, and 5 meters	X
Total Phosphorus	Near Bottom Sample at 0.5 meters above the bottom	X
Soluble Reactive Phosphorus	0-2 meter Composite Sample	X
Total Nitrogen	0-2 meter Composite Sample	X
pH	0-2 meter Composite Sample	X
pH	Samples at 3, 4, and 5 meters	X
pH	Near Bottom Sample at 0.5 meters above the bottom	X
Chlorophyll *a*	0-2 meter Composite Sample	X
Turbidity	0-2 meter Composite Sample	X

Table C-2 Procedures for Chemical Analyses Performed on Water Samples

Analysis	Procedure	Reference
Total Phosphorus	Persulfate digestion, manual ascorbic acid	Standard Methods, 18th Edition, 1992, 4500-P B, E
Soluble Reactive Phosphorus	Manual ascorbic acid	Standard Methods, 18th Edition, 1992, 4500-P E
Total Nitrogen	Persulfate digestion, scanning spectrophotometricl	Bachman, R.W. and D.E. Canfield, Jr. 1991. A Comparability Study of a New Method for Measuring Total Nitrogen in Florida Waters. A Report Submitted to the Florida Department of Env. Reg.
Chlorophyll *a*	Spectrophotometric	Standard Methods, 18th Edition, 1992, 10200 H
pH	Potentiometric measurement, glass electrode	Standard Methods, 18th Edition, 1992, 4500-H B
Specific Conductance	Wheatstone bridge	Standard Methods, 18th Edition, 1992, 2510
Temperature	Thermometric	Standard Methods, 18th Edition, 1992, 2550 B
Dissolved Oxygen	Electrode	Standard Methods, 18th Edition, 1992, 4500-O G
Phytoplankton Identification and Enumeration	Inverted Microscope	Standard Methods, 18th Edition, 1992, 10200 F
Zooplankton Identification and Enumeration	Sedgewick Rafter	Standard Methods, 18th Edition, 1992, 10200 G
Transparency	Secchi disc	
Turbidity	Nephelometric via turbidimeter	Standard Methods, 20th Edition, 1998, 2130B, pages 2-9.

C.2 Ecosystem Data Collection

Ecosystem data collected from April to October 1999 included:

- **Phytoplankton**—A composite 0-2 meter sample was collected during each water quality sampling event during the period April 1999 thorough September 1999.
- **Zooplankton**—A zooplankton sample was collected (i.e., bottom to surface tow) during each water quality sample event during the period April 1999 thorough October 1999.
- **Macrophytes**—Macrophyte surveys were completed during June and August 1999.

Phytoplankton and zooplankton samples were identified and enumerated to provide information on species diversity and abundance. The macrophyte community was surveyed to determine species locations, composition, and abundance.

C.3 Watershed Pond Survey

During 2002, 29 ponds in the Red Rock Lake watershed were surveyed. The bathymetry of the ponds were determined in the survey. This work was completed to help establish current conditions of water bodies that affect the flow of storm water runoff from the Red Rock Lake watershed. The survey of the wet detention ponds began by recording the type and size of the outlet and estimating the height to the low overflow point. A Global Positioning System (GPS) was then used to record the perimeter of each pond. Staff walked the perimeter and used the GPS to record the longitude and latitude of selected points along the perimeter. A grid was then marked off on the pond with points approximately 20 feet apart. A depth gage was dropped to the bottom to get the water depth at each survey point. The grid points and associated water depths were then recorded on a map of the pond. The maps were then placed in the Geographical Information System (GIS) and pond volumes, both dead and live storage, were determined. The information was used for P8 modeling of the Red Rock Lake watershed to determine the lake's watershed phosphorus load.

Pond data from ponds located in the Red Rock Lake subwatershed (see Figure 1 of this report) are summarized in Appendix A.

Appendix D

P8 Model Parameter Selection

Appendix D: P8 Model Parameter Selection

P8 version 2.4 was used for Red Rock Lake watershed modeling. The parameters selected for the Red Rock Lake P8 model are discussed in the following paragraphs. P8 parameters not discussed in the following paragraphs were left at the default setting.

Time Step, Snowmelt, and Runoff Parameters (Case-Edit-Other)

- **Time Steps Per Hour (Integer)—6.** Selection was based upon the number of time steps required to eliminate continuity errors greater than 2 percent.
- **Minimum Inter-Event Time (Hours)—10.** The selection of this parameter was based upon an evaluation of storm hydrographs to determine which storms should be combined and which storms should be separated to accurately depict runoff from the lake's watershed.
- **Snowmelt Factors—Melt Coef (Inches/Day-Deg-F)—0.06.** The selection was based upon the snowmelt rate that provided the best match between the observed and predicted snowmelt.
- **Snowmelt Factors—Scale Factor For Max Abstraction—1.** This factor controls the quantity of snowmelt runoff (i.e., controls losses due to infiltration). Selection was based upon the factor that resulted in the closest fit between modeled and observed runoff volumes.
- **Growing Season/Non-Growing Season AMC-II = 0.5 and AMC-III = 1.2 (growing season); AMC-II = 0.5 and AMC-III = 1.1 (non-growing season).** This indicates that AMC-II is used if the 5-day antecedent moisture is 0.5 inches or greater during the growing season and 0.5 inches or greater during the non-growing season and AMC-III is used if antecedent moisture is 1.2 (growing season) or 1.1 (non-growing season) inches or greater.

Particle Scale Factor (Case-Edit-Components)

- **Scale Fac.—tp—1.0** The particle scale factor adjusts phosphorus loading for site specific factors. A factor of 1.0 indicates no adjustment.

Particle File Selection (Case—Read—Particles)

- **NURP50PAR.** The NURP 50 particle file was used to predict phosphorus loading and settling in wet detention ponds.

Precipitation File Selection (Case—Edit—First—Prec. Data File

- **Rroc4902.PCP.** The precipitation file rroc4902.PCP is comprised of hourly precipitation data during the period 1949 through 2002. Data were obtained from the Minneapolis-St. Paul International Airport prior to 1998. During 1998 through 2002, precipitation for the Red Rock Lake watershed was calculated using monthly grids created from State Climatologist data. The monthly precipitation amounts were compared with hourly precipitation amounts recorded by a gage in Eden Prairie to determine the adjustment factor that would convert the

Eden Prairie data to equal the monthly Red Rock Lake watershed data. Then the adjustment factor was applied to the hourly Eden Prairie rainfall amounts to adjust them so that the monthly Eden Prairie rainfall would equal the monthly Red Rock Lake watershed rainfall amounts.

Air Temperature File Selection (Case—Edit—First—Air Temp. File)

- **MSP4902.TMP**. The temperature file was comprised of temperature data from the Minneapolis—St. Paul International airport during the period 1949 through 2002.

Devices Parameter Selection (Case—Edit—Devices—Data—Select Device)

- **Pond Bottom**—The surface area of the pond bottom of each detention pond was determined and entered here.
- **Detention Pond—Permanent Pool—Area and Volume**—The surface area and dead storage volume of each detention pond was determined and entered here.
- **Detention Pond—Flood Pool—Area and Volume**—The surface area and storage volume under flood conditions (i.e., the storage volume between the normal level and flood elevation) was determined and entered here.
- **Detention Pond—Orifice Diameter and Weir Length**—The orifice diameter or weir length was determined for each detention pond and entered here.
- **Detention Pond or Generalized Device—Particle Removal Scale Factor**—0.3 for ponds less than 2 feet deep, 0.6 for ponds from 2 to 3 feet deep, and 1 for all ponds 3 feet deep or greater. The particle removal factor for watershed devices determines particle removal by devices.
- **Detention Pond or Generalized Device—Outflow Device No's**—The number of the downstream device receiving water from the detention pond outflow was entered for infiltration, normal, and spillway.
- **Generalized Device**—Infiltration Outflow Rates (cfs)—0 for all ponds.
- **Detention Pond—Infiltration Rate (in/hr)**—0 for all ponds.
- **Pipe/Manhole—Time of Concentration**—The time of concentration for each pipe/manhole device was determined and entered here. A "dummy" pipe/manhole device was placed immediately upstream of each pond and a time of concentration of 0 hours per "dummy" pipe was generally selected. Because the timing of stormwater runoff was not an issue in this watershed, no lag time was needed. However, a "dummy" pipe called P-RRL-1 was used to combine all of the inflow pipes into one source. The Red Rock Lake pipe (i.e., P-RRL-1) in each model received all water and phosphorus loads that enter Red Rock Lake. A time of concentration of 0 was used for the Red Rock Lake pipe in each model. Use of the pipe forced each model to total the water and phosphorus loads entering the lake, thus avoiding hand tabulation.

Watersheds Parameter Selection (Case—Edit—Watersheds—Data—Select Watershed)

- **Outflow Device Number**—The device number of the device receiving runoff from the watersheds was selected.
- **Pervious Curve Number**—A weighted SCS curve number was used as outlined in the following procedure. The P8 Pre-Processor (GIS algorithm) was used to compute a SCS curve number for each watershed. The computation was based upon soil types in the watershed, land use, and hydrologic conditions. The computation also weighted the pervious curve number with indirect (i.e., disconnected) impervious areas in each sub watershed as follows:

WCN = {[(Indirect Impervious Area) * (98)] + [(Pervious Area) * (Pervious Curve Number)]}/(Total Area)

The assumptions for direct, indirect, and total impervious areas were based upon measurements from representative areas within the Riley-Purgatory-Bluff Creek watershed.

- **Swept/Not Swept**—An "unswept" assumption was made for the entire impervious watershed area. A sweeping frequency of 0 was selected for swept. Hence, selected parameters were placed in the unswept category, including impervious fraction, depression storage, impervious runoff coeff, and scale factor for particle loads.
- **Impervious Fraction**—The direct or connected impervious fraction for each subwatershed was determined and entered here. The direct or connected impervious fraction includes driveways and parking areas that are directly connected to the storm sewer system. The P8 pre-processor performed the computations to determine impervious fractions for the subwatersheds. The direct impervious fraction for each subwatershed was based upon measurements from representative areas within the Riley-Purgatory-Bluff Creek Watershed. The direct impervious fraction for each land use type was weighted with the acres of each land use to obtain a weighted average for each subwatershed.
- **Depression Storage**—0.1
- **Impervious Runoff Coef.**—0.94

Passes Through the Storm File (Case—Edit—First—Passes Thru Storm File)

Passes Thru Storm File—3. The number of passes through the storm file was determined after the model had been set up and a preliminary run completed. The selection of the number of passes through the storm file was based upon the number required to achieve model stability. Multiple passes through the storm file were required because the model assumes that dead storage waters contain no phosphorus. Consequently, the first pass through the storm file results in lower phosphorus loading than occurs with subsequent passes. Stability occurs when subsequent passes do not result in a change in phosphorus concentration in the pond waters. It was determined that all three P8 models (i.e., wet, dry, average) achieved stability at 3 passes.

Appendix E

Monitoring Data

Appendix E-1

1999 Monitoring Data

Red Rock Lake

Date	Max Depth (m)	Sample Depth (m)	Secchi Depth (m)	Chl. a (mg/cu.m)	Turbidity (NTU's)	D. O. (mg/L)	Temp (°C)	Sp. Cond. (µmho/cm @ 25°C)	Total P (mg/L)	Ortho P (mg/L)	Total N (mg/L)	pH (S.U.)
04/09/99	5.8	0-2	1.7	10.7	--	--	--	--	0.033	<0.003	0.73	8.2
		0.0		--	--	11.3	10.0	435	--	--	--	--
		1.0		--	--	11.3	10.0	435	--	--	--	--
		2.0		--	--	11.3	10.0	435	--	--	--	--
		3.0		--	--	11.3	10.0	435	0.038	--	--	8.3
		4.0		--	--	11.3	10.0	435	0.025	--	--	8.3
		5.2		--	--	11.3	10.0	435	0.031	--	--	8.3
05/10/99	5.8	0-2	2.0	13.7	3.3	--	--	--	0.028	0.000	1.67	8.4
		0.0		--	--	9.9	16.3	410	--	--	--	--
		1.0		--	--	9.9	16.3	411	--	--	--	--
		2.0		--	--	10	16.3	412	--	--	--	--
		3.0		--	--	10.1	15.0	410	0.033	--	--	8.4
		4.0		--	--	7.5	14.9	417	0.033	--	--	8.3
		5.2		--	--	5.0	13.9	425	0.037	--	--	8.1
06/08/99	5.5	0-2	2.3	8.4	3.0	--	--	--	0.031	0.002	2.10	8.3
		0.0		--	--	8.3	23.8	356	--	--	--	--
		1.0		--	--	8.3	23.7	356	--	--	--	--
		2.0		--	--	7.2	22.2	361	--	--	--	--
		3.0		--	--	1.4	18.6	376	0.040	--	--	8.4
		4.0		--	--	0.00	17.1	393	0.053	--	--	8.0
		5.0		--	--	0.00	15.1	432	0.080	--	--	7.8
06/22/99	5.8	0-2	1.1	19.1	14.0	--	--	--	0.051	0.003	1.04	8.8
		0.0		--	--	11.8	22.8	349	--	--	--	--
		1.0		--	--	11.4	22.3	353	--	--	--	--
		2.0		--	--	9.1	21.0	357	--	--	--	--
		3.0		--	--	5.7	20.3	362	0.047	--	--	8.7
		4.0		--	--	0.2	18.8	384	0.049	--	--	8.3
		5.3		--	--	0.0	15.0	463	0.172	--	--	7.9
07/06/99	5.8	0-2	0.8	62.7	19.4	--	--	--	0.086	0.003	1.47	8.9
		0.0		--	--	8.2	26.0	339	--	--	--	--
		1.0		--	--	8.1	25.9	339	--	--	--	--
		2.0		--	--	2.2	24.3	355	--	--	--	--
		3.0		--	--	0.0	20.7	387	0.104	--	--	8.7
		4.0		--	--	0.0	18.5	409	0.270	--	--	8.2
		5.5		--	--	0.0	16.2	463	0.515	--	--	7.9
		5.3				0.0	15.5	480	0.602			7.7

Red Rock Lake

Date	Max Depth (m)	Sample Depth (m)	Secchi Depth (m)	Chl. a (mg/cu.m)	Turbidity (NTU's)	D. O. (mg/L)	Temp (°C)	Sp. Cond. (µmho/cm @ 25°C)	Total P (mg/L)	Ortho P (mg/L)	Total N (mg/L)	pH (S.U.)
07/19/99	5.5	0-2	0.3	69.0	35.0	--	--	--	0.104	0.002	1.97	8.8
		0.0		--	--	8.7	25.4	325	--	--	--	--
		1.0		--	--	7.7	25.2	325	--	--	--	--
		2.0		--	--	6.2	25.0	329	--	--	--	--
		3.0		--	--	0.1	22.0	383	0.104	--	--	8.6
		4.0		--	--	0.0	19.1	425	0.157	--	--	8.1
		5.0		--	--	0.0	16.6	477	0.533	--	--	7.7
08/09/99	5.8	0-2	0.5	57.9	27.0	--	--	--	0.138	0.007	1.87	7.6
		0.0		--	--	4.3	23.9	341	--	--	--	--
		1.0		--	--	4.2	23.9	341	--	--	--	--
		2.0		--	--	4.1	23.9	348	--	--	--	--
		3.0		--	--	3.5	23.9	348	0.142	--	--	7.7
		4.0		--	--	0.1	21.1	432	0.155	--	--	7.7
		5.0		--	--	0.0	18.0	498	0.592	--	--	7.4
		5.5		--	--	0.0	17.7	513	0.628	--	--	7.3
08/23/99	5.5	0-2	0.5	74.4	30.0	--	--	--	0.107	0.002	1.82	8.2
		0.0		--	--	6.8	23.0	351	--	--	--	--
		1.0		--	--	6.0	22.9	351	--	--	--	--
		2.0		--	--	5.6	22.8	352	--	--	--	--
		3.0		--	--	4.9	22.7	354	0.095	--	--	8.3
		4.0		--	--	0.0	21.5	400	0.102	--	--	8.2
		5.0		--	--	0.0	18.7	511	0.125	--	--	8.2
09/07/99	6.0	0-2	0.6	41.8	20.0	--	--	--	0.107	0.003	1.68	7.9
		0.0		--	--	5.3	22.2	372	--	--	--	--
		1.0		--	--	5.3	22.2	372	--	--	--	--
		2.0		--	--	5.0	22.1	372	--	--	--	--
		3.0		--	--	0.1	21.8	381	0.113	--	--	7.9
		4.0		--	--	0.0	21.3	392	0.104	--	--	7.8
		5.0		--	--	0.0	19.4	517	--	--	--	7.5
		5.5		--	--	0.0	18.5	589	0.736	--	--	7.2
10/11/99	5.8	0-2	2.2	17.5	4.5	--	--	--	0.054	0.005	1.34	7.7
		0.0		--	--	6.1	14.3	413	--	--	--	--
		1.0		--	--	5.8	14.0	413	--	--	--	--
		2.0		--	--	5.6	13.9	414	--	--	--	--
		3.0		--	--	5.6	13.8	415	0.058	--	--	7.7
		4.0		--	--	5.5	13.7	414	0.055	--	--	7.7
		5.0		--	--	5.3	13.7	416	--	--	--	7.7
		5.5		--	--	5.2	13.5	417	0.050	--	--	7.7

RED ROCK LAKE
SAMPLE: 0-2 METERS (INT. TUBE)
STANDARD PHYTOPLANKTON CLUMP COUNT

DIVISION	TAXON	4/9/1999 units/mL	5/10/1999 units/mL	6/8/1999 units/mL	6/22/1999 units/mL	7/6/1999 units/mL	7/19/1999 units/mL	8/9/1999 units/mL	8/23/1999 units/mL	9/7/1999 units/mL
CHLOROPHYTA (GREEN ALGAE)	*Ankistrodesmus falcatus*	1,562	0	0	0	0	0	0	0	0
	Botryococcus sudeticus	0	0	0	0	0	0	117	0	0
	Ankistrodesmus Brauni	0	0	0	0	0	0	0	39	0
	Chlamydomonas globosa	6,168	1,913	11,125	234	703	555	1,249	2,264	768
	Closterium sp.	0	0	0	0	39	0	156	0	144
	Oocystis parva	0	39	0	156	312	167	195	0	96
	Pandorina morum	39	0	42	156	0	56	0	0	0
	Pediastrum duplex v. clathratum	0	0	0	0	0	0	0	39	0
	Quadrigula sp.	0	0	42	0	0	0	0	0	0
	Schroederia Judayi	1,327	0	506	390	1,132	0	664	312	48
	Scenedesmus sp.	0	0	0	0	0	0	0	39	0
	Sphaerocystis Schroeteri (Colony)	0	0	0	0	78	0	39	0	0
	Staurastrum sp.	0	39	0	0	39	0	0	0	96
	CHLOROPHYTA TOTAL	9,096	1,991	11,715	937	2,303	777	2,420	2,694	1,152
CHRYSOPHYTA (YELLOW-BROWN ALGAE)	*Dinobryon sociale*	156	195	0	0	0	0	0	0	0
	CHRYSOPHYTA TOTAL	156	195	0	0	0	0	0	0	0
CYANOPHYTA (BLUE-GREEN ALGAE)	*Anabaena affinis*	0	0	0	78	39	555	547	1,444	864
	Anabaena flos-aquae	0	0	464	273	156	56	0	0	0
	Anabaena spiroides v. crassa	0	0	0	1,171	273	1,277	429	117	288
	Cylindrospermopsis raciborskii	0	0	0	0	0	0	78	16,631	13,874
	Aphanizomenon flos-aquae	0	0	253	2,264	14,211	26,367	9,370	2,538	2,496
	Aphanocapsa delicatissima	0	0	0	0	0	0	390	78	0
	Coelosphaerium Naegelianum	0	0	0	0	39	167	273	664	144
	Merismopedia tenuissima	0	0	0	0	0	0	78	0	48
	Merismopedia sp.	0	0	0	0	0	0	0	39	0
	Microcystis aeruginosa	0	0	84	234	351	0	156	234	144
	Microcystis incerta	0	0	0	0	0	0	0	0	96
	Oscillatoria limnetica	0	0	42	0	0	0	0	0	48
	Oscillatoria Agardhii	0	0	0	0	0	0	351	351	7,057
	CYANOPHYTA TOTAL	0	0	843	4,020	15,069	28,422	11,672	22,096	25,059
BACILLARIOPHYTA (DIATOMS)	*Asterionella formosa*	1,132	2,186	42	0	0	0	0	0	0
	Cymbella sp.	39	0	0	0	0	0	0	0	0
	Fragilaria crotonensis	0	976	0	156	0	0	0	0	0
	Melosira granulata	0	0	0	0	0	0	0	0	48
	Navicula sp.	195	0	0	0	0	0	0	0	0
	Stephanodiscus sp.	0	39	0	117	0	0	0	0	0
	Synedra ulna	117	0	0	0	0	0	39	234	0
	BACILLARIOPHYTA TOTAL	1,484	3,201	42	273	0	0	39	234	48
CRYPTOPHYTA (CRYPTOMONADS)	*Cryptomonas erosa*	3,787	2,147	1,391	390	1,484	555	547	1,249	720
	CRYPTOPHYTA TOTAL	3,787	2,147	1,391	390	1,484	555	547	1,249	720
EUGLENOPHYTA (EUGLENOIDS)	*Phacus sp.*	195	0	0	0	0	0	0	0	0
	EUGLENOPHYTA TOTAL	195	0	0	0	0	0	0	0	0
PYRRHOPHYTA (DINOFLAGELLATES)	*Ceratium hirundinella*	0	0	42	0	0	0	0	39	0
	PYRRHOPHYTA TOTAL	0	0	42	0	0	0	0	39	
	TOTALS	14,718	7,535	14,033	5,620	18,856	29,754	14,676	26,312	26,979

Red Rock Lake

ZOOPLANKTON ANALYSIS

DIVISION	TAXON — Vertical Tow (m)	4/9/1999 #/m2	5/10/1999 #/m2	6/8/1999 #/m2	8/22/1999 #/m2	7/6/1999 #/m2	7/19/1999 #/m2	8/9/1999 #/m2	8/23/1999 #/m2	9/7/1999 #/m2	10/12/1999 #/m2
CLADOCERA	*Bosmina sp.*	14,402	163,123	49,843	125,268	66,817	45,520	539,211	146,051	232,095	182,962
	Ceriodaphnia sp.				44,907	168,119	60,693	120,077	39,238	101,401	13,226
	Chydorus sp.	14,402	31,718	20,390	28,362	36,841	49,855	92,889	104,634	45,067	17,635
	Daphnia ambigua/parvula				2,364						
	Daphnia galeata mendotae	4,801	58,905	138,201	165,450	99,147	8,670	18,125	15,259	24,787	63,927
	Daphnia retrocurva							2,266		2,253	4,409
	Diaphanosoma sp.			24,922	7,091	4,311	13,006	61,171	74,116	11,267	
	CLADOCERA TOTAL	**33,604**	**253,747**	**233,356**	**373,443**	**375,035**	**177,745**	**833,739**	**379,297**	**416,869**	**282,158**
COPEPODA	*Cyclops sp.*	76,810	38,515	18,125	7,091	4,311	6,503	6,797	6,540	38,307	70,540
	Mesocyclops sp.	2,400		4,531	7,091	17,243	32,514	131,404	56,677	45,067	17,635
	Diaptomus sp.	14,402	45,312	18,125	66,180	10,777	8,670	33,984	6,540	6,760	15,431
	Nauplii	223,228	299,058	192,576	283,628	135,789	140,895	185,779	337,880	218,575	15,431
	COPEPODA TOTAL	**318,840**	**382,885**	**233,356**	**363,989**	**168,120**	**188,583**	**357,964**	**407,636**	**308,709**	**119,036**
	Asplanchna sp.	379,248	72,499	163,123	16,545	4,311	30,347	244,684	17,439	9,013	61,722
	Brachionus sp.	33,604		2,266	2,364		2,168	6,797	15,259	27,040	
	Chonochilus sp.	2,400	672,882	194,841	4,727	17,243	858,379	1,320,842	503,550	205,055	2,204
	Filinia longiseta	48,006	2,266			2,155	134,393	11,328	8,719	2,253	
	Keratella cochlearis	151,219	947,018	95,155	30,726	73,283	394,507	38,250	128,612		74,948
	Keratella quadrata	19,202	4,531			2,155				259,135	
	Kellicottia sp.	112,814	616,242	65,702	75,634	10,777	4,335	6,797	198,368	209,561	
	Notholca sp.	4,801									
	Polyarthra vulgaris	98,413	24,922	167,654	271,810	45,263	26,011	9,062	32,698	187,028	57,313
ROTIFERA	*Trichocerca sp.*	2,400		20,390	56,726	58,195	151,734	18,125	71,936	33,800	2,204
	ROTIFERA TOTAL	**852,108**	**2,340,359**	**709,131**	**458,532**	**213,382**	**1,601,873**	**1,653,884**	**976,580**	**932,886**	**198,393**
	TOTALS	**1,202,553**	**2,976,991**	**1,175,843**	**1,195,964**	**756,537**	**1,968,201**	**2,845,587**	**1,763,514**	**1,658,464**	**599,587**

Appendix E-2

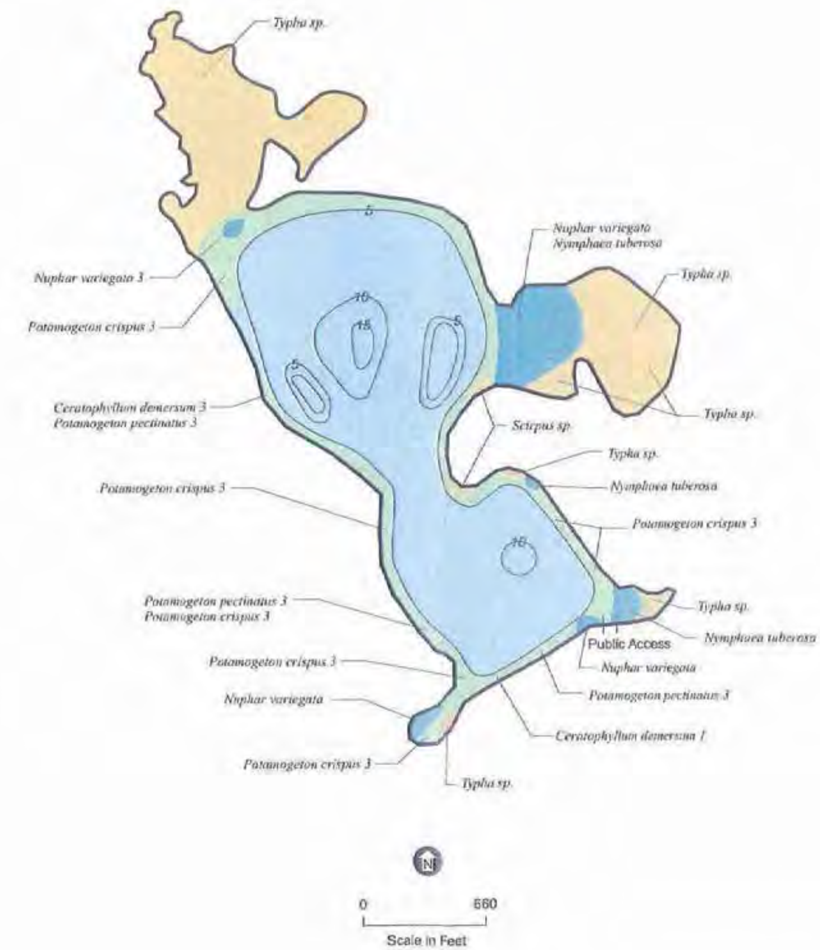
Historical Monitoring Data

Red Rock Water Quality Data (1972-1996)

Date	CHLa (ug/L)	Total P (ug/L)	Secchi Disc (m)		Red Rock Average		
					Chl-a	Phos	Secchi
06/05/72	20.3	53	1.4				
08/07/72	72.5	83	0.7		46.4	68.0	1.05
06/10/75	6.8	91	2.8				
08/14/75	99.0	109	0.3		52.9	100.0	1.55
06/05/78	7.0	37	2.2				
08/29/78	22.0	52	0.7		14.5	44.5	1.45
06/03/81	15.0	60	1.1				
08/10/81	28.7	71	0.9		21.9	65.5	1.00
06/19/84	3.2	24	3.0				
08/02/84	27.2	61	1.0		15.2	42.5	2.00
06/20/88	60.7	67	0.9				
07/14/88	192.2	132	0.3				
08/18/88	73.1	140	0.5		108.7	113.0	0.57
06/17/91	34.2	35	1.9	84.3			
07/09/91	75.4	70	0.4	85.8			
08/05/91	66.2	52	0.4	0.7			
08/26/91	64.3	77	0.5		60.0	58.5	0.80
06/29/93	7.9	70	0.7				
07/12/93	21.9	77	1.2				
08/03/93	46.1	89	0.8		27.1	76.8	0.88
08/24/93	32.4	71	0.8				
04/30/96	13.3	57	1.5				
06/18/96	12.1	42	2.3				
07/15/96	103.4	66	0.4				
08/05/96	38.4	79	0.6				
08/19/96	31.6	64	0.5				
09/03/96	37.0	79	0.6		46.4	62.8	0.95

* No Macrophytes Found In Water > 5.0'.
* Macrophyte Densities Estimated As Follows: 1 = light; 2 = moderate; 3 = heavy

	Common Name	Scientific Name
Submerged Aquatic Plants:	Coontail Curlyleaf pondweed Sago pondweed	*Ceratophyllum demersum* *Potamogeton crispus* *Potamogeton pectinatus*
Floating Leaf Plants:	White waterlily Yellow waterlily	*Nymphaea tuberosa* *Nuphar variegata*
Emergent Plants:	Bulrush Cattail	*Scirpus sp.* *Typha sp.*
No Aquatic Vegetation Found:		

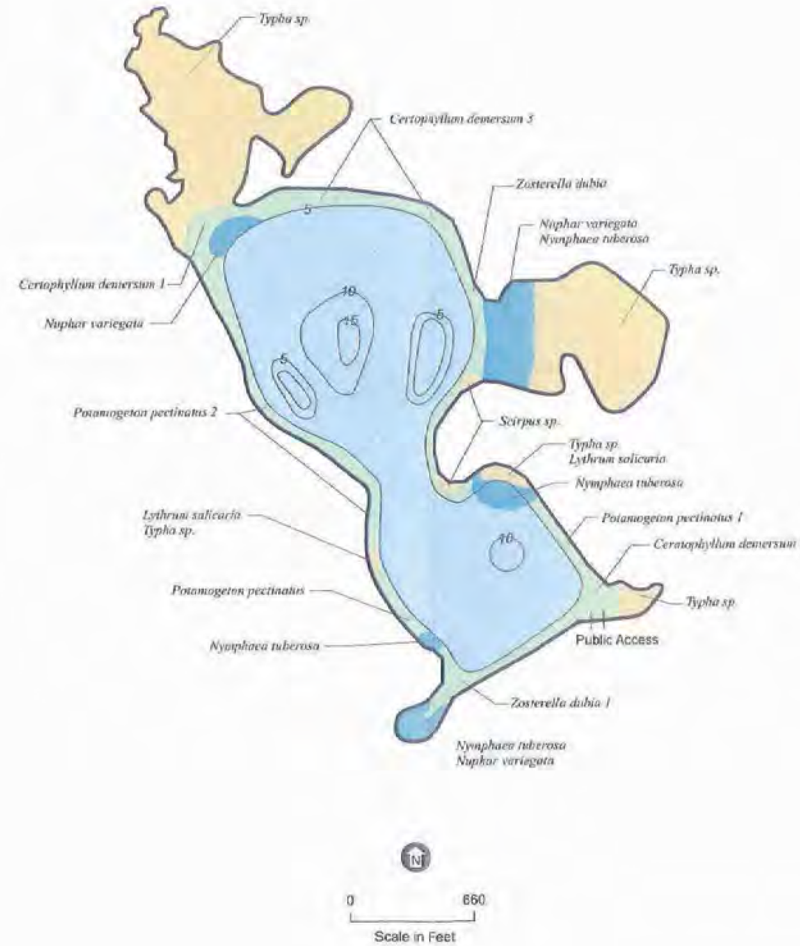


RED ROCK LAKE
MACROPHYTE SURVEY
JUNE 29, 1993

P:\23\27\053\LakeMacrophyteMaps\RedRock\1993\JUNE 1993.CDR RLG 06-17-04

• No Macrophytes Found In Water > 5.0'.
• Macrophyte Densities Estimated As Follows: 1 = light; 2 = moderate; 3 = heavy

	Common Name	Scientific Name
Submerged Aquatic Plants:	Coontail Sago pondweed Water stargrass	*Ceratophyllum demersum* *Potamogeton pectinatus* *Zosterella dubia*
Floating Leaf Plants:	White waterlily Yellow waterlily	*Nymphaea tuberosa* *Nuphar variegata*
Emergent Plants:	Bulrush Cattail Purple Loosestrife	*Scirpus sp.* *Typha sp.* *Lythrum salicaria*
No Aquatic Vegetation Found:		

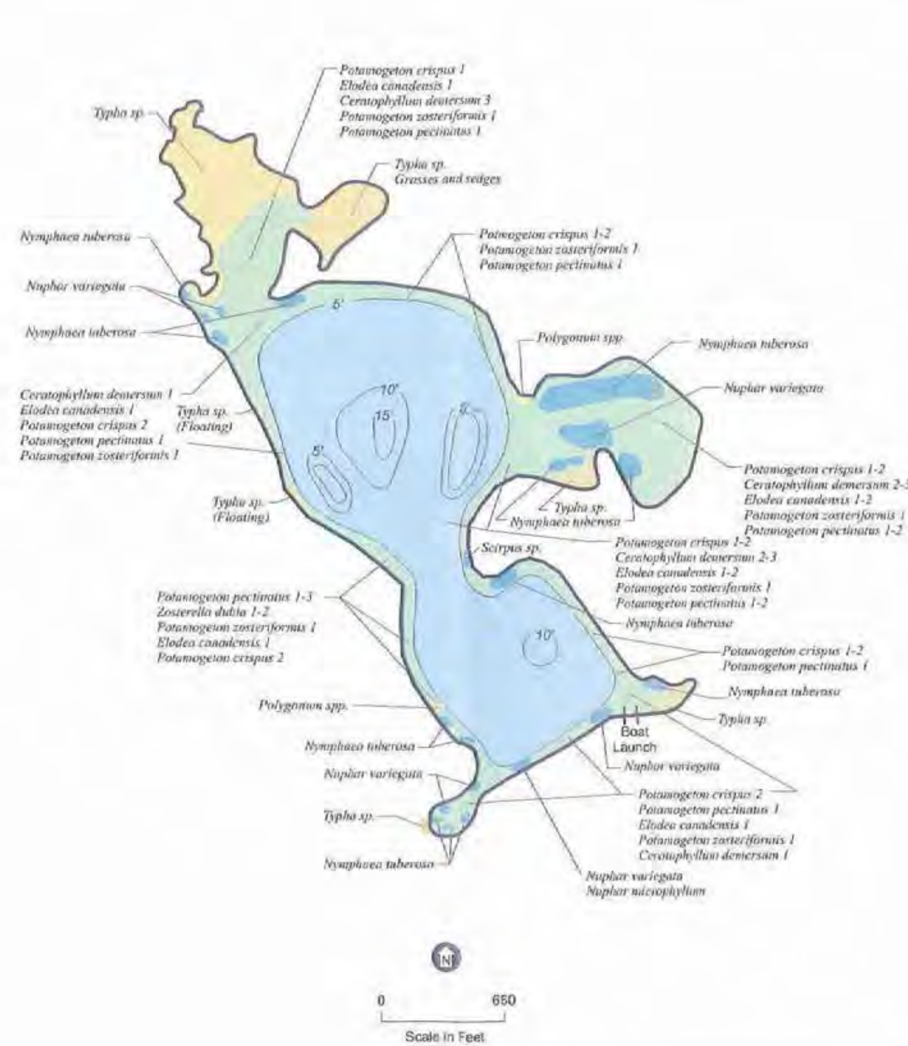


RED ROCK LAKE
MACROPHYTE SURVEY
AUGUST 24, 1993

P:\23\27\053\LakeMacrophyteMaps\RedRock\1993AUGUST1993 CDR RLG 06-17-04

* No Macrophytes Found In Water > 5.0' to 6.0'
* Macrophyte Densities Estimated As Follows: 1 = light; 2 = moderate; 3 = heavy

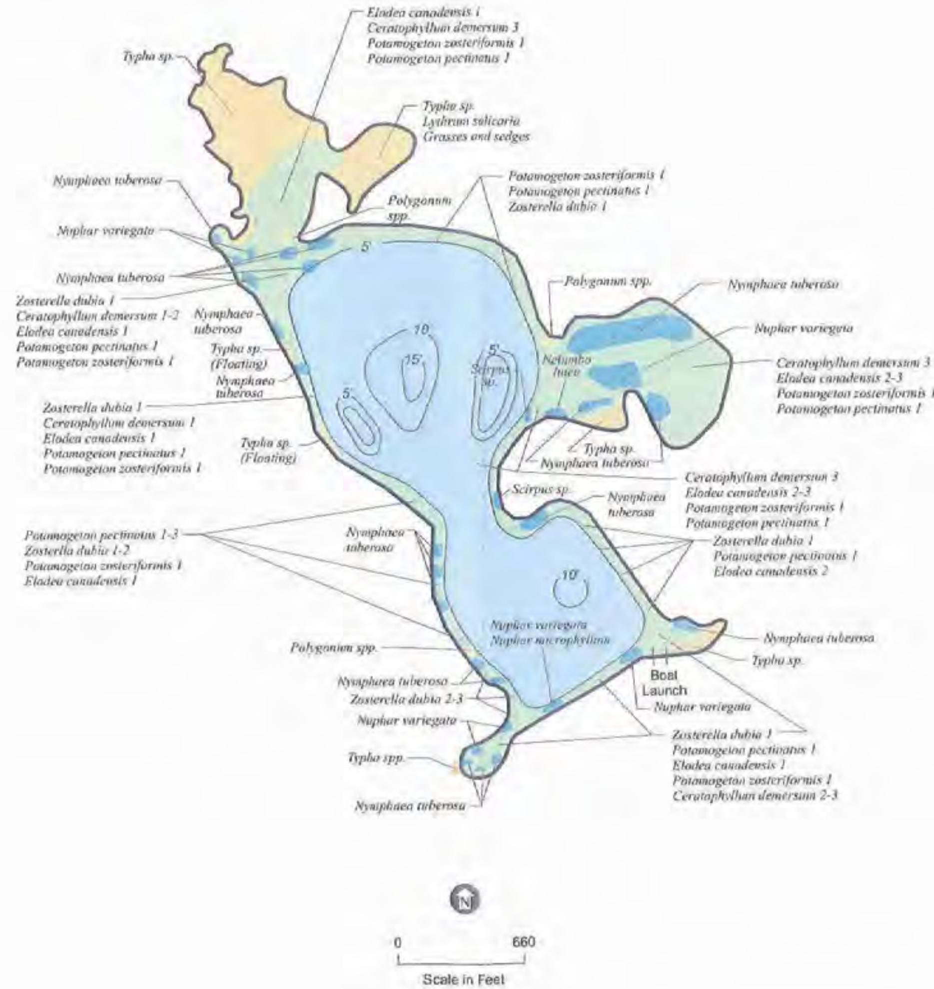
	Common Name	Scientific Name
Submerged Aquatic Plants:	Curlyleaf pondweed	*Potamogeton crispus*
	Flatstem pondweed	*Potamogeton zosteriformis*
	Sago Pondweed	*Potamogeton pectinatus*
	Elodea	*Elodea canadensis*
	Coontail	*Ceratophyllum demersum*
	Water stargrass	*Zosterella dubia*
Floating Leaf Plants:	White waterlily	*Nymphaea tuberosa*
	Yellow waterlily	*Nuphar variegata*
Emergent Plants:	Cattail	*Typha sp.*
	Water smartweed	*Polygonum spp.*
	Bulrush	*Scirpus sp.*
No Aquatic Vegetation Found:		



RED ROCK LAKE
MACROPHYTE SURVEY
JUNE 20, 1996

- No Macrophytes Found in Water >5.0' - 6.0'
- Macrophyte Densities Estimated as Follows: 1 = light; 2 = moderate; 3 = heavy
- Young *Potamogeton crispus* (Curlyleaf pondweed) from nodes observed in shallow areas
- *Lythrum salicaria* (Purple loosestrife) observed along shoreline (sporadic).

	Common Name	Scientific Name
Submerged Aquatic Plants:	Curlyleaf pondweed	*Potamogeton crispus*
	Flatstem pondweed	*Potamogeton zosteriformis*
	Sago Pondweed	*Potamogeton pectinatus*
	Elodea	*Elodea canadensis*
	Coontail	*Ceratophyllum demersum*
	Water stargrass	*Zosterella dubia*
Floating Leaf Plants:	White waterlily	*Nymphaea tuberosa*
	Yellow waterlily	*Nuphar variegata*
	Yellow lotus	*Nelumbo lutea*
Emergent Plants:	Cattail	*Typha sp.*
	Water smartweed	*Polygonum spp.*
	Bulrush	*Scirpus sp.*
	Purple loosestrife	*Lythrum salicaria*
No Aquatic Vegetation Found:		



RED ROCK LAKE
MACROPHYTE SURVEY
AUGUST 21, 1996

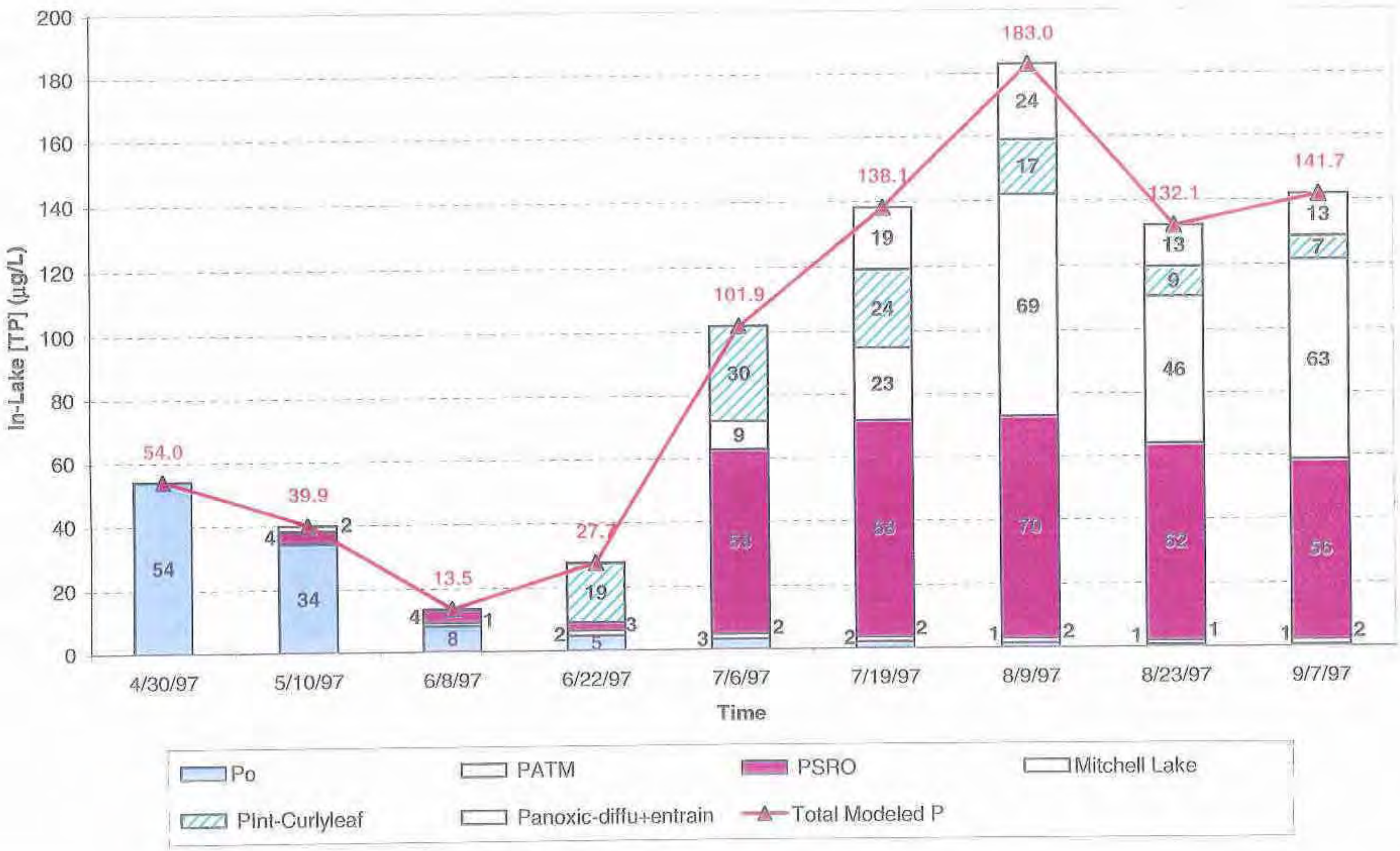
Appendix F

In-Lake Modeling Results

Appendix F-1

Wet Climatic Condition (1997)

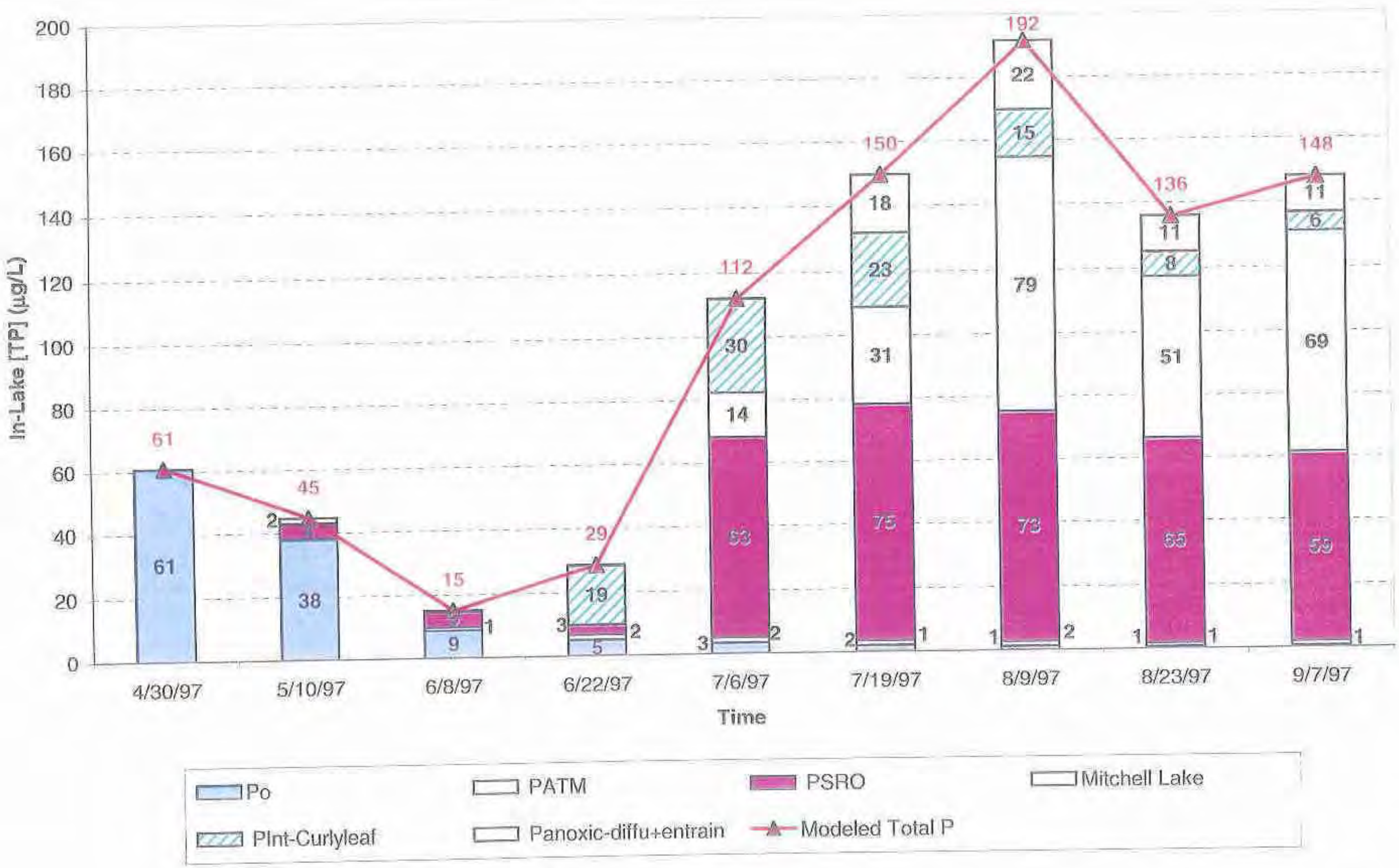
Red Rock Lake No Treatment - Existing Wet Year (1997)



P:\23\27\053\LAKE\UAA\RROCKUAA\In Lake\Red Rock Partition Model Variations\SASPartIn-LakeMol_RedRock_wetyr 1.45 TP SC FAC Ex No Treat: CalibrationBarChart

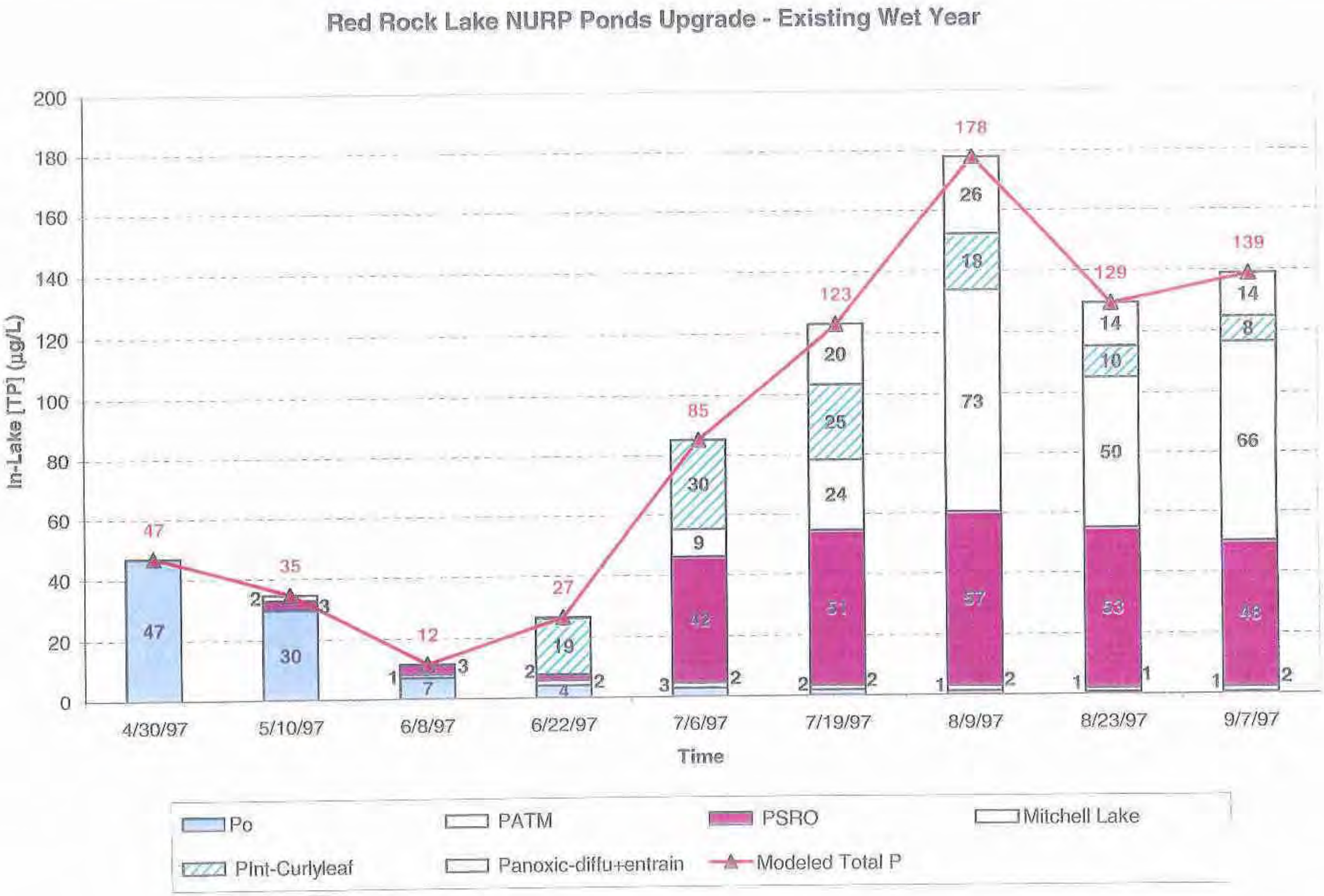
4/19/2006
11:00 AM

Red Rock Lake No Treatment - Future Wet Year



4/19/2006
11:03 AM

P:\23\27\053\LAKE\UAA\RROCKUAA\In Lake\Red Rock Partition Model Variations\SASPartIn-LakeMol_RedRock_wetyr 1.45 TP SC FAC Fut No Treat: CalibrationBarChart



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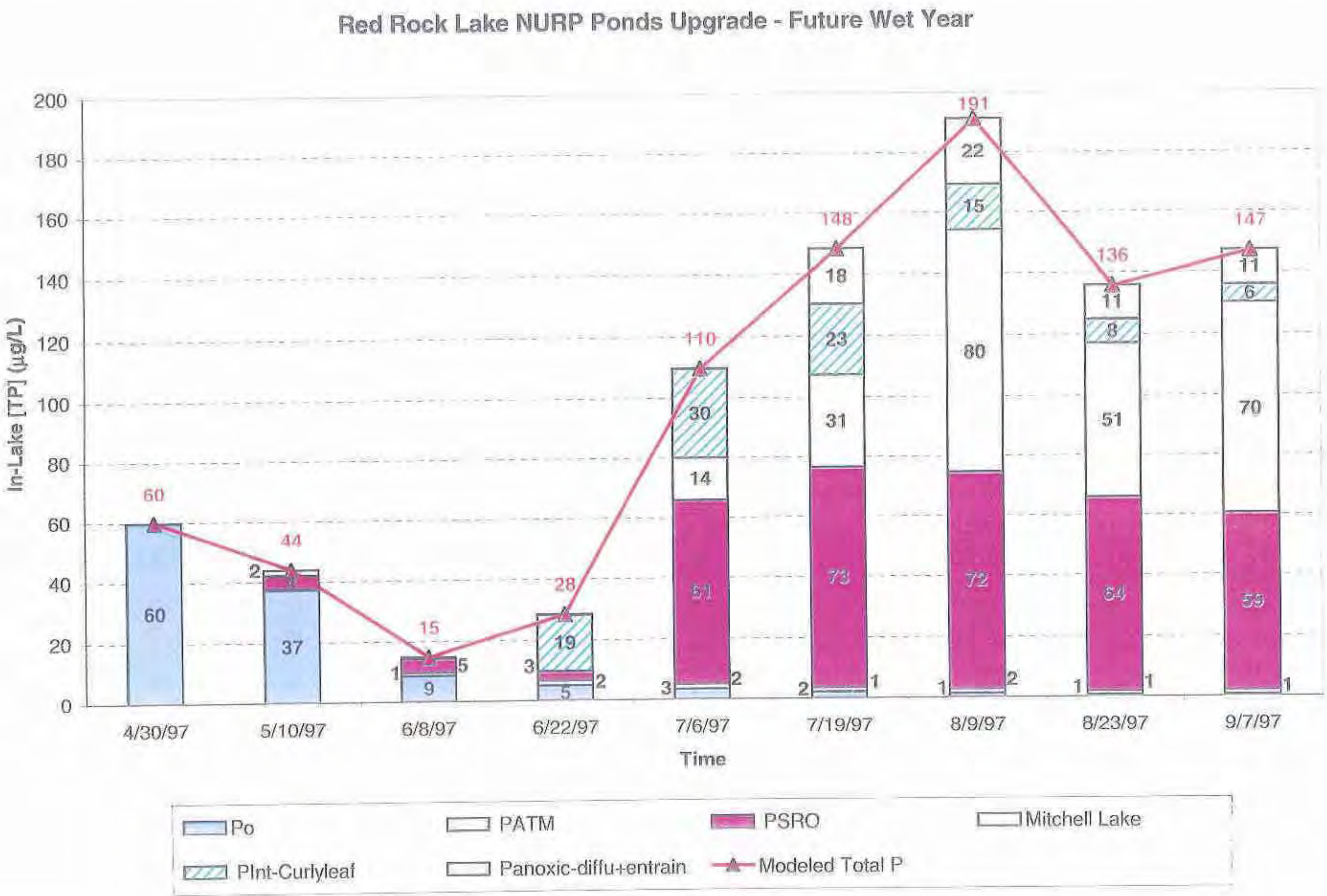
4/19/2006
11:06 AM



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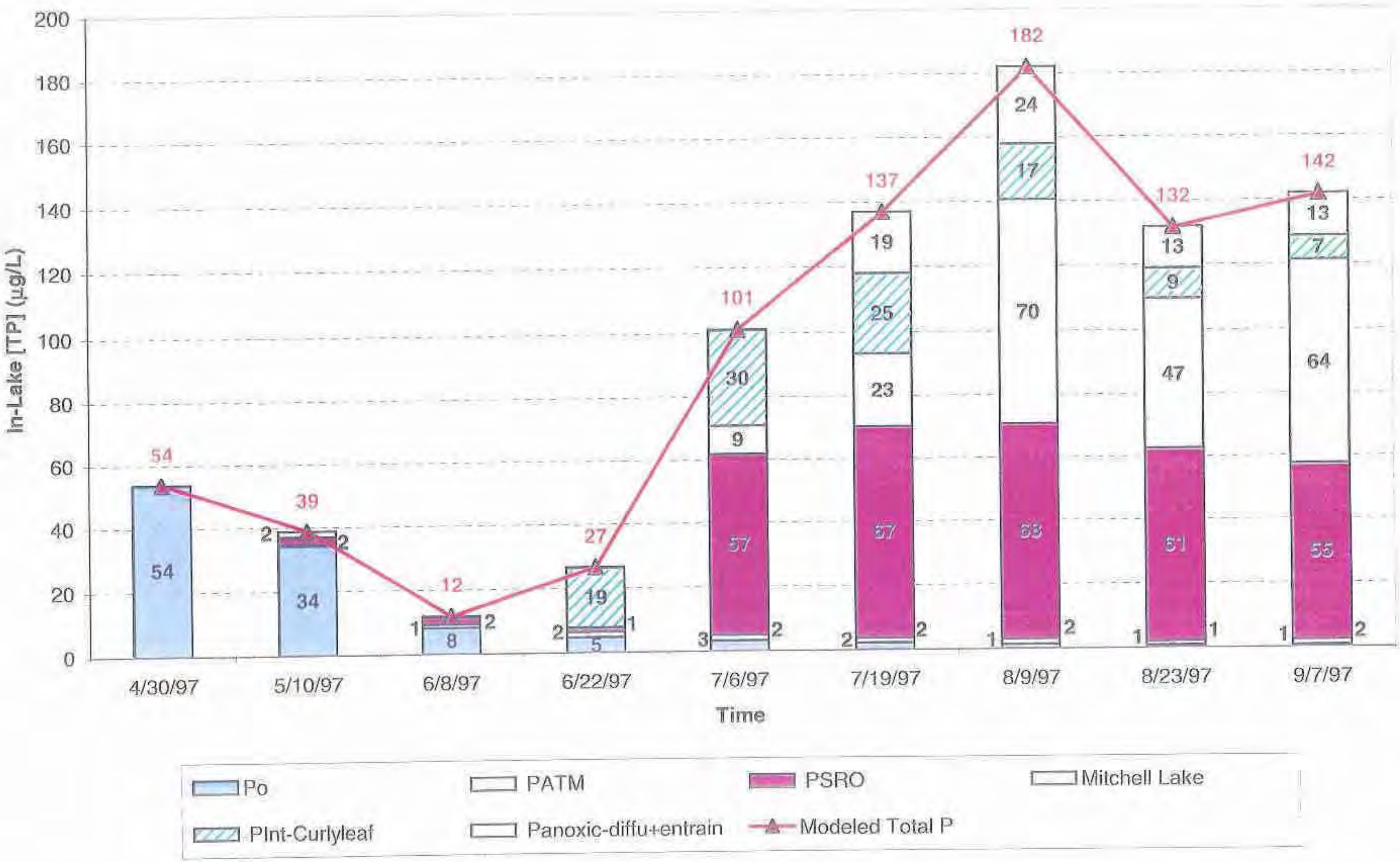
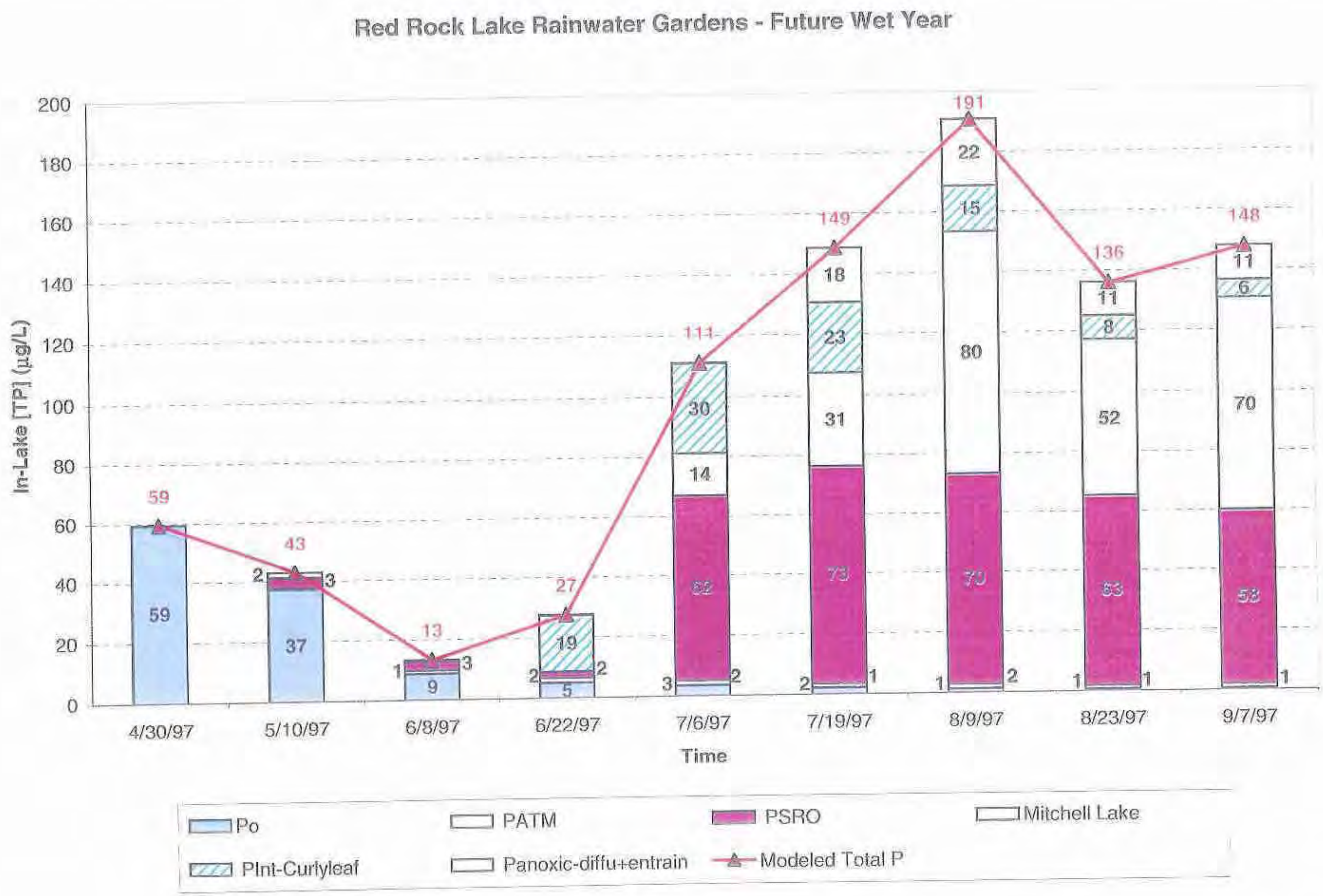
4/19/2006
11:02 AM

Red Rock Lake Rainwater Gardens - Existing Wet Year



P:\23\27\053\LAKE\UAA\RROCKUAA\In Lake\Red Rock Partition Model Variations\SASPartIn-LakeMol_RedRock_wetyr 1.45 TP SC FAC Ex RWG: CalibrationBarChart

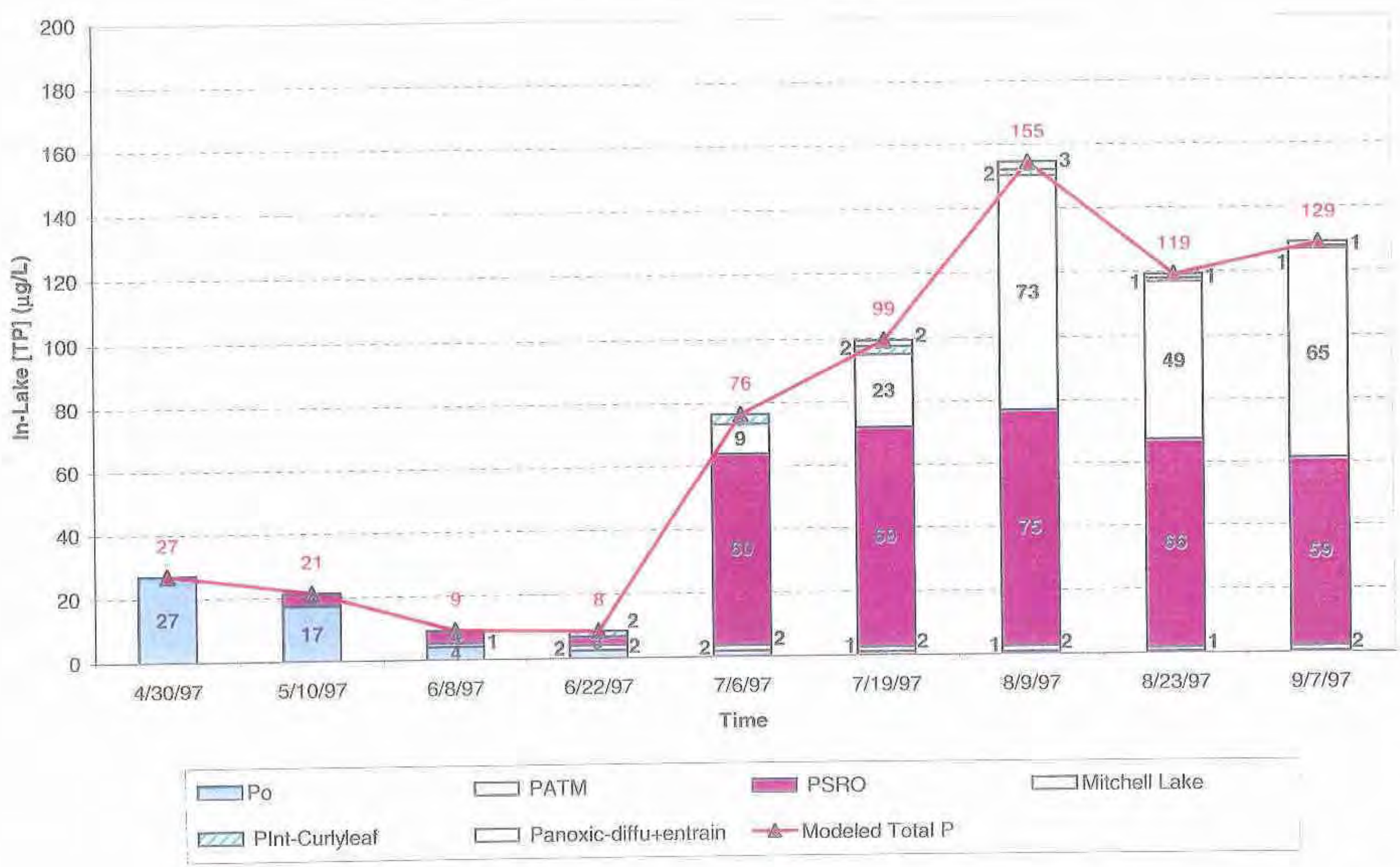
4/19/2006
11:04 AM



P:\23\27\053\LAKE\UAA\RROCKUAA\In Lake\Red Rock Partition Model Variations\SASPartIn-LakeMol_RedRock_welyr 1.45 TP SC FAC Fut RWG: CalibrationBarChart

4/19/2006
11:07 AM

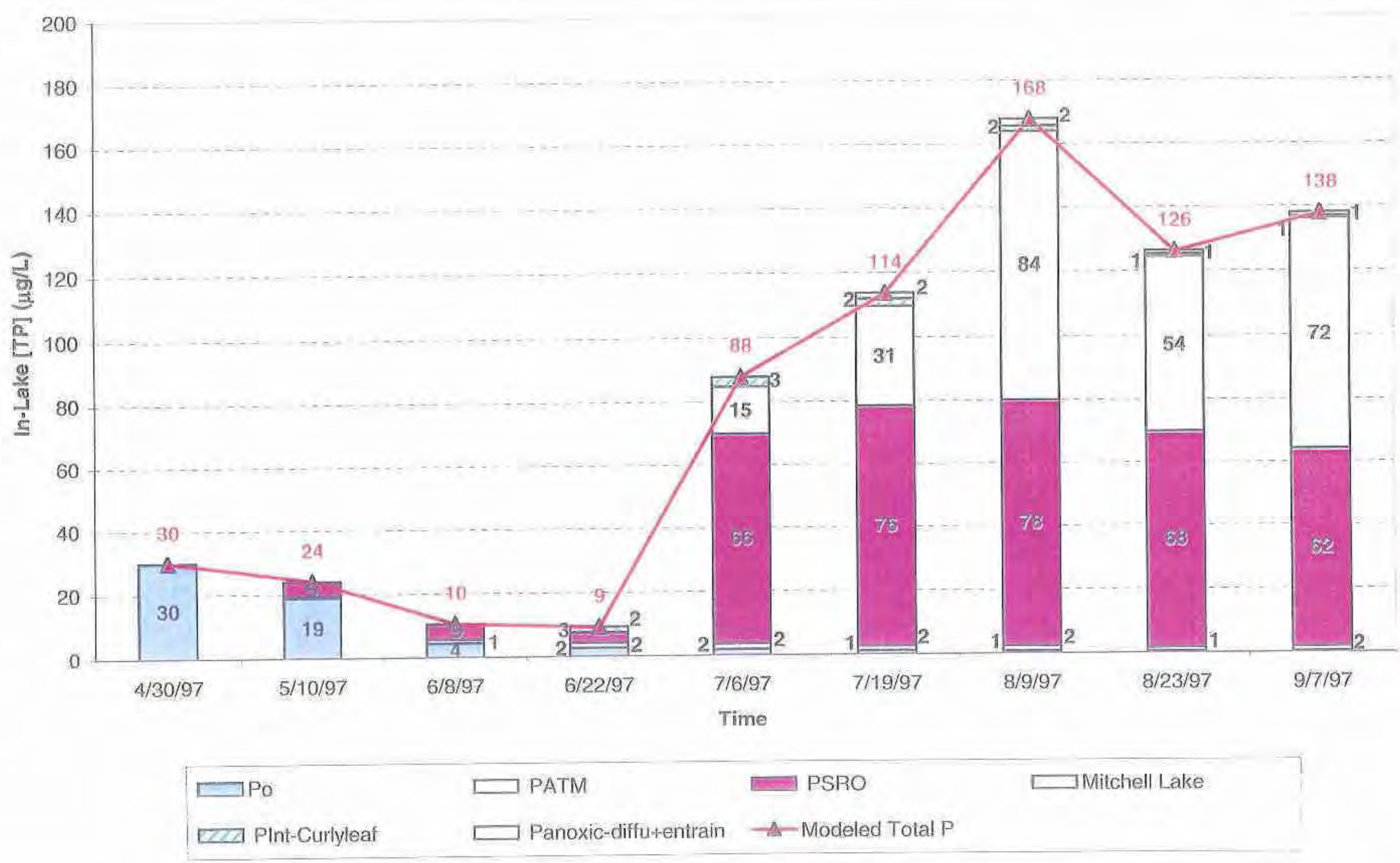
Red Rock Lake Alum Treatment - Existing Wet Year



P:\23\27\053\LAKE\UAA\RROCKUAA\In Lake\Red Rock Partition Model Variations\SASPartIn-LakeMol_RedRock_wetyr 1.45 TP SC FAC Ex Red Rock alum: CalibrationBarChart

4/19/2006
11:05 AM

Red Rock Lake Alum Treatment - Future Wet Year



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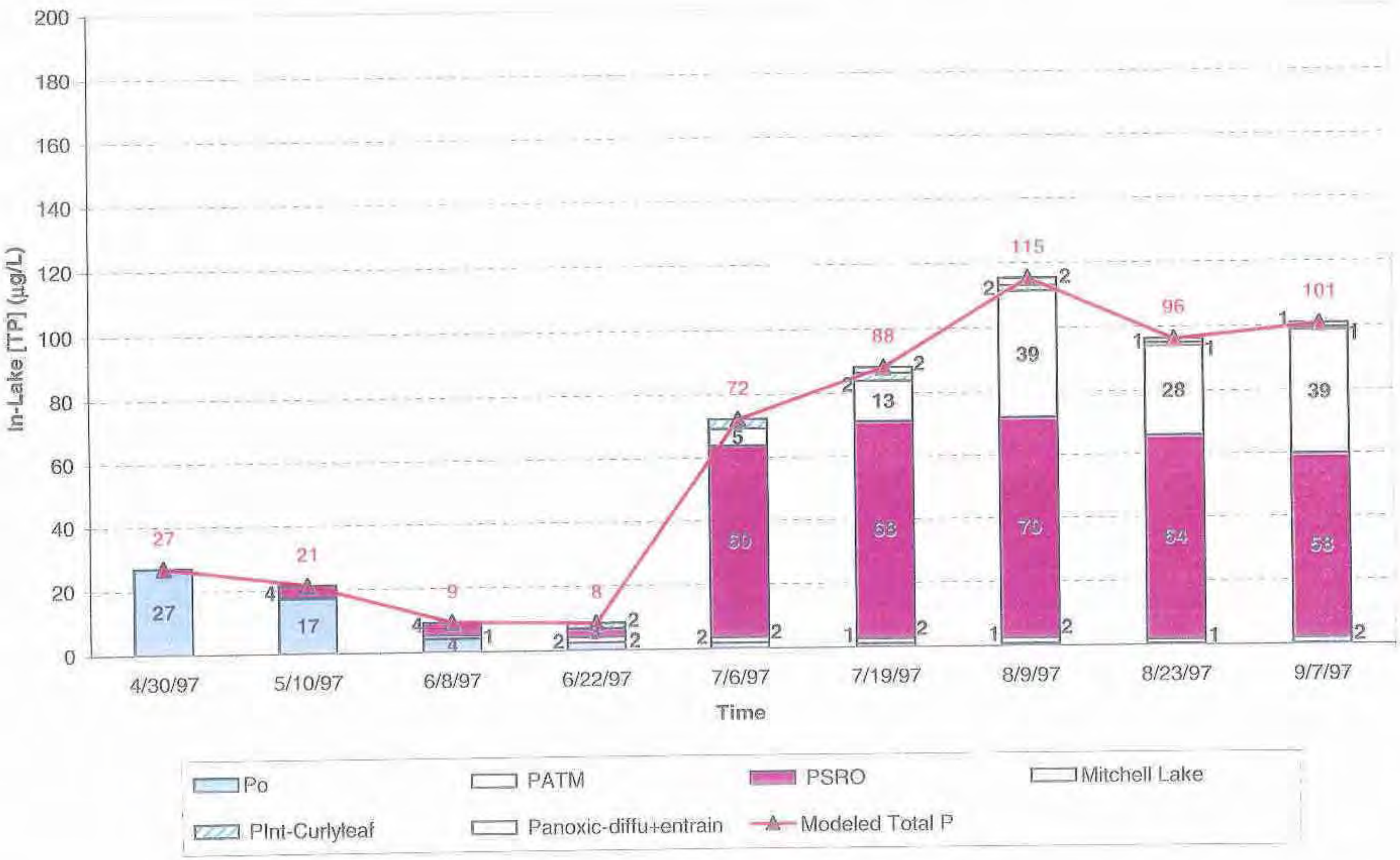
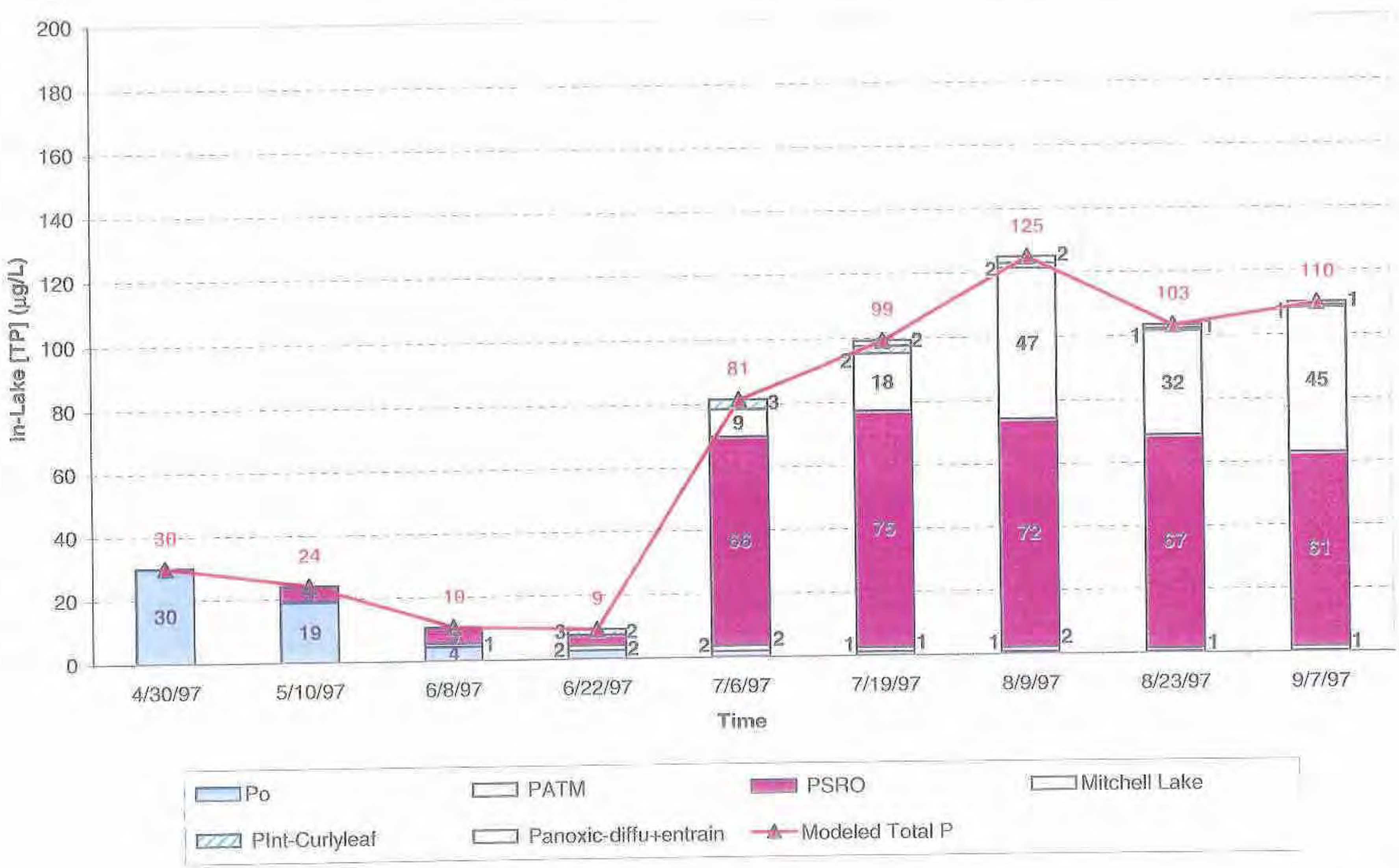
4/19/2006
11:01 AM

Red Rock Lake and Mitchell Lake Alum Treatment - Existing Wet Year



P:\23\27\053\LAKE\UAA\RROCKUAA\In Lake\Red Rock Partition Model Variations\SASPartIn-LakeMol RedRock_wetyr 1.45 TP SC FAC Ex RR and Mit alum: CalibrationBarChart 4/19/2006 11:05 AM

Red Rock Lake and Mitchell Lake Alum Treatment - Future Wet Year



4/19/2006
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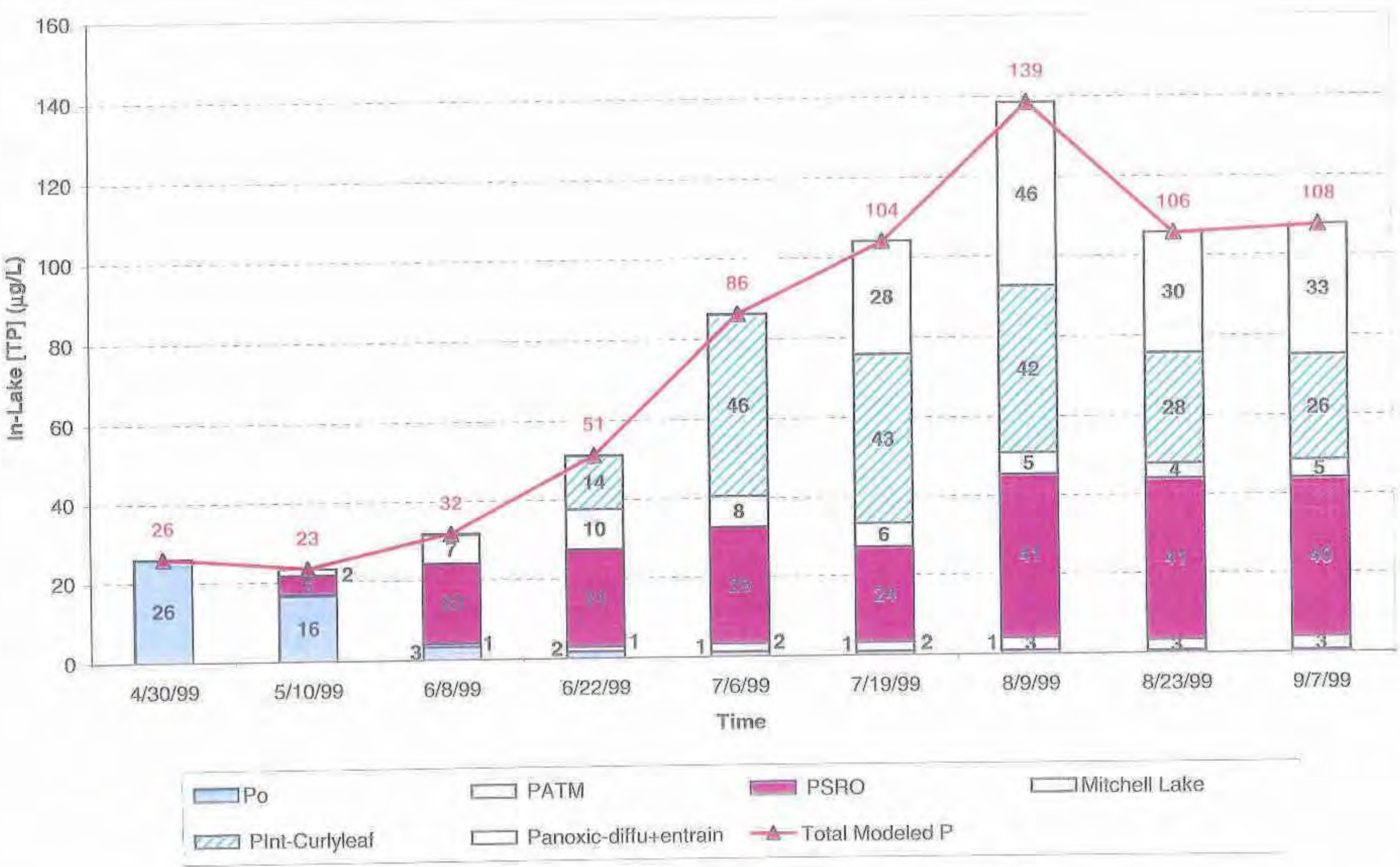
Appendix F-2

Average Climatic Condition (1999)

Red Rock Lake No Treatment - Existing Average Year (1999)



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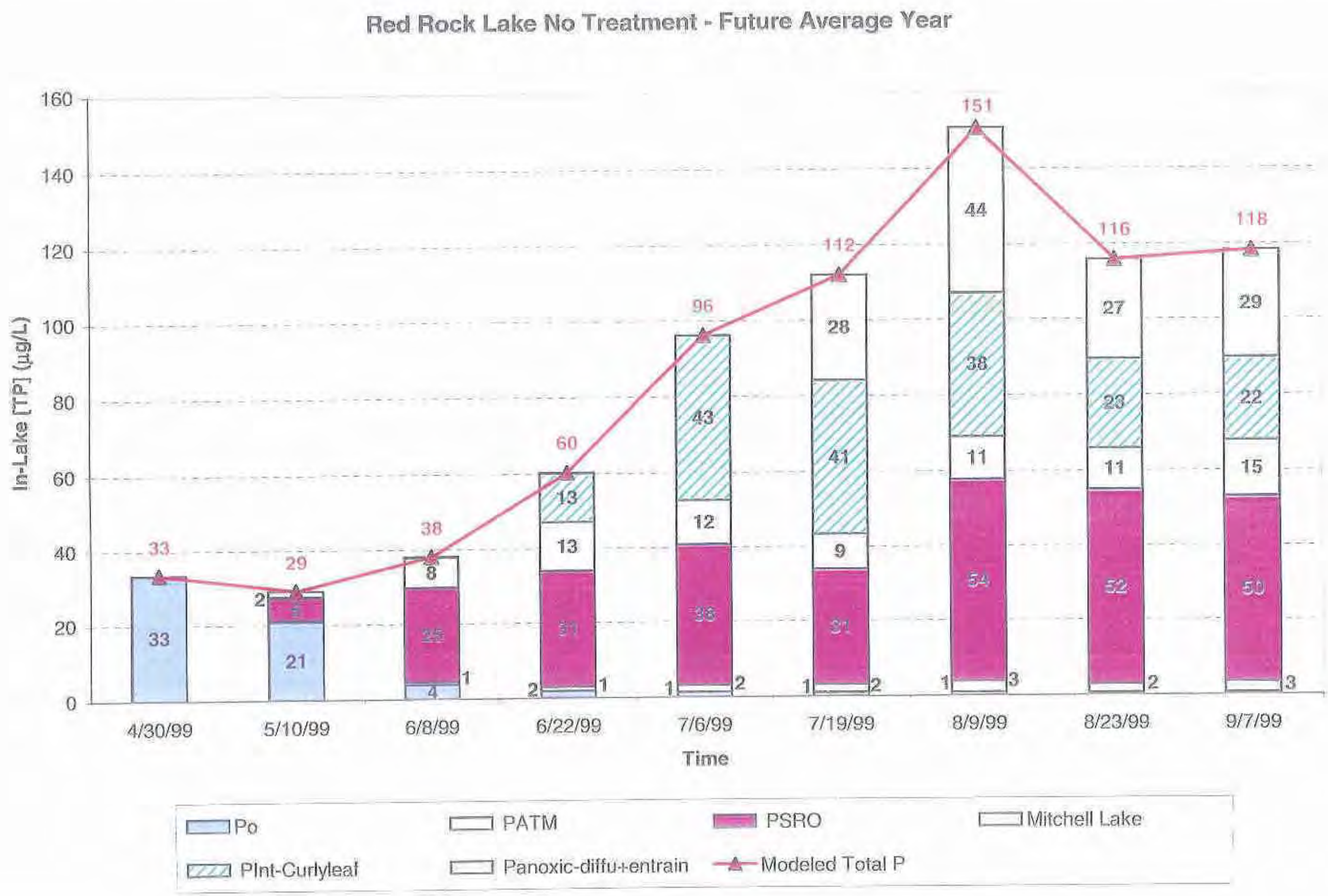
4/19/2006
10:05 AM



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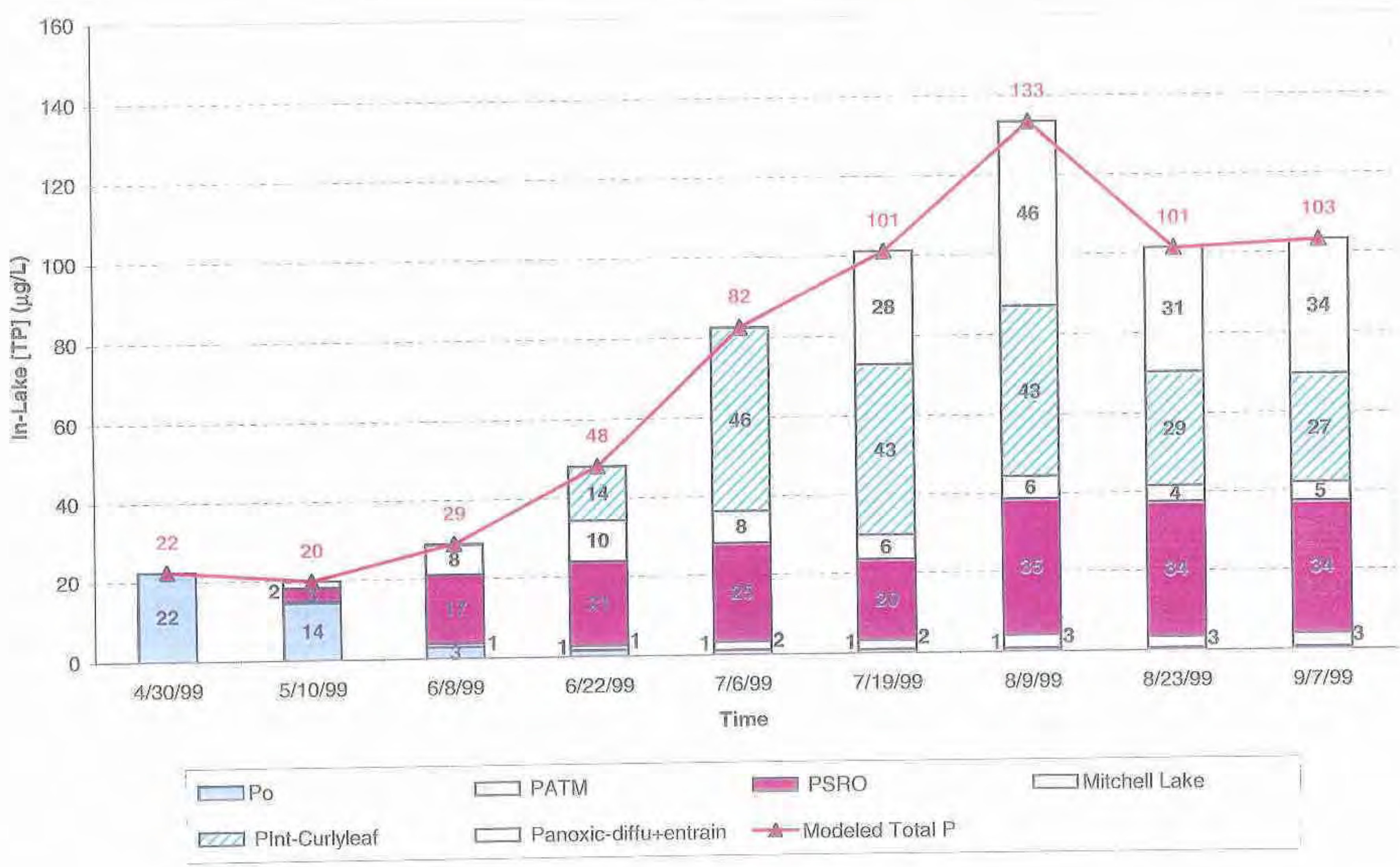
4/19/2006
10:11 AM

Red Rock Lake NURP Ponds Upgrade - Existing Average Year



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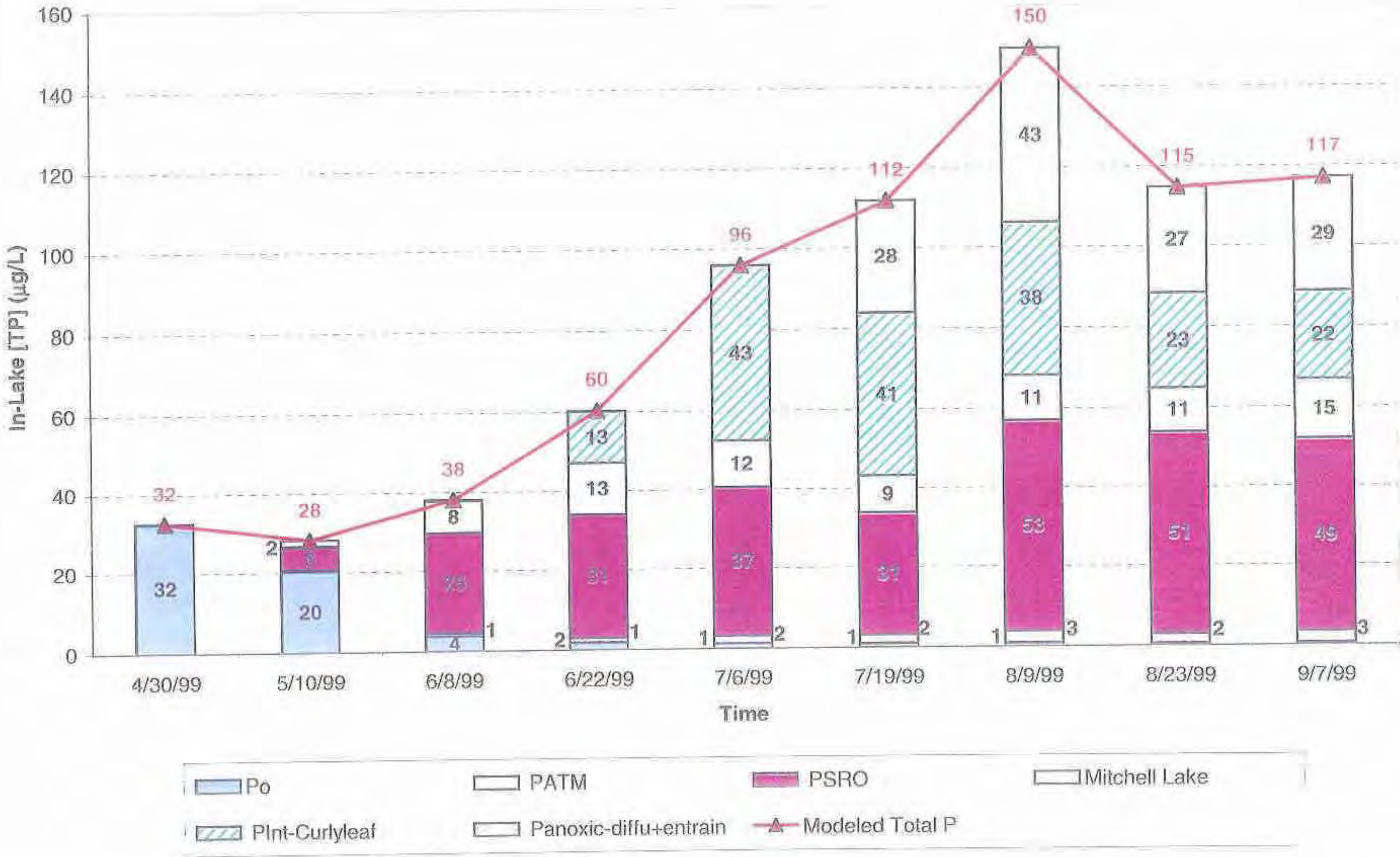
4/19/2006
10:29 AM

Red Rock Lake NURP Ponds Upgrade - Future Average Year



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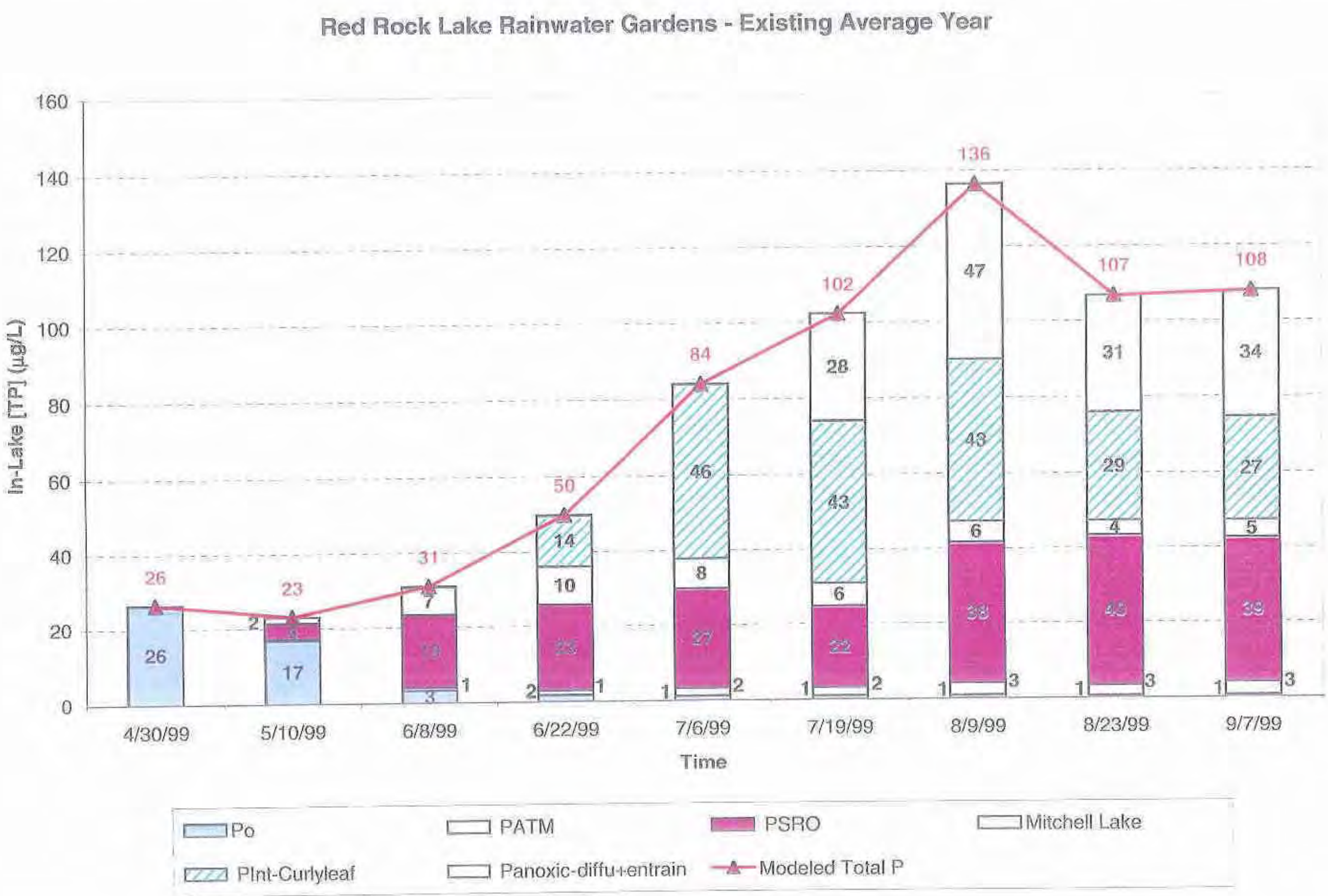
4/19/2006
10:09 AM



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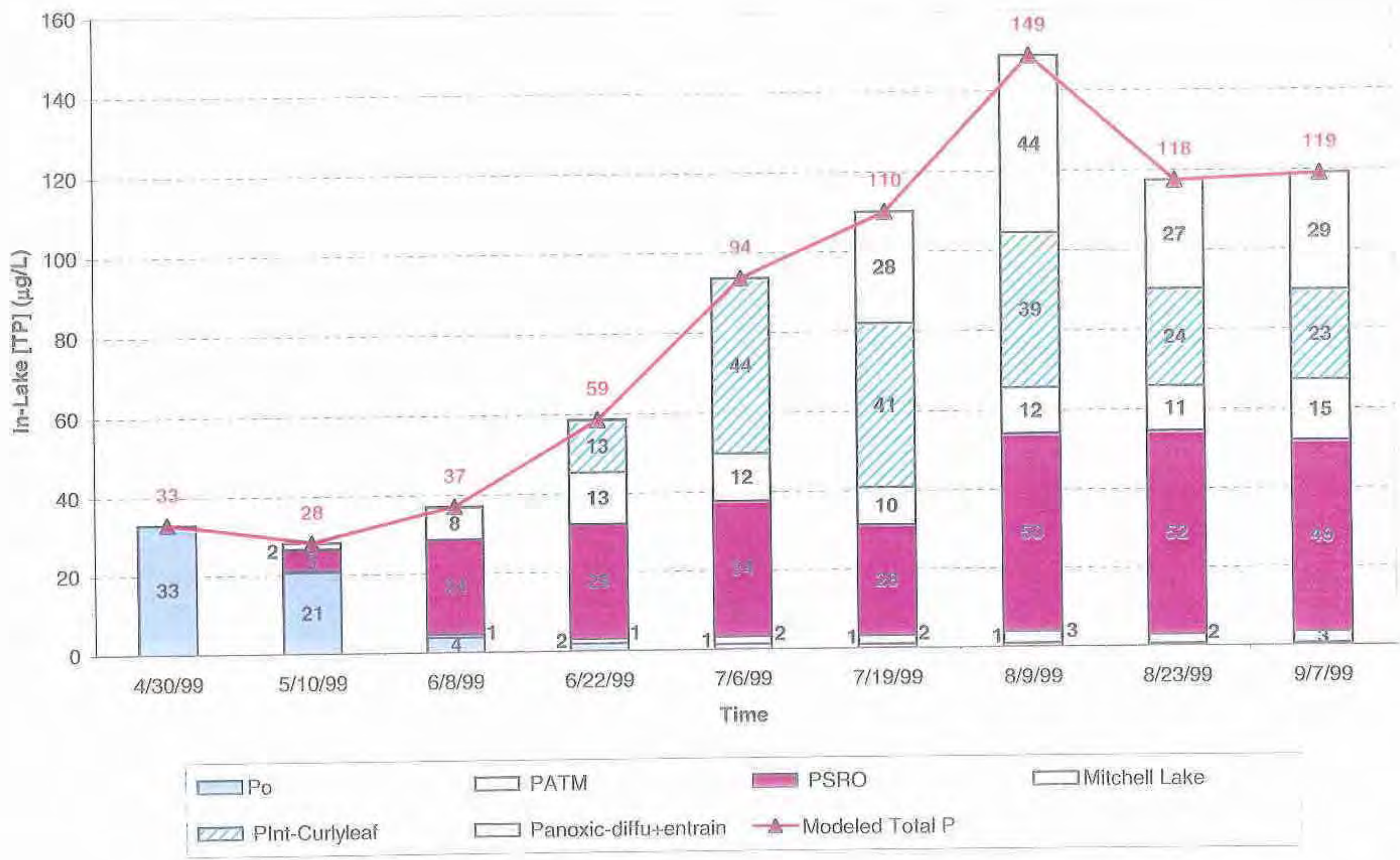
4/19/2006
10:12 AM

Red Rock Lake Rainwater Gardens - Future Average Year



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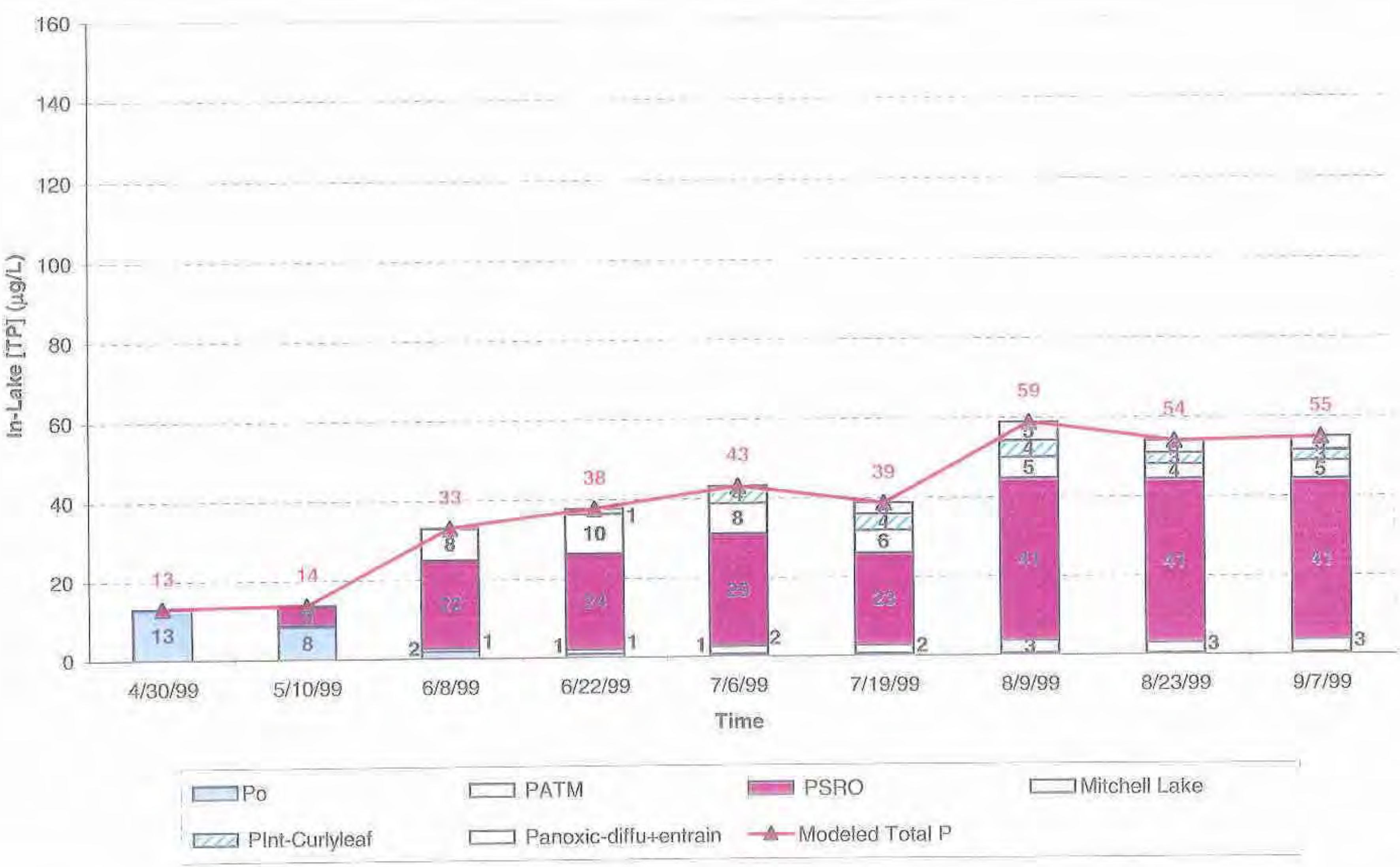
4/19/2006
10:30 AM

Red Rock Lake Alum Treatment - Existing Average Year

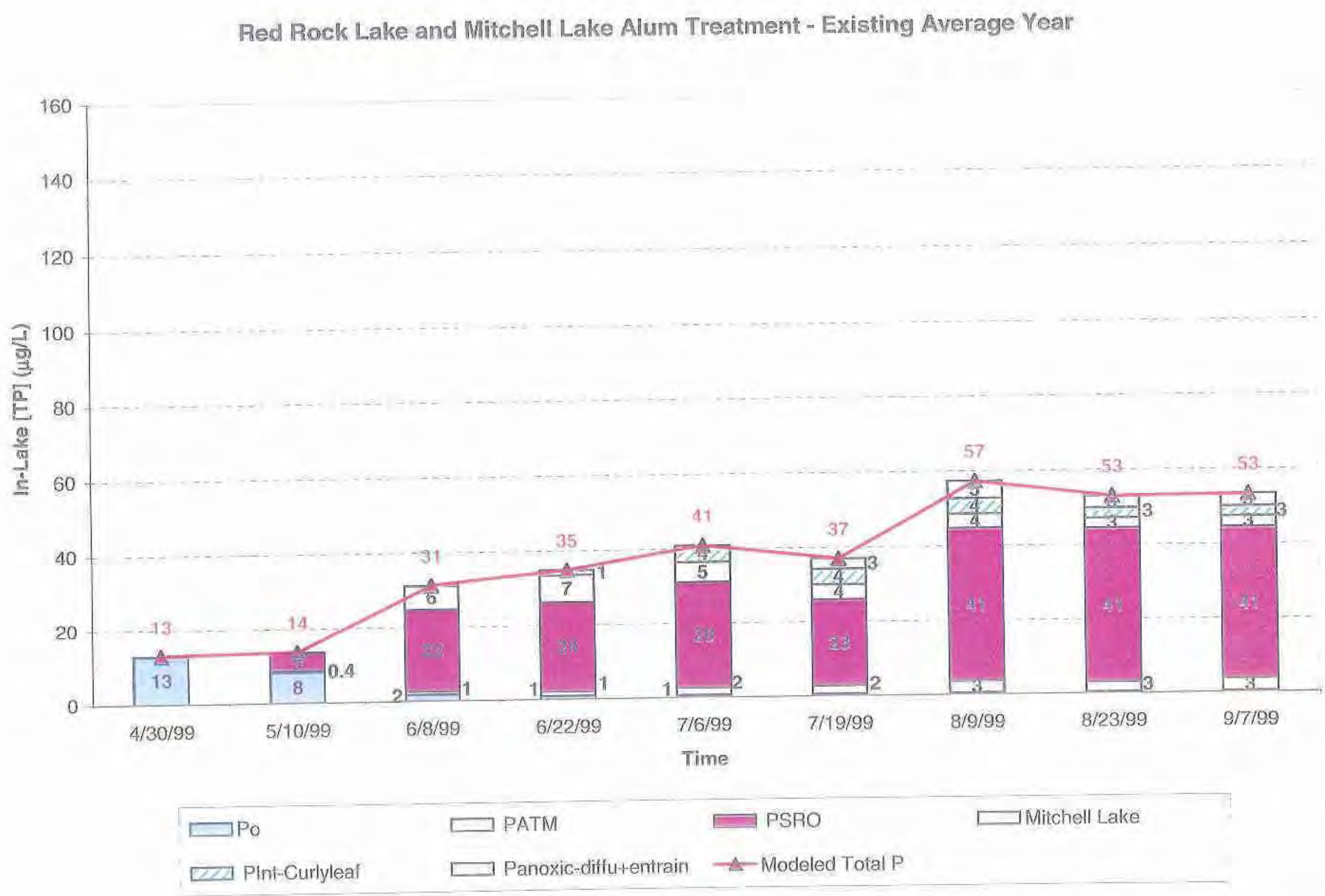


4/19/2006
10:28 AM

P:\23\27\053\LAKE\UAA\RROCKUAA\In Lake\Red Rock Partition Model Variations\SASPartIn-LakeMol_RedRock_avgyr 1.45 TP SC FAC Ex Red Rock alum: CalibrationBarChart

Red Rock Lake Alum Treatment - Future Average Year

4/19/2006
P:\23\27\053\LAKE\UAA\RROCKUAA\In Lake\Red Rock Partition Model Variations\SASPartIn-LakeMol_RedRock_avgyr 1.45 TP SC FAC Fut Red Rock alum: CalibrationBarChart 10:08 AM



4/19/2006
P:\23\27\053\LAKE\UAA\RROCKUAA\In Lake\Red Rock Partition Model Variations\SASPartIn-LakeMol_RedRock_avgyr 1.45 TP SC FAC Ex RR and Mit alum: CalibrationBarChart 10:27 AM

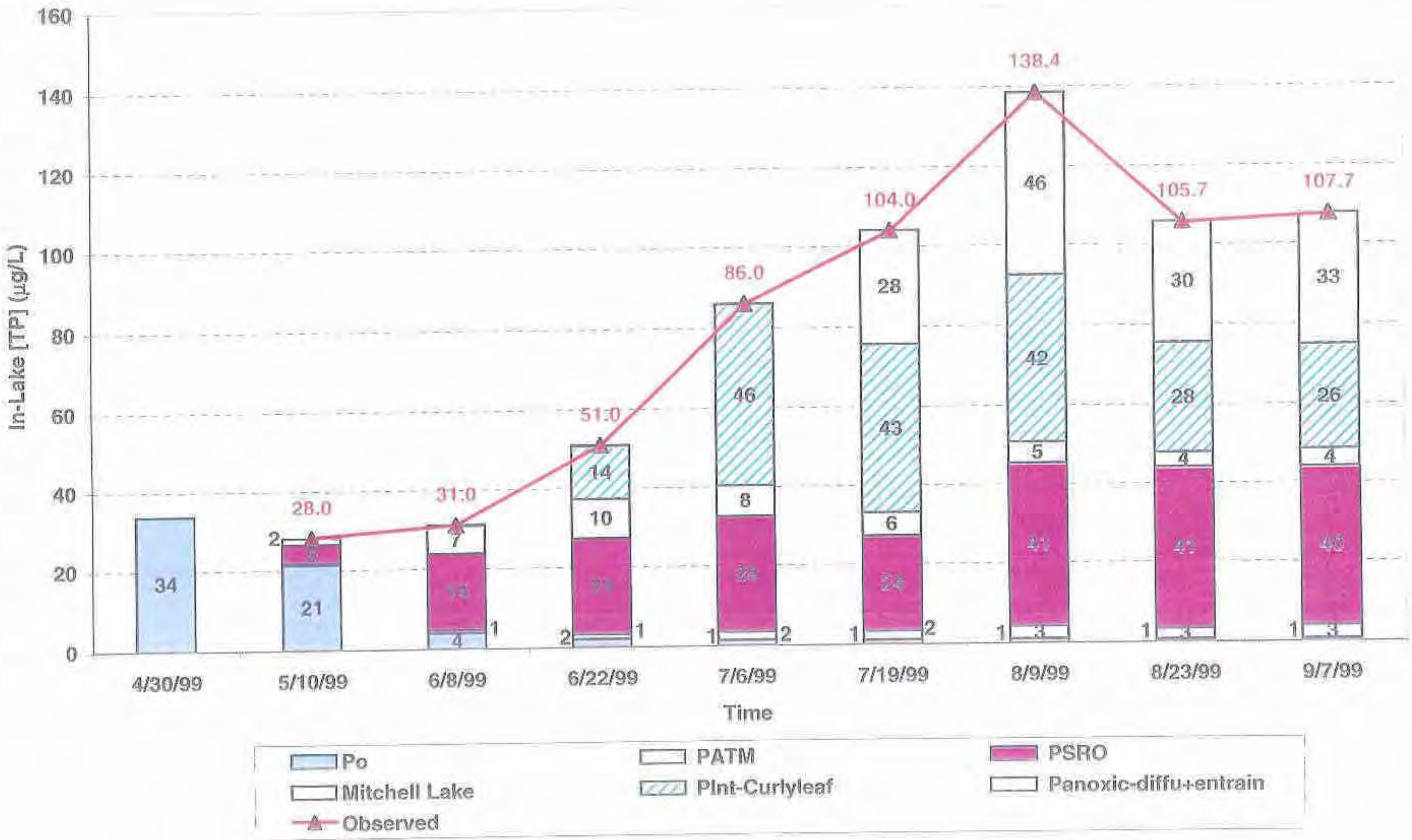
Red Rock Lake and Mitchell Lake Alum Treatment - Future Average Year

P:\23\27\053\LAKE\UAA\RROCKUAA\In Lake\Red Rock Partition Model Variations\SASPartIn-LakeMol_RedRock_avgyr 1.45 TP SC FAC Fut RR and Mit alum: CalibrationBarChart 4/19/2006 10:06 AM

Appendix F-2

Calibration Year Climatic Condition (1999)

Red Rock Lake No treatment - Existing Calibration Year (1999)



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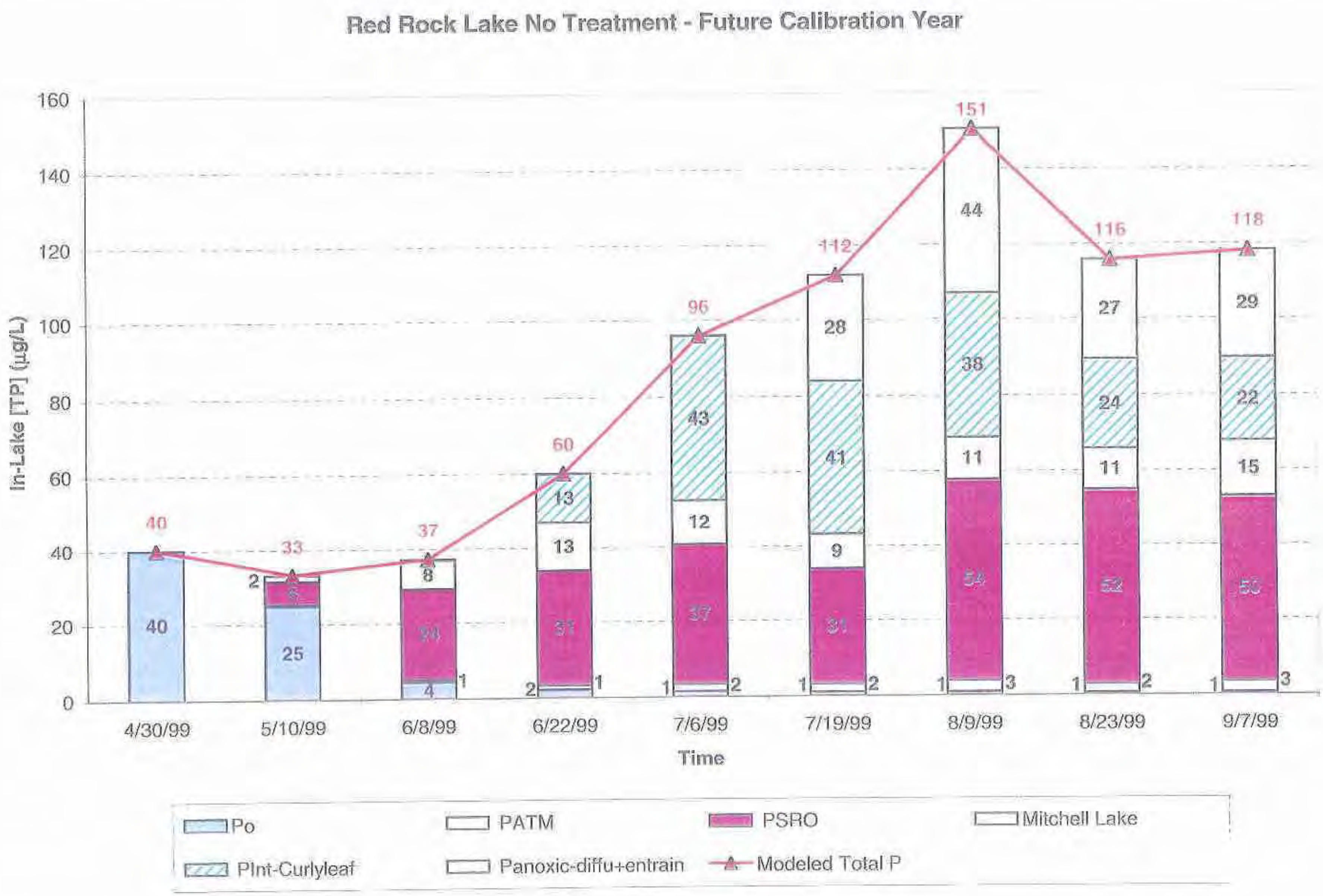
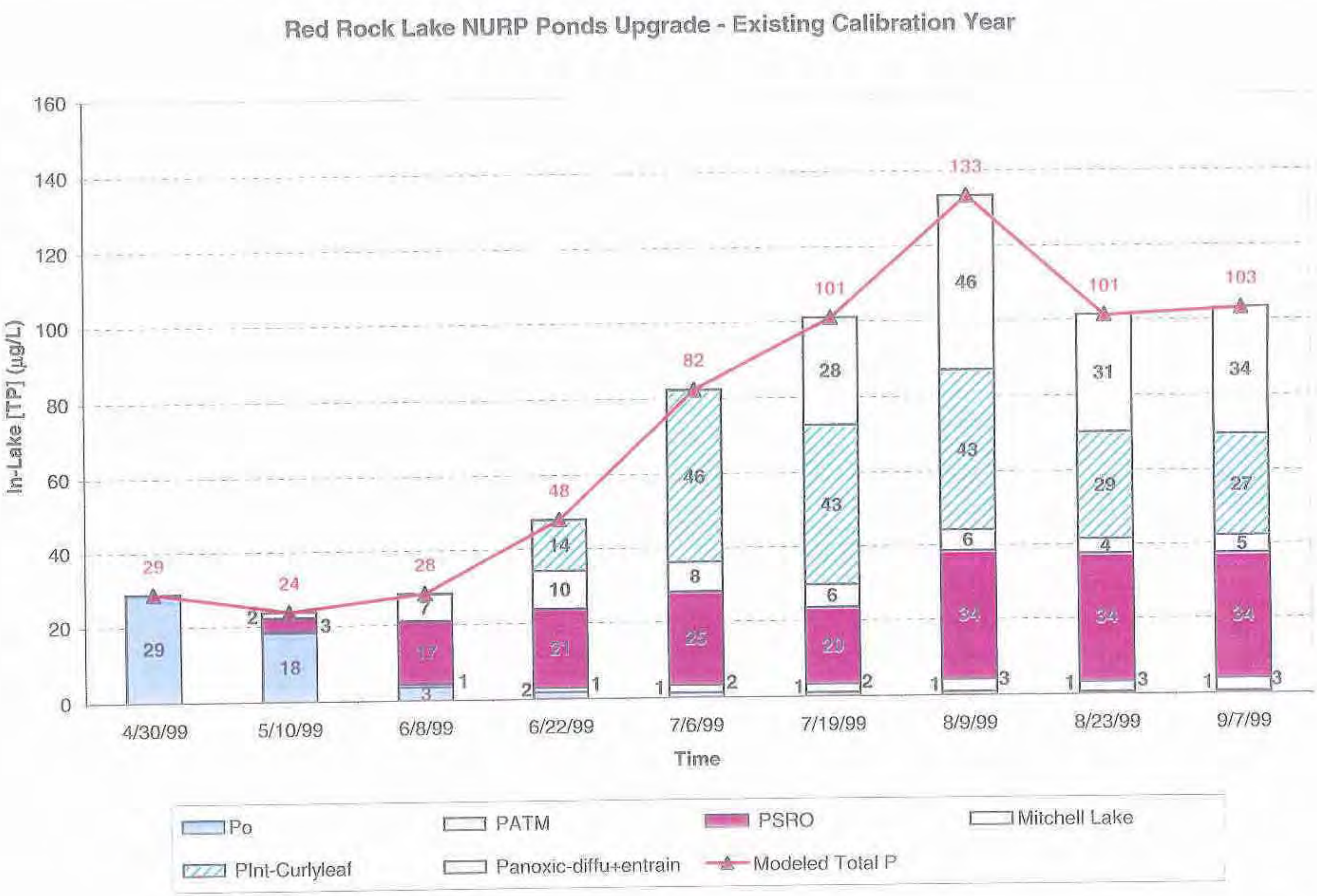
4/19/2006
10:37 AM



P:\23\27\053\LAKE\UAA\RROCKUAA\In Lake\Red Rock Partition Model Variations\SASPartIn-LakeMol_RedRock_caliyr 1.45 TP SC FAC Fut No Treat: CalibrationBarChart

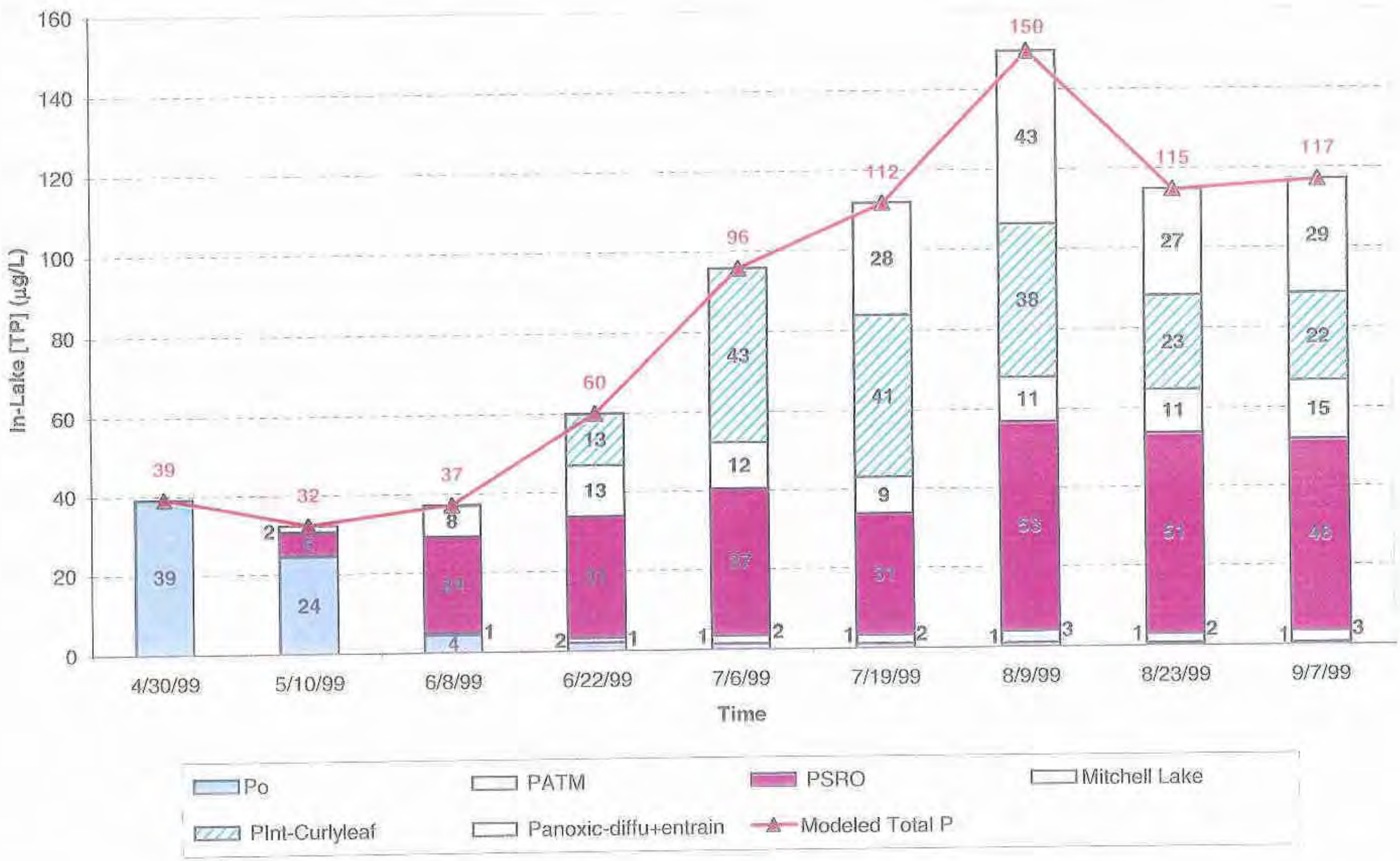
4/19/2006
10:41 AM



P:\23\27\053\LAKE\UAA\RROCKUAA\In Lake\Red Rock Partition Model Variations\SASPartIn-LakeMol_RedRock_caliyr 1.45 TP SC FAC Ex NURP: CalibrationBarChart

4/19/2006
10:45 AM

Red Rock Lake NURP Ponds Upgrade - Future Calibration Year



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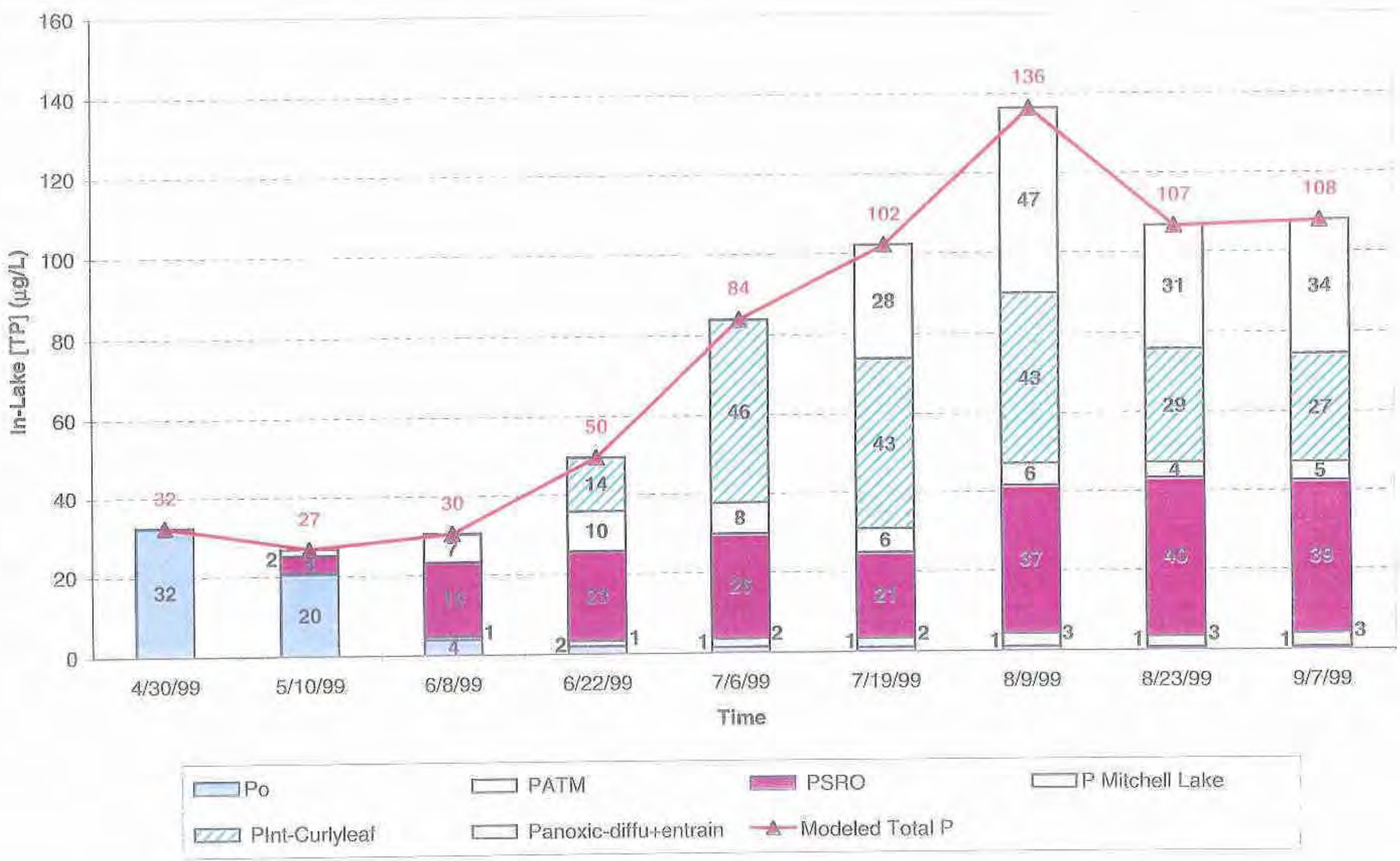
4/19/2006
10:39 AM

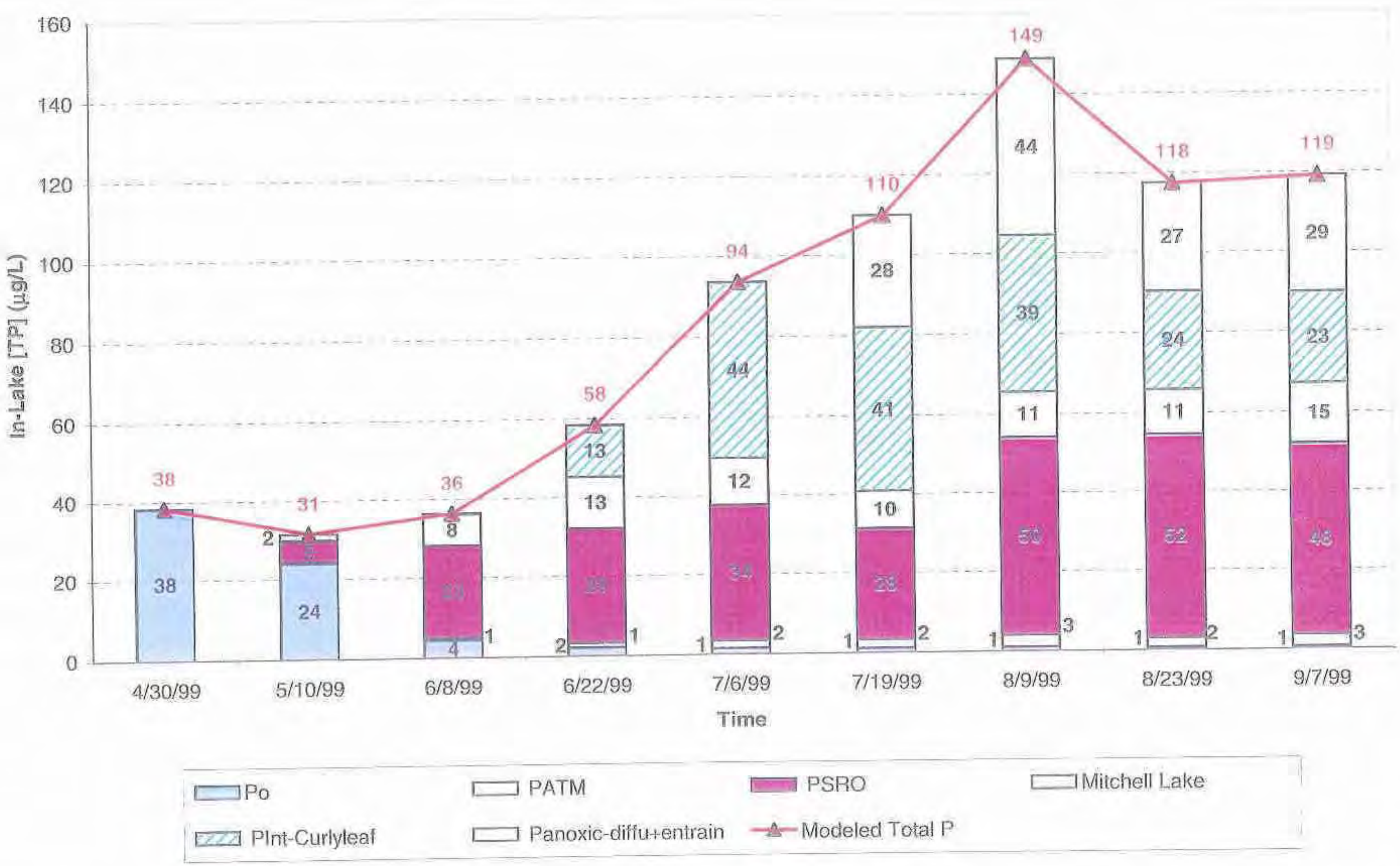
Red Rock Lake Rainwater Gardens - Existing Calibration Year



P:\23\27\053\LAKE\UAA\RROCKUAA\In Lake\Red Rock Partition Model Variations\SASPartIn-LakeMol_RedRock_caliyr 1.45 TP SC FAC Ex RWG: CalibrationBarChart

4/19/2006
10:42 AM

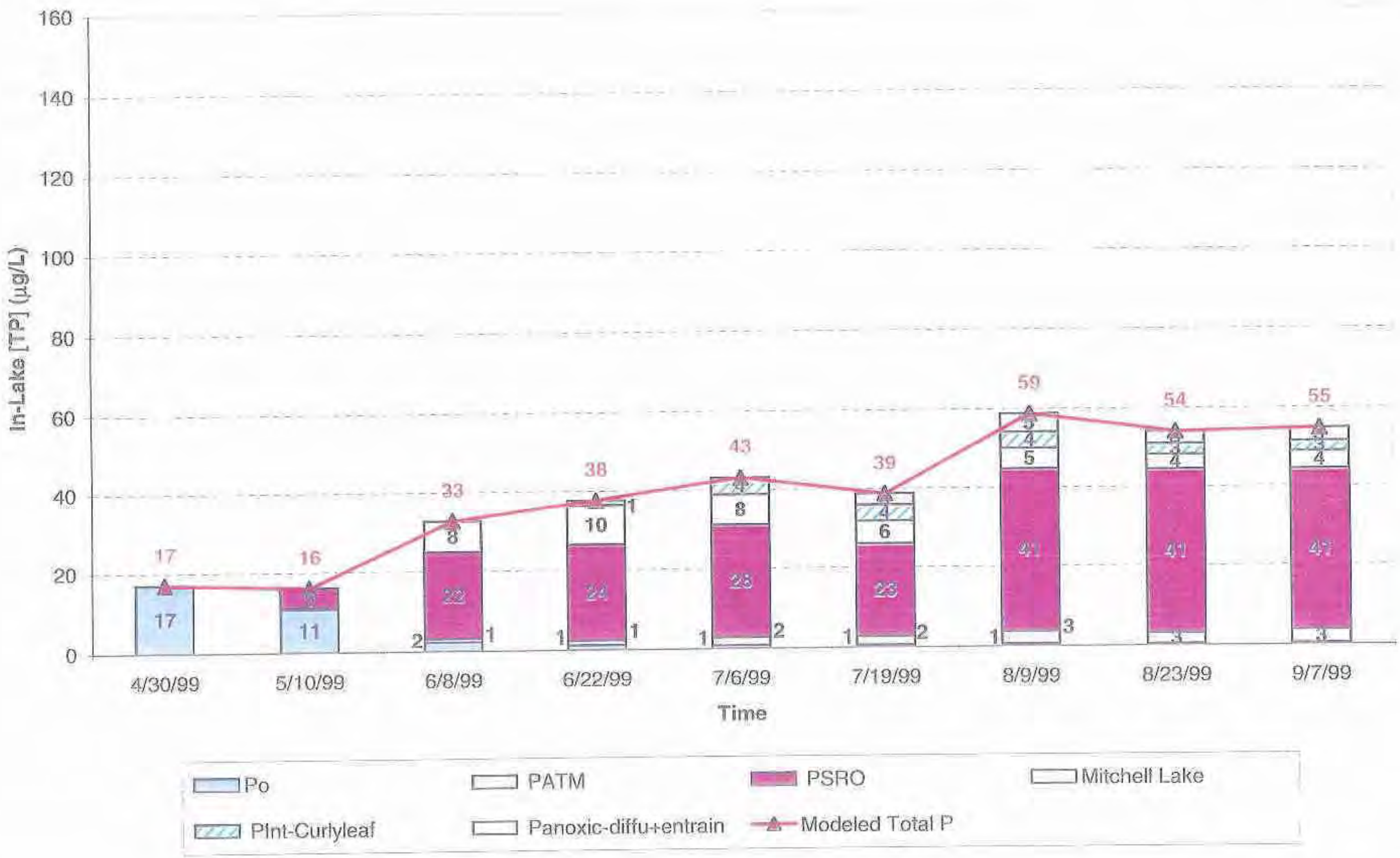
Red Rock Lake Rainwater Gardens - Future Calibration Year



P:\23\27\053\LAKE\UAA\RROCKUAA\In Lake\Red Rock Partition Model Variations\SASPartIn-LakeMol_RedRock_caliyr 1.45 TP SC FAC Fut RWG: CalibrationBarChart

4/19/2006
10:46 AM

Red Rock Lake Alum Treatment - Existing Calibration Year



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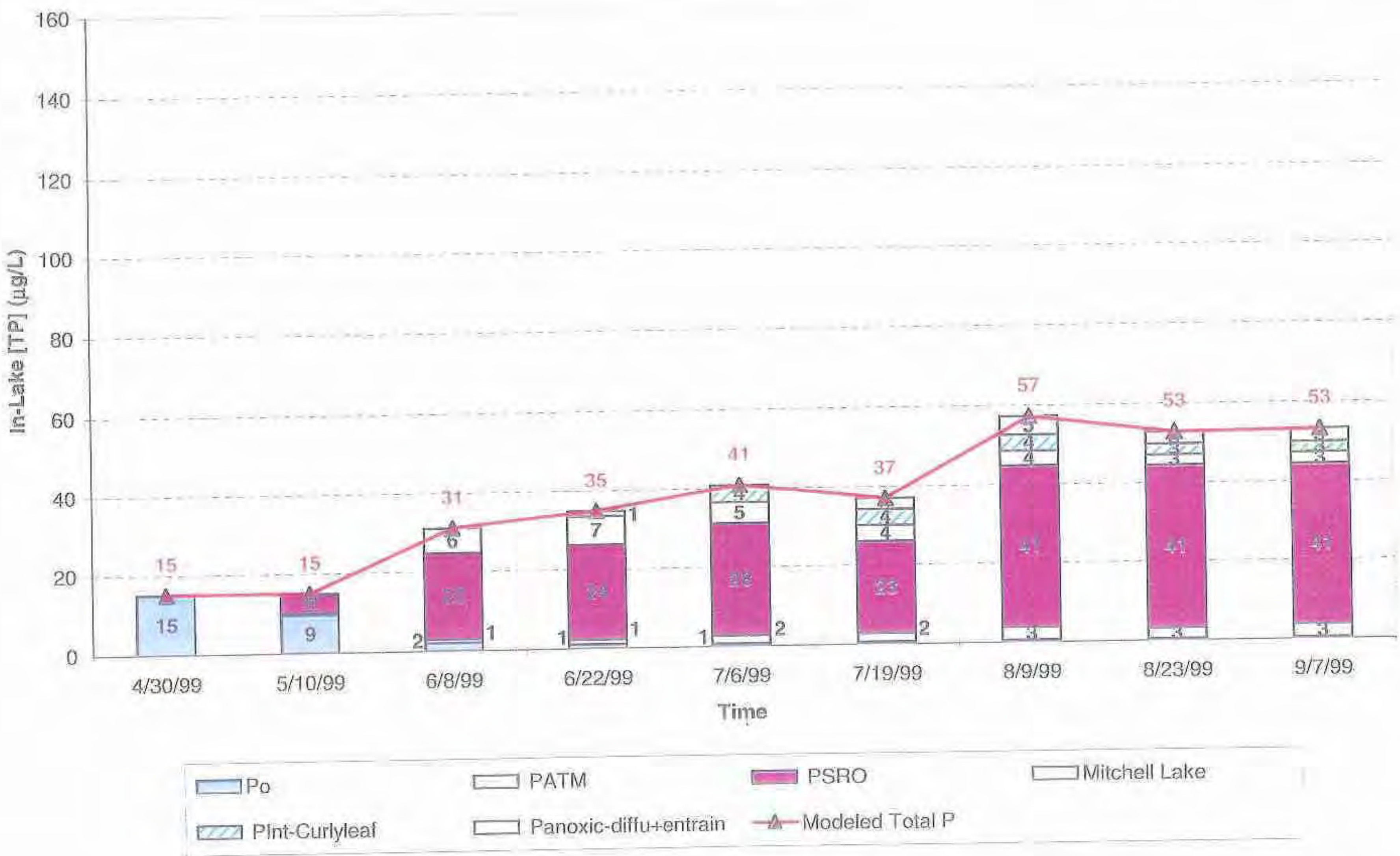
Red Rock Lake Alum Treatment - Future Calibration Year

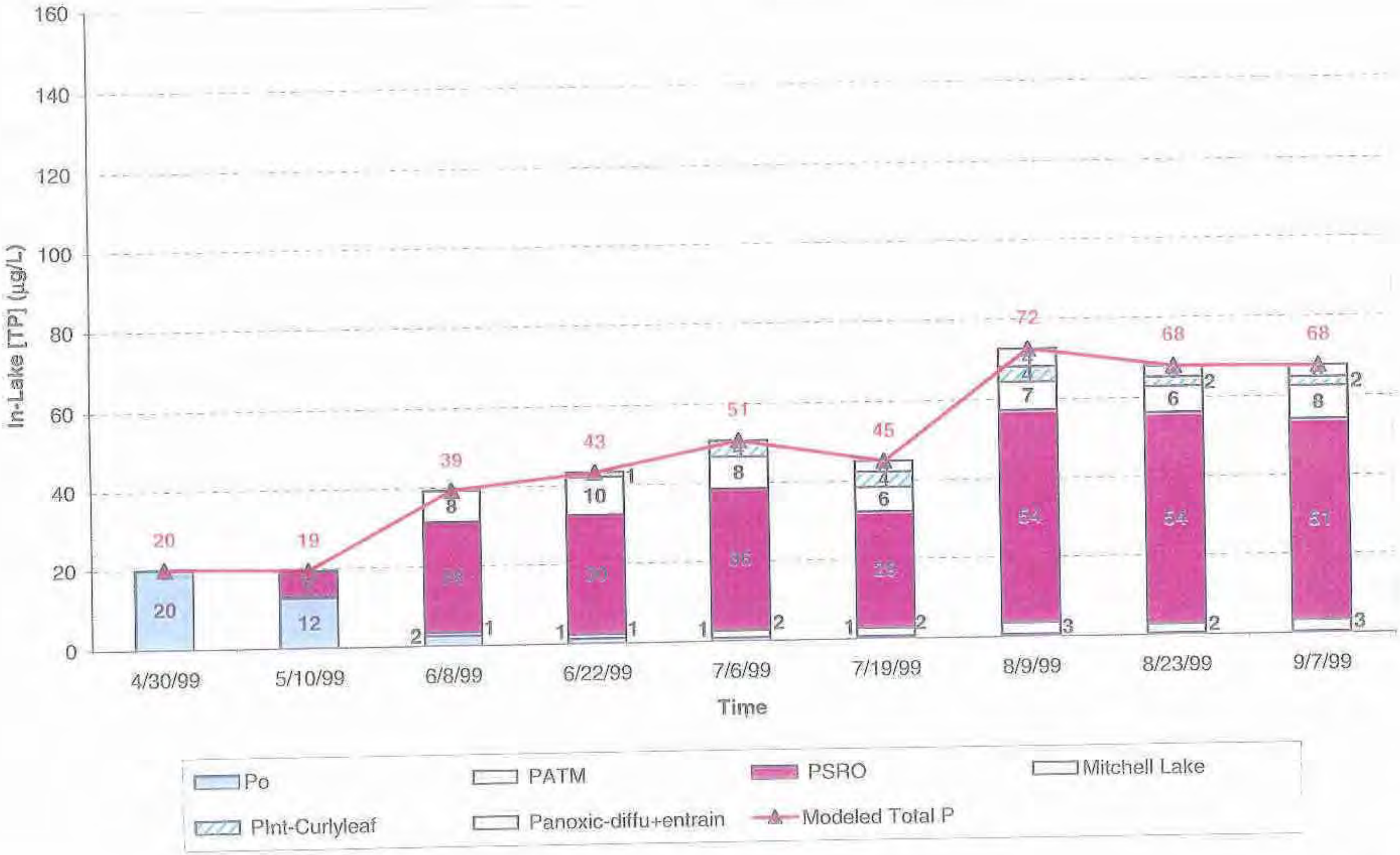
Red Rock Lake and Mitchell Lake Alum Treatment - Existing Calibration Year



4/19/2006
10:43 AM

P:\23\27\053\LAKE\UAA\RROCKUAA\In Lake\Red Rock Partition Model Variations\SASPartIn-LakeMol_RedRock_caliyr 1.45 TP SC FAC Ex RR and Mit alum: CalibrationBarChart

Red Rock Lake and Mitchell Lake Alum Treatment - Future Calibration Year



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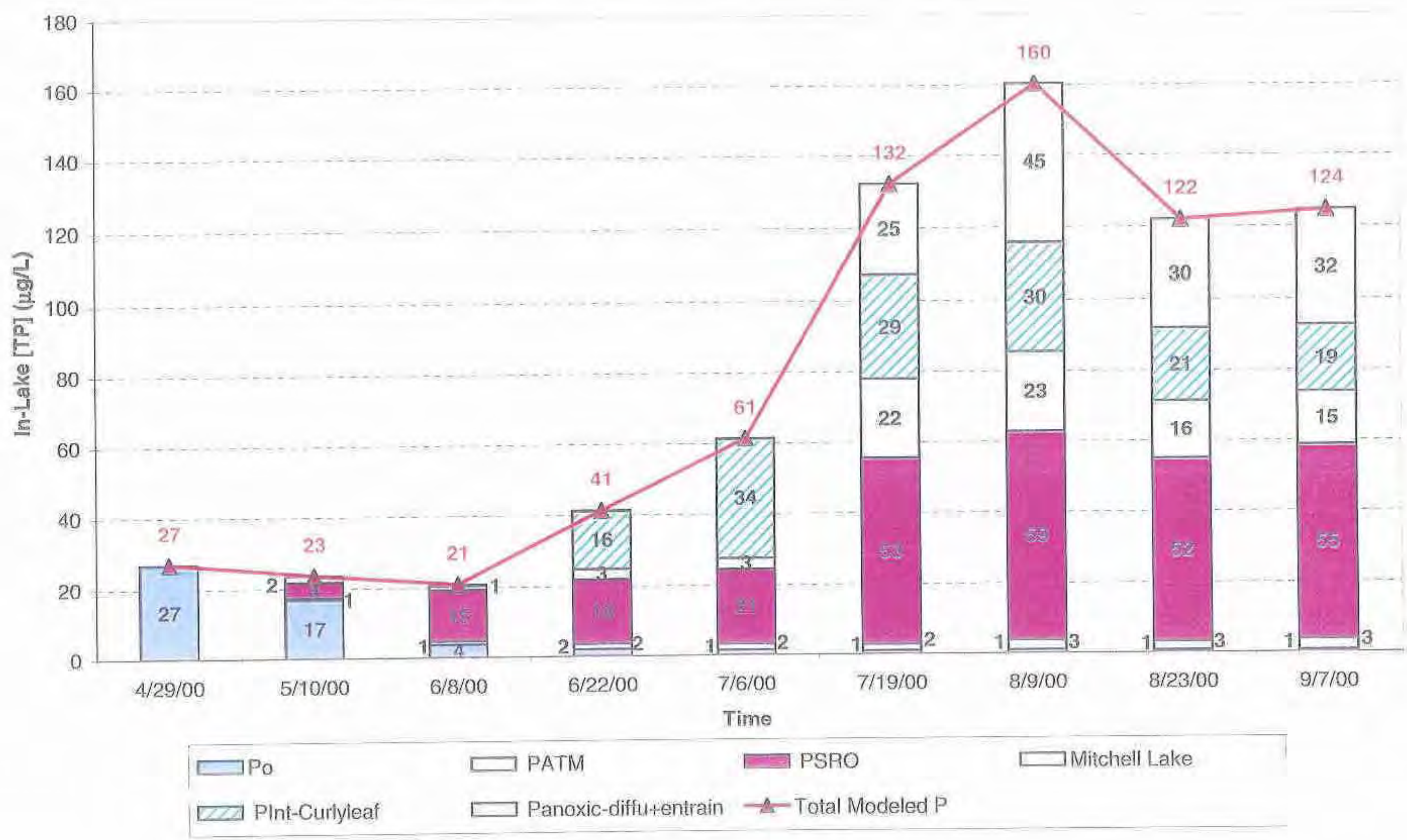
Appendix F-2

Dry Climatic Condition (2000)

Red Rock Lake No Treatment - Existing Dry Year (2000)



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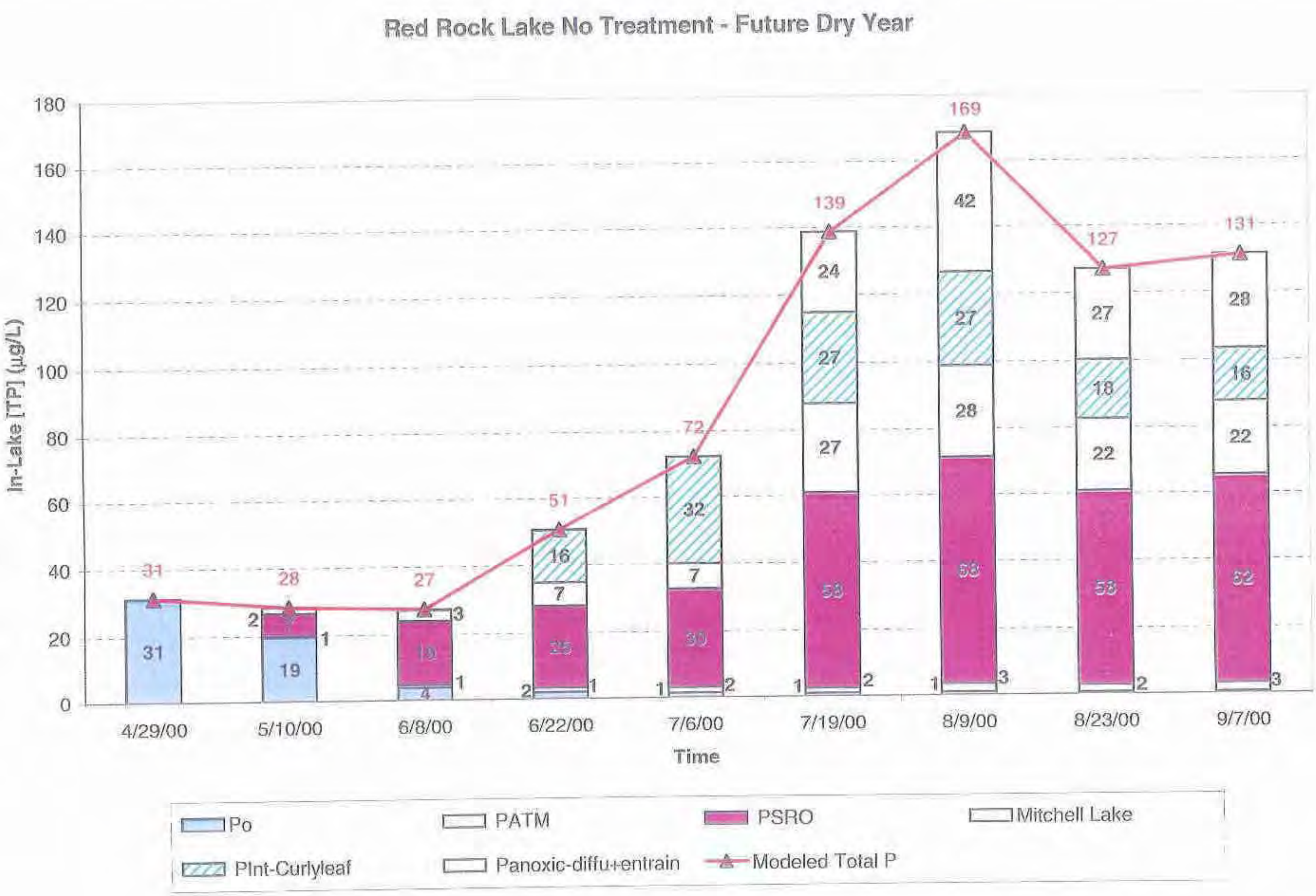
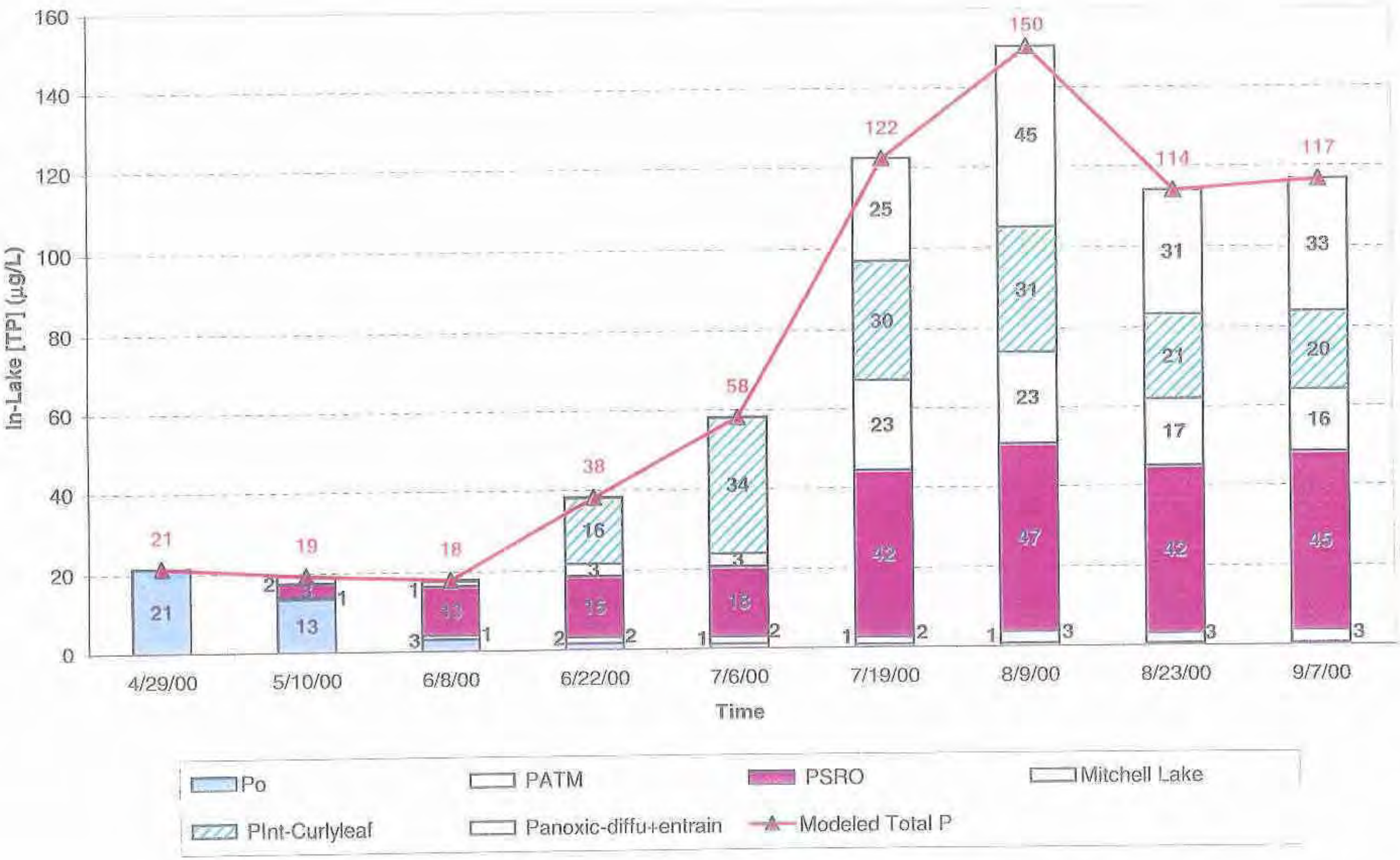
4/19/2006
10:49 AM



P:\23\27\053\LAKE\UAA\RROCKUAA\In Lake\Red Rock Partition Model Variations\SASPartIn-LakeMol_RedRock_dryyr 1.45 TP SC FAC Fut No Treat: CalibrationBarChart

4/19/2006
10:53 AM

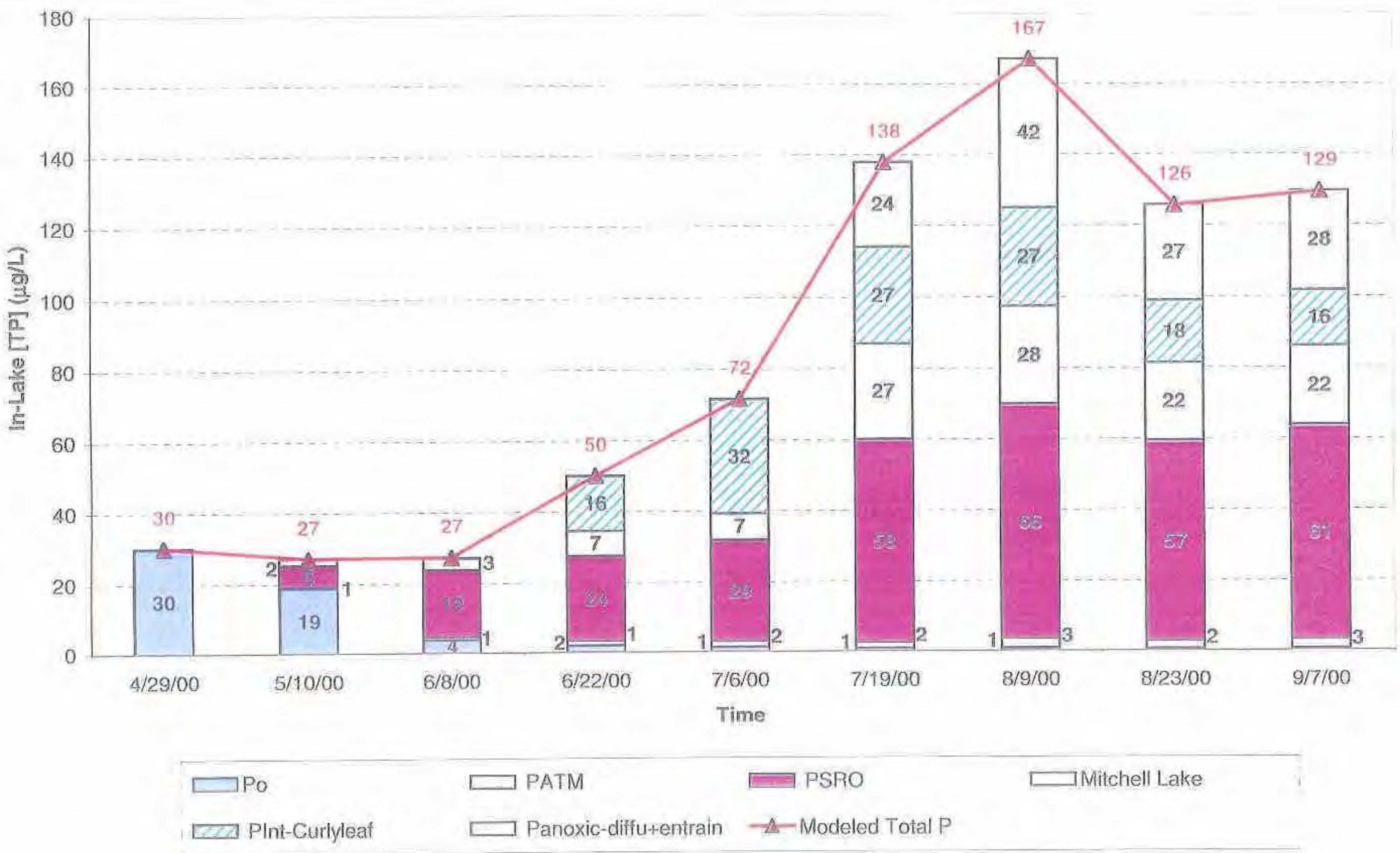
Red Rock Lake NURP Ponds Upgrade - Existing Dry Year



P:\23\27\053\LAKE\UAA\RROCKUAA\In Lake\Red Rock Partition Model Variations\SASPartIn-LakeMol_RedRock_dryyr 1.45 TP SC FAC Ex NURP: CalibrationBarChart

4/19/2006
10:57 AM

Red Rock Lake NURP Ponds Upgrade - Future Dry Year



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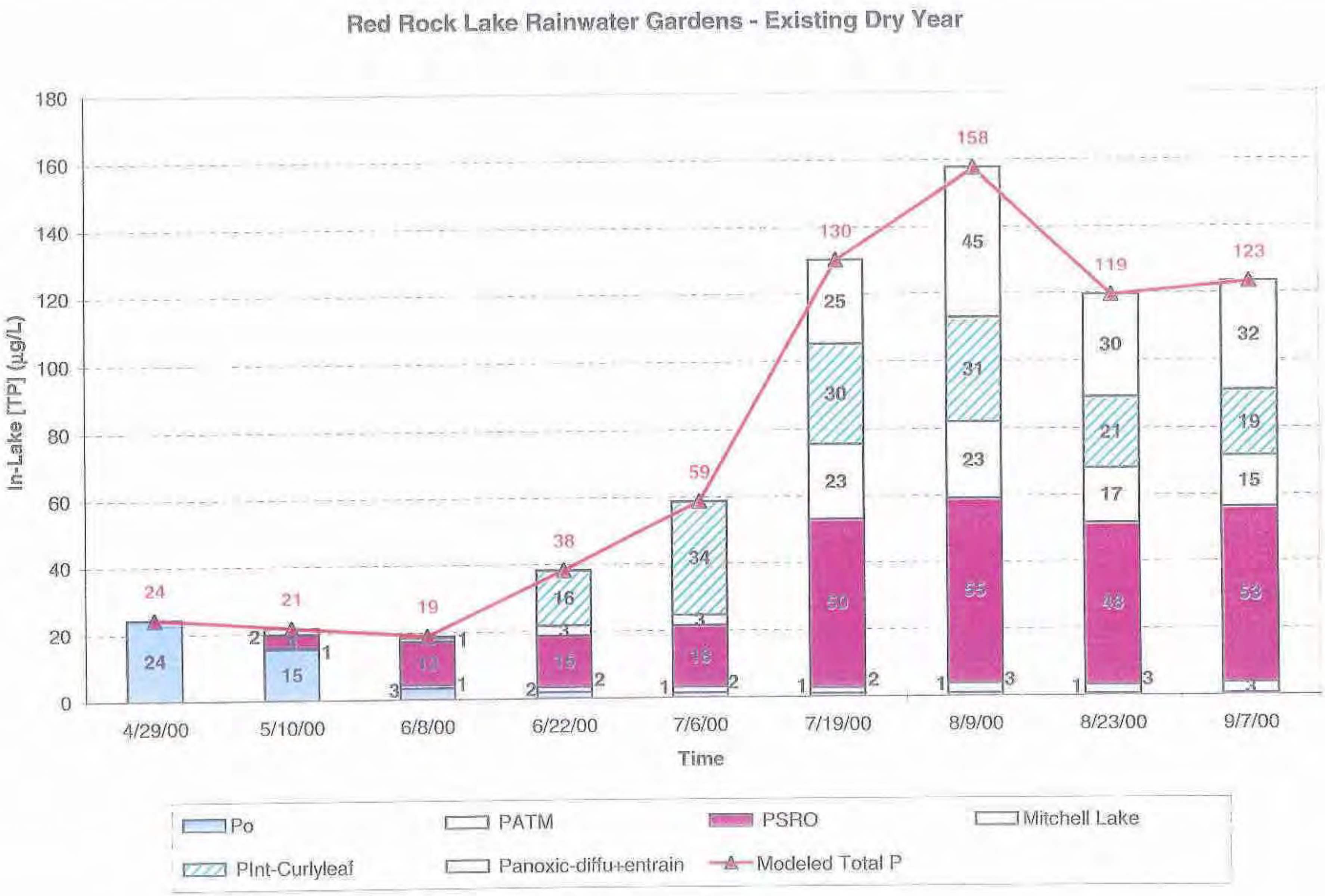
4/19/2006
10:52 AM



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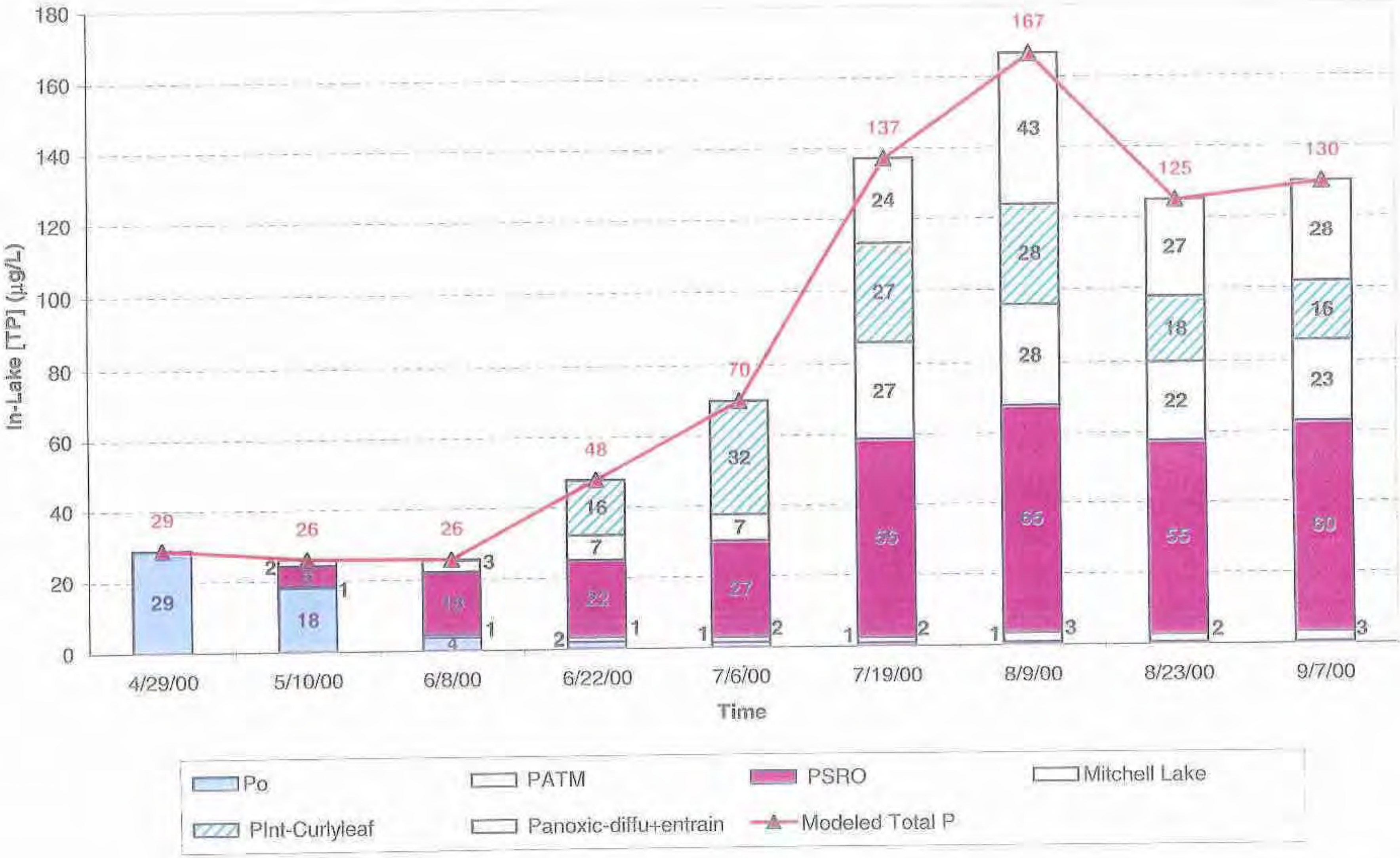
4/19/2006
10:54 AM

Red Rock Lake Rainwater Gardens - Future Dry Year



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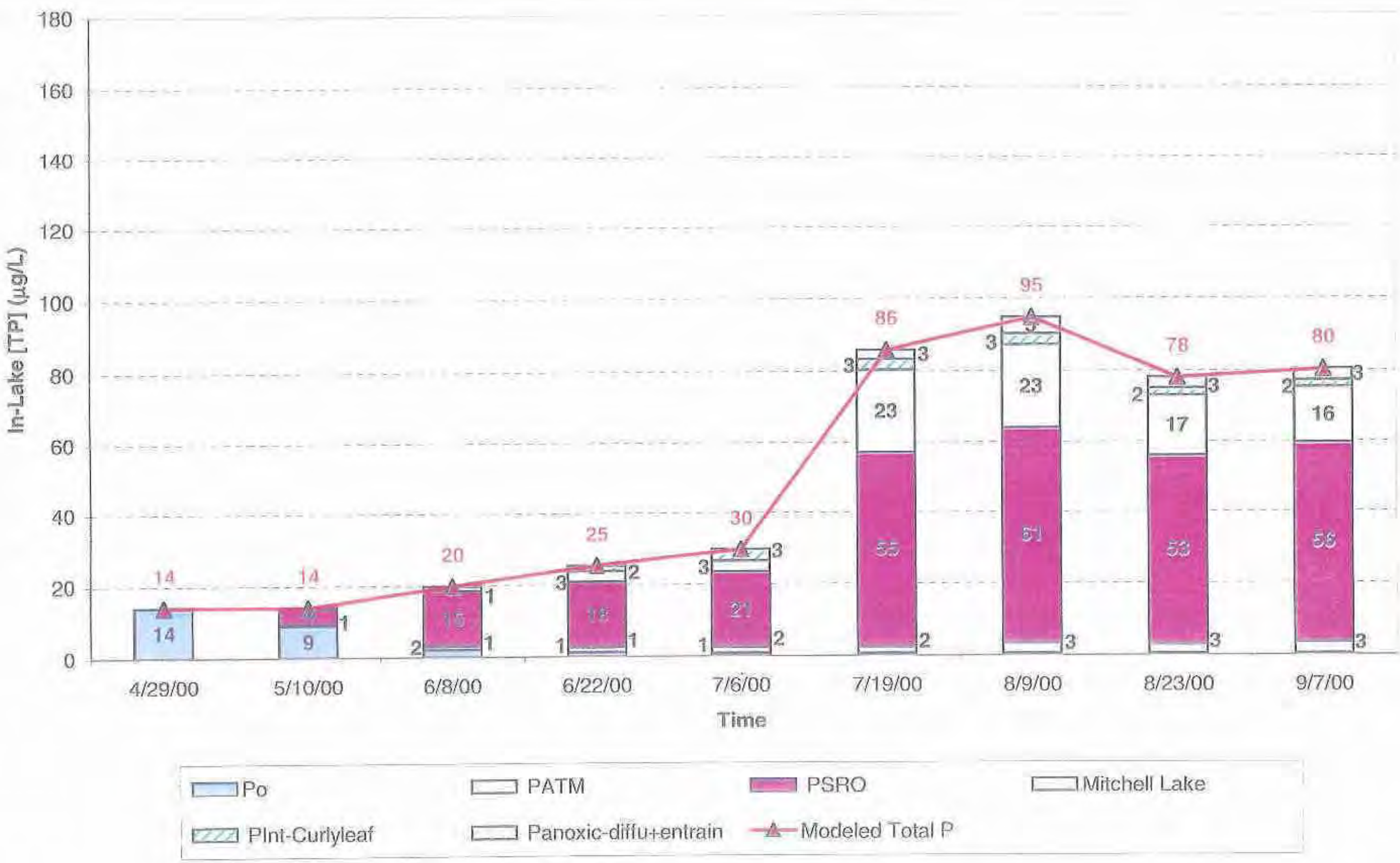
4/19/2006
10:57 AM

Red Rock Lake Alum Treatment - Existing Dry Year



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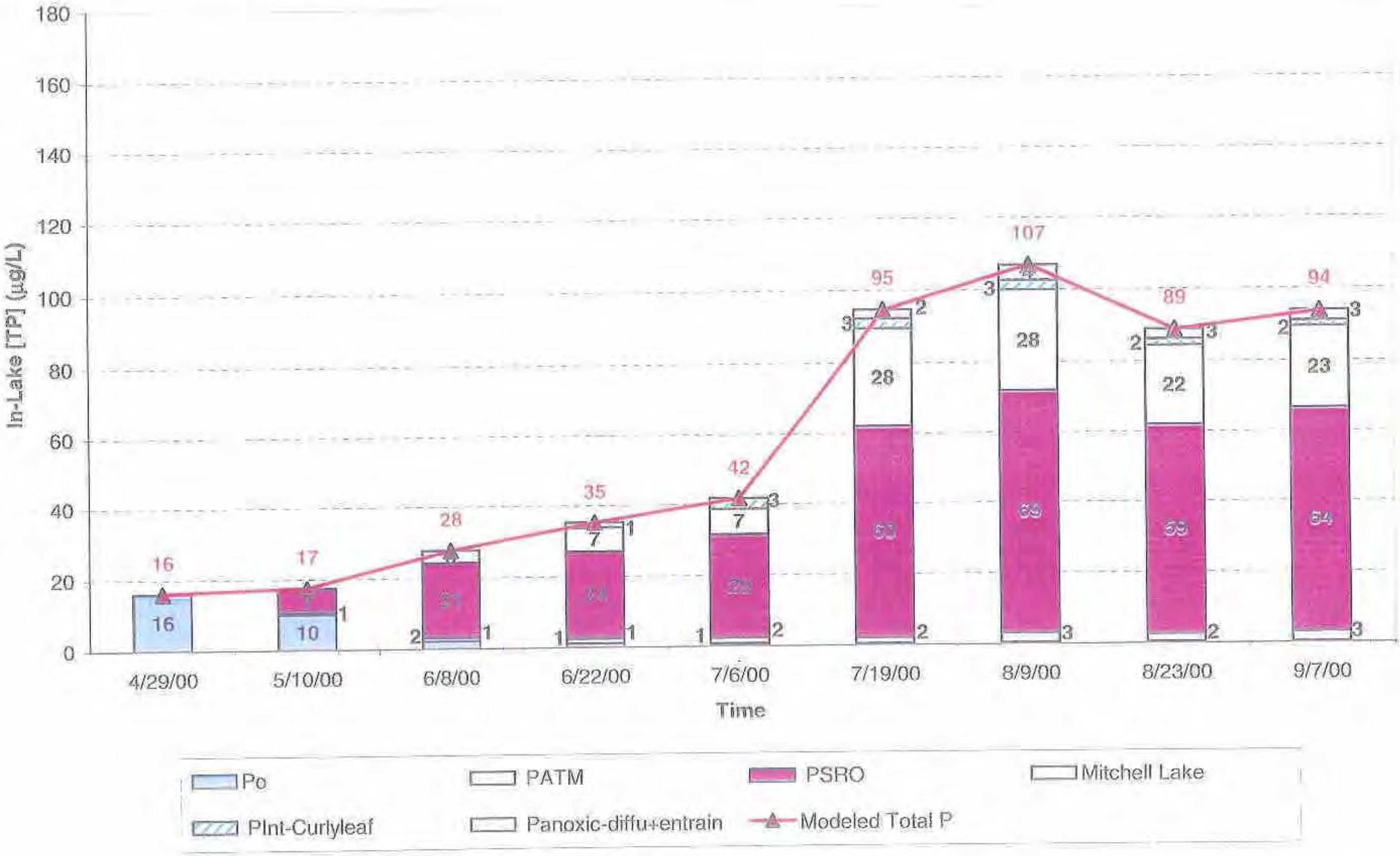
Red Rock Lake Alum Treatment - Future Dry Year



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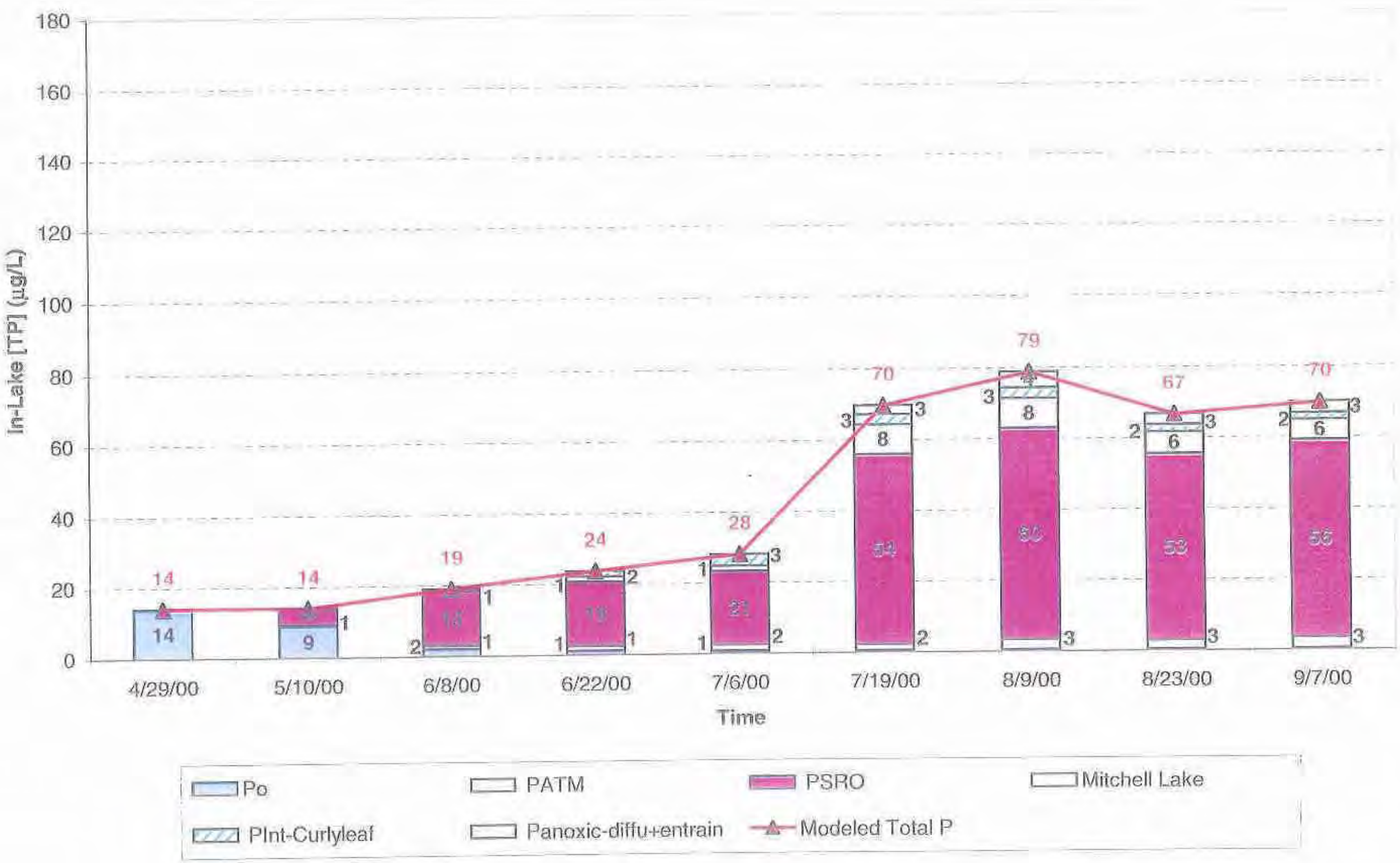
Red Rock Lake and Mitchell Lake Alum Treatment - Existing Dry Year



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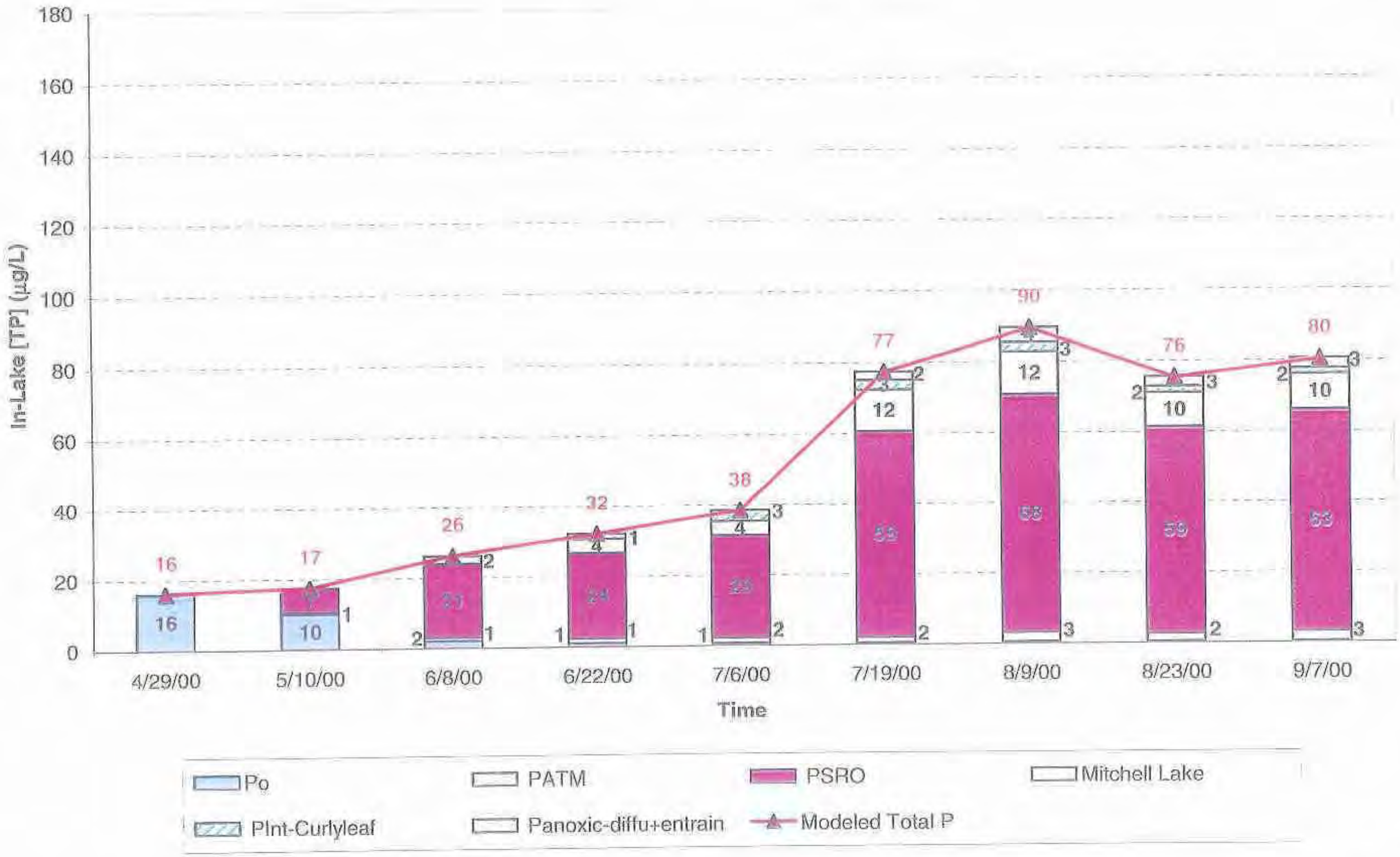
6/2/2006
5:20 PM

Red Rock Lake and Mitchell Lake Alum Treatment - Future Dry Year



4/19/2006
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