2.0 Assessment of Lake Riley Problems

2.1 Appropriations

There are no known water appropriations from Lake Riley.

2.2 Discharges

The discharge of excess phosphorus to Lake Riley has resulted in degraded water quality. A detailed analysis of discharges was completed to determine phosphorus sources and management opportunities to reduce the amount of phosphorus added to the lake. Since phosphorus typically moves either in water as soluble phosphorus dissolved in the water or attached to sediments carried by water, the determination of the volume of water discharged to Lake Riley annually was an important step in defining the amount of phosphorus discharged to the lake. During development of the District Water Management Plan, literature export rate coefficients were used to estimate the annual water and phosphorus loads to the lake. The District Plan recommended using the water quality model XP-SWMM, XP-Stormwater and Waste Water Model, in the completion of the Use Attainability Analysis to provide a more precise estimate of water and phosphorus loads. Because the P8 model (Program for Predicting Polluting Particle Passage through Pits, Puddles, and Ponds; IEP, Inc., 1990) provides more accurate predictions of phosphorus loads to a lake than the XP-SWMM model, the P8 model was selected instead of the XP-SWMM model. The Use Attainability Analysis used the P8 model to estimate the volume of water and phosphorus mass entering the lake. An intensive inflow monitoring program collected flow information and total phosphorus concentration information from two inflow locations throughout the 1998 water year. The data were used to calibrate the P8 model to ensure accurate predictions of annual water and phosphorus loads. Details of phosphorus discharges to the lake and management opportunities follow.

2.2.1 Natural Conveyance Systems

Natural conveyance systems contribute stormwater to Lake Riley via overland flow or via a natural stream. Under existing land use conditions and wet, dry, average, and model calibration year climatic conditions (i.e., the four climatic conditions described in Section 1.2—Major Hydrologic Characteristics), approximately 60 to 68 percent of the lake's annual phosphorus load is conveyed to Lake Riley by natural conveyance systems.

2.2.1.1 Direct Watershed

The direct watershed to Lake Riley contributes stormwater to the lake via overland flow along the land area immediately adjacent to the lake. Runoff from the direct watershed does not receive treatment before entering the lake. The annual amount of phosphorus added to Lake Riley from its direct watershed was estimated for four climatic conditions, previously shown to affect the lake's volume, outflow volume, and hydrologic residence time (See Section 1.2—Major Hydrologic Characteristics):

- **Wet Year**—an annual precipitation of 41 inches, the amount of precipitation occurring during the 1983 water year.
- **Model Calibration Year**—an annual precipitation of 34 inches, the amount of precipitation occurring during the 1998 water year. (The model calibration year is the year in which data were collected from the lake and from two inflow locations. The data were used to calibrate the P8 model and in-lake model.)
- **Average Year**—an annual precipitation of 27 inches, the amount of precipitation occurring during the 1995 water year
- **Dry Year**—an annual precipitation of 19 inches, the amount of precipitation occurring during the 1988 water year

The amount of phosphorus added to the lake from the direct watershed under these climatic conditions is estimated to range from 49 to 175 pounds per year under existing watershed land use conditions. This amount represents between 8 to 11 percent of the lake's annual load (See Table 5).

Table 5 Estimated Total Phosphorus Loads from Lake Riley Direct Watershed Under Varying Climatic Conditions for Existing Watershed Land Uses

Climatic Condition (inches of precipitation)	Annual Total Phosphorus Load From Direct Watershed (Pounds)	% of Total Annual Lake Riley Total Phosphorus Load
Wet (41")	128	8
Model Calibration (30")	175	11
Average (27")	73	8
Dry (19")	49	7

The amount of phosphorus added to the lake from the direct watershed under proposed future land use conditions is estimated to range from 50 to 140 pounds per year. This amount represents between 6 to 9 percent of the lake's annual load (See Table 6). Hence, land use changes under proposed future conditions are expected to reduce the lake's annual phosphorus load from the direct watershed under wet, average, and calibration year precipitation conditions. However, proposed future land use conditions are expected to result in higher phosphorus loading from the lake's direct watershed under dry precipitation conditions.

Table 6 Estimated Total Phosphorus Loads from Lake Riley Direct Watershed Under Varying Climatic Conditions for Proposed Future Watershed Land Uses

Climatic Condition (inches of precipitation)	Annual Total Phosphorus Load From Direct Watershed (Pounds)	% of Total Annual Lake Riley Total Phosphorus Load	% Change from Loads Under Existing Watershed Land Use
Wet (41")	116	6	–9
Model Calibration (30")	140	9	-20
Average (27")	71	6	-3
Dry (19")	50	6	+2

2.2.1.2 Riley Creek

Riley Creek receives stormwater runoff from the lake's direct and indirect watersheds and conveys the runoff to Lake Riley. Stormwater runoff in the watersheds tributary to Lakes Lucy, Ann, Susan, and Rice Marsh are treated by a network of wet detention basins and by the lakes prior to entering Lake Riley via Riley Creek. Much of the stormwater runoff from the lake's direct watershed is treated by wet detention ponds prior to entering Lake Riley via Riley Creek. The amount of phosphorus added to the lake from Riley Creek under existing land use conditions is estimated to range from 354 to 1,006 pounds per year. This amount represents between 51 to 61 percent of the lake's annual load (See Table 7). Most of the creek's phosphorus load is from the lake's indirect watershed (i.e., outflow from Rice Marsh Lake). Hence, the lake's direct watershed only contributes approximately 18 to 55 pounds of phosphorus per year to Riley Creek, representing 3 to 4 percent of the lake's annual total phosphorus load. The lake's indirect watershed contributes approximately 336 to 951 pounds of phosphorus per year to Riley Creek, representing from 47 to 57 percent of the lake's annual total phosphorus load.

Table 7 Estimated Total Phosphorus Loads from Riley Creek Under Varying Climatic Conditions for Existing Watershed Land Uses

Climatic Condition (inches of precipitation)	Annual Total Phosphorus Load From Riley Creek, Direct Watershed Load, (% of Total Annual Lake Riley Total Phosphorus Load)	Annual Total Phosphorus Load From Riley Creek at Rice Marsh Lake Outflow (% of Total Annual Lake Riley Total Phosphorus Load)	Annual Total Phosphorus Load from Riley Creek (% of Total Annual Lake Riley Total Phosphorus Load)
Wet (41")	55 (3)	951 (57)	1,006 (61)
Model Calibration (30")	62 (4)	748 (47)	810 (51)
Average (27")	27 (3)	523 (55)	550 (57)
Dry (19")	18 (3)	336 (50)	354 (53)

The amount of phosphorus added to the lake from Riley Creek under proposed future land use conditions is estimated to range from 401 to 1,133 pounds per year. This amount represents between 51 to 61 percent of the lake's annual load (See Table 8). Most of the creek's phosphorus load is from the lake's indirect watershed (i.e., outflow from Rice Marsh Lake). Hence, the lake's direct watershed only contributes approximately 23 to 64 pounds of phosphorus per year, representing 3 to 4 percent of the lake's annual total phosphorus load. The lake's indirect watershed (i.e., Rice Marsh Lake outflow) contributes approximately 378 to 1,069 pounds of phosphorus per year, representing 48 to 58 percent of the lake's annual total phosphorus load. Proposed future land use conditions are expected to result in Riley Creek phosphorus load increases under all climatic conditions. Increases are expected to range from 47 to 127 pounds per year.

Table 8 Estimated Total Phosphorus Loads from Riley Creek Under Varying Climatic Conditions for Proposed Future Watershed Land Uses

Climatic Condition (inches of precipitation)	Annual Total Phosphorus Load From Riley Creek, Direct Watershed Load, (% of Total Annual Lake Riley Total Phosphorus Load)	Annual Total Phosphorus Load From Riley Creek at Rice Marsh Lake Outflow (% of Total Annual Lake Riley Total Phosphorus Load)	Annual Total Phosphorus Load from Riley Creek (% of Total Annual Lake Riley Total Phosphorus Load)
Wet (41")	64 (3)	1,069 (58)	1,133 (61)
Model Calibration (30")	66 (4)	822 (51)	888 (55)
Average (27")	34 (3)	592 (53)	626 (56)
Dry (19")	23 (3)	378 (48)	401 (51)

Dissolved phosphorus is estimated to comprise the majority of the Rice Marsh Lake outflow phosphorus load. The chain of upstream lakes and treatment ponds in the lakes' watersheds effectively remove particulate phosphorus from stormwater runoff waters. Therefore, over a range of climatic conditions, dissolved phosphorus is estimated to comprise an average of 93 to 97 percent of the total phosphorus load entering Riley Creek at the Rice Marsh Lake outflow (See Table 9). Hence, treatment or management options for Riley Creek are limited to options that effectively remove dissolved phosphorus from the Rice Marsh Lake outflow.

Table 9 Estimated Average % Dissolved Phosphorus Load from Riley Creek at the Rice Marsh Lake Outflow Under Varying Climatic Conditions for Existing and Proposed Future Watershed Land Uses

Climatic Condition	Average % Dissolved Phosphorus Load From Riley Creek at Rice Marsh Lake Outflow
Existing Watershed Land Use	
Wet (41")	93
Model Calibration (30")	92
Average (27")	95
Dry (19")	96
Proposed Future Watershed Land Use	
Wet (41")	93
Model Calibration (30")	93
Average (27")	95
Dry (19")	97

One management option effectively reduces Riley Creek phosphorus loading to Lake Riley. Details follow.

Manage Rice Marsh Lake—A substantial reduction in Rice Marsh Lake's internal phosphorus load is expected to reduce Riley Creek's total phosphorus load at the outflow from Rice Marsh Lake by approximately 65 percent. The estimated reduction is based upon an analysis of Metropolitan Council and District monitoring results:

Metropolitan Council Monitoring Results—Metropolitan Council monitoring results of the inflow and outflow to Rice Marsh Lake indicated Rice Marsh Lake was acting as a nutrient pump and increasing the total phosphorus mass of Riley Creek three-fold as the creek passed through the lake. Stream flow weighted mean total phosphorus concentrations were determined for three periods in 1982 – snowmelt, spring, and early-summer. Stream flow was not observed during other portions of 1982 (late-summer and fall). Weighted mean total phosphorus concentrations for the creek flowing into Rice Marsh Lake ranged from 50 μg/L to 110 μg/L, while concentrations flowing out of Rice Marsh Lake ranged from 160 μg/L to 250 μg/L (Nelson et al, 1983).

The mass of phosphorus entering and leaving Rice Marsh Lake via Riley Creek was determined for these same three periods in 1982. During this period, a total of 94.6 kg of phosphorus entered Rice Marsh Lake by way of Riley Creek, while a total of 298.6 kg of phosphorus was conveyed by the creek out of Rice Marsh Lake (Nelson et al, 1983). The two primary sources of nutrient regeneration within Rice Marsh Lake are sediment release and decaying vegetation.

Sediment phosphorus release from Rice Marsh Lake adds a substantial mass of phosphorus to Lake Riley annually. The large reservoir of phosphorus in the lake's sediment is attributed to earlier sewage discharges to Rice Marsh Lake. Nurnberg (1984) has shown that sediment release of phosphorus occurs in lakes having anoxic bottom waters. The 1984, 1988, and 1994 Rice Marsh lake data shows that anoxic bottom waters (less than 1 mg/L dissolved oxygen concentration) occurred in the lake during all or a portion of the summer period.

Decaying vegetation within Rice Marsh Lake appears to add phosphorus mass to Lake Riley each fall and spring. Nichols (1983) has shown that the net effect of rooted emergent vegetation is to transfer nutrients from the soil to the water. Lee et al. (1975) concluded that much of the phosphorus assimilated by two Wisconsin cattail marshes during a growing season is "flushed-out" in the fall and again in the spring. This is the apparent situation with Rice Marsh Lake – Lake Riley. Decaying vegetation within Rice Marsh Lake and surrounding marsh areas is believed to be flushed out in the spring, resulting in increased phosphorus concentrations reaching Lake Riley.

District Monitoring Results—2000 water quality data collected by the District from Riley Creek at two locations (i.e., Lake Susan outflow and Lake Riley inflow) indicate that up to 70 percent of the phosphorus load leaving Rice Marsh Lake may result from internal loading. Data collected from the Lake Susan outflow during 2000 indicated the outflow concentration represented 30 percent of the Lake Riley inflow concentration.

The data indicate phosphorus concentrations in Riley Creek increase by as much as a factor of three as the creek passes through Rice Marsh Lake. Because Riley Creek contributes from half to two thirds of the lake's annual phosphorus load, a substantial reduction in Riley Creek's phosphorus load is expected to result in a substantial improvement in Lake Riley's water quality. Therefore, one option to reduce phosphorus inflow to Lake Riley is to reduce internal loading within Rice Marsh Lake. A concurrent reduction in sediment phosphorus release and mass of decaying vegetation within Rice Marsh Lake would reduce internal phosphorus loading.

Alum-Lime Slurry Treatment of Rice Marsh Lake—Phosphorus release from the sediments can be reduced by chemically treating the sediments to block this release. This may be achieved by the addition of a mixture of alum and lime to the lake water. Alum applied to the lake acts as a flocculent to precipitate phosphorus from the lake's surface waters. As this precipitate settles on the lake bottom, it forms a layer preventing the release of phosphorus from the sediments. The application of alum has successfully been used to treat a number of lakes in the metropolitan area. The addition of lime to alum is recommended to prevent wind resuspension of alum floc. Alum treatment of lakes for sediment-sealing purposes has not been particularly successful in shallow lakes. Knauer and Garrison (1980) reported that alum floc in Pickerel Lake, Wisconsin (average depth 2.4 meters) was subject to redistribution by wind-driven currents and tended to concentrate in the deepest areas of the lake. Rice Marsh Lake is significantly shallower (mean depth <1.0 meters) than Pickerel Lake and probably more susceptible to dispersal of floc by winds. Use of a mixture of alum and lime is expected to prevent the resuspension of alum floc. Burley et al. (2001) found that a mixture of alum and lime effectively reduced phosphorus loading from sediments.

Use of lime in the treatment of Rice Marsh Lake sediments is expected to concurrently prevent the resuspension of alum floc and reduce vegetation density within the lake. Chambers et al

(2001) and Barr (2001) found that lime treatment effectively reduced vegetation density. Hence, the alum plus lime mixture is expected to reduce sediment phosphorus loading to Rice Marsh Lake while concurrently reducing loading from decaying vegetation by reducing vegetation mass within the lake.

Following alum plus lime treatment of Rice Marsh Lake, the total amount of phosphorus added to the lake from Riley Creek is expected to range from 136 to 388 pounds per year, a reduction of 218 to 618 pounds of phosphorus annually under existing watershed land use conditions (See Table 10). Under future watershed land use conditions, the total amount of phosphorus added to the lake from Riley Creek is expected to range from 155 to 438 pounds per year, a reduction of 246 to 695 pounds of phosphorus annually (See Table 10). Treatment of Rice Marsh Lake with alum plus lime is expected to cost approximately $200,000 (2001 cost basis). A MDNR permit is required and a monitoring program to determine treatment effectiveness may be required by the MDNR permit. Monitoring program costs will be dependent upon permit requirements.

Table 10 Estimated Riley Creek Phosphorus Loading Reduction from Treatment of Rice Marsh Lake with Alum Plus Lime

Climatic Condition (inches of precipitation)	Total Annual Riley Creek TP Load Before Treatment	Total Annual Riley Creek TP Load After Treatment (Estimate 65% TP Removal)
Existing Watershed Land Use Conditions		
Wet (41")	1,006	388
Model Calibration (30")	810	324
Average (27")	550	210
Dry (19")	354	136
Proposed Future Watershed Land Use Conditions		
Wet (41")	1,133	438
Model Calibration (30")	888	354
Average (27")	626	241
Dry (19")	401	155

2.2.2 Stormwater Conveyance Systems

Under existing watershed land use and wet, dry, average, and model calibration year climatic conditions (i.e., the four climatic conditions described in Section 1.2—Major Hydrologic Characteristics), the annual phosphorus load added to Lake Riley from seven stormwater conveyance systems (i.e., does not include stormwater conveyance systems contributing flow to Riley Creek) was estimated to range from 123 to 452 pounds per year (See Table 11). This amount represents from 18 to 29 percent of the lake's annual phosphorus load. Under proposed future land use conditions, the annual phosphorus load added to Lake Riley from stormwater conveyance systems was estimated to range from 190 to 456 pounds per year, 24 to 27 percent of the lake's annual phosphorus load (See Table 11).

Table 11 Estimated Total Phosphorus Loads from Lake Riley Stormwater Conveyance Systems Under Varying Climatic Conditions

Climatic Condition (Inches of precipitation)	Annual Total Phosphorus Load From Stormwater Conveyance Systems (Pounds)	% of Lake Riley Annual Total Phosphorus Load
Existing Watershed Land Use		
Wet (41")	378	23
Model Calibration (30")	452	29
Average (27")	191	20
Dry (19")	123	18
Proposed Future Land Use		
Wet (41")	456	25
Model Calibration (30")	440	27
Average (27")	277	25
Dry (19")	190	24

Each of the seven storm sewer systems discharging into Lake Riley (See Figure 12) adds a different amount of phosphorus to the lake, based on the size of the watershed, the land uses within the watershed, and the stormwater treatment that occurs prior to discharge to the lake. All stormwater conveyed to Lake Riley via storm sewers is treated by at least one detention/water quality basin before it is discharged to the lake.

As shown in Table 12, inflow locations 2.11, 3.11, SP3, 9.11, Station 1, and 6.11 each contribute less than 5 percent of the lake's annual load under existing and proposed future land use conditions. Collectively, these 6 subwatersheds: (1) comprise 12 percent of the lake's watershed, (2) add from

10 to 12 percent of the lake's annual total phosphorus load under existing watershed land use conditions, and (3) add from 8 to 12 percent of the lakes' annual total phosphorus load under proposed future watershed land use conditions.

Storm sewer outlet 4.45 contributes a phosphorus load to the lake that is similar or higher than the collective total of the other six stormwater conveyance systems. Under existing watershed land use conditions, the storm sewer outlet 4.45 is estimated to add from 59 to 264 pounds of phosphorus per year to Lake Riley, which comprises from 9 to 17 percent of the lake's annual phosphorus load. Under proposed future watershed land use conditions, the storm sewer outlet 4.45 is estimated to add from 124 to 268 pounds of phosphorus per year to Lake Riley, which comprises 15 to 16 percent of the lake's annual phosphorus load.

Table 12 A Comparison of Estimated Total Phosphorus Loads from Seven Lake Riley Stormwater Conveyance Systems Under Varying Climatic Conditions

	Annual Total Phosphorus Load in pounds			
Stormwater Conveyance System	**Wet (41")**	**Model Calibration (34")**	**Average (27")**	**Dry (19")**
Existing Watershed Land Use Conditions				
2.11	27	25	13	8
3.11	24	35	12	7
SP3	43	16	22	15
4.45	185	264	93	59
6.11	4	6	2	1
Station 1	68	69	34	23
9.11	27	37	14	10
Total Annual Load from Stormwater Conveyance Systems	**378**	**452**	**191**	**123**
Proposed Future Land Use Conditions				
2.11	30	24	17	12
3.11	30	42	15	9
SP3	33	36	18	12
4.45	268	233	178	124
6.11	5	7	2	2
Station 1	67	68	34	24
9.11	23	31	12	8
Total Annual Load from Stormwater Conveyance Systems	**456**	**440**	**277**	**190**

The treatment effectiveness of the 31 detention ponds within the seven stormwater conveyance systems was estimated under wet, dry, average, and model calibration precipitation conditions. Under average precipitation conditions, 13 basins removed at least 50 percent of the phosphorus load (See Table 13). Under wet, dry, and model calibration precipitation conditions, 10 to 12 basins removed at least 50 percent of the phosphorus load.

Table 13 Estimated Total Phosphorus Removal Efficiency of Lake Riley Watershed Detention Ponds Under Existing Watershed Land Use Conditions

Stormwater Conveyance System	Pond Name	Total Phosphorus Removal Efficiency (% Removed)			
		Wet ('83) 41" pptn.	Dry ('88) 19" pptn.	Avg. ('95) 27" pptn.	Model Calibration ('98) 30" pptn.
2.11	2.41	52	53	52	73
	2.31	12	12	13	21
	2.21	51	53	51	74
	2.22	48	21	50	72
	2.11	50	53	51	67
3.11	3.11	8	9	9	5
SP3	SP3	7	7	8	29
4.45	4.51	48	46	49	54
	SP4	20	22	22	16
	9999.42	61	60	60	71
	9999.43	22	22	24	18
	4.15	49	52	51	44
	4.14	57	53	56	65
	4.13	31	30	30	50
	4.12	45	43	46	46
	4.11	7	9	8	4
	4.21	16	14	16	15
6.11	6.11	45	51	59	45
Station 1	7.52	53	60	59	51
	7.42	36	37	39	27
	7.31	50	57	56	50
	7.21	20	18	20	24
	7.11	29	30	28	60
	7.01	2	3	3	5
	8.31	19	19	21	16
	8.21	36	35	37	46
	8.11	18	22	21	16
9.11	9.31	53	56	56	48
	9.22	56	59	58	77
	9.21	58	60	59	63
	9.11	36	40	38	25

Some of the detention basins in the lake's direct watershed were constructed prior to the establishment of current MPCA- and NURP-criteria. An assessment of the 43 basins in the lake's direct watershed (12 basins tributary Lake Riley via Riley Creek and 31 basins tributary to Lake Riley via a stormwater conveyance system) was completed to determine whether the ponds currently meet the minimum criteria established by the MPCA (i.e., Protecting Water Quality in Urban Areas, 1989) and NURP-criteria (i.e., based upon results from the Nationwide Urban Runoff Program). Current criteria by the MPCA and NURP require a minimum permanent pool or dead storage volume for each pond based upon its watershed size. As discussed previously, the treatment effectiveness of a pond is directly related to its dead storage volume. Pond surveys were completed during 1999 to estimate current dead storage volume for all ponds in the direct watershed. Thirty two of the 43 ponds in the lake's direct watershed currently meet MPCA/NURP-criteria .

- **Upgrade**—Model simulations were completed to estimate the reduction in phosphorus loading to Lake Riley if eleven treatment basins (3.11, SP3, 9999.43, SP4, 4.11, 5.03, 7.21, and 8.31 shown in Figure 12) were upgraded to meet MPCA/NURP-criteria. Following an upgrade of the basins, the amount of phosphorus added to the lake annually would be reduced by 12 to 76 pounds under existing watershed land use conditions. Under proposed future land use conditions, an annual phosphorus reduction of 50 to 95 pounds would occur. However, the reduced phosphorus load from the upgrade alone would be insufficient to meet District goals (See Table 14). Upgrading these treatment basins is estimated to cost approximately $273,460.

Table 14 Estimated Phosphorus Loading Reduction from Upgrade of Ponds 3.11, SP3, 9999.43, SP4, 4.11, 5.03, 7.21, and 8.31 to Meet MPCA/NURP-Criteria

Climatic Condition (Inches of precipitation)	Annual Total Phosphorus Load Reduction From Stormwater Conveyance Systems Following Upgrade of Ponds 3.11, SP3, 9999.43, SP4, 4.11, 5.03, 7.21, and 8.31 to Meet MPCA/NURP-Criteria (Pounds)
Existing Watershed Land Use	
Wet (41")	60
Average (27")	76
Dry (19")	12
Proposed Future Watershed Land Use	
Wet (41")	95
Average (27")	68
Dry (19")	50

2.2.3 Highway 312 Impacts

Proposed future watershed land uses for the Lake Riley watershed include the construction of Highway 312 (See Figure 13). Highway 312 construction will add approximately 75 acres of highway land use to the lake's watershed. If no new ponds are constructed to treat highway runoff waters, Lake Riley total phosphorus watershed loading increases are expected to range from 34 pounds under dry climatic conditions (i.e., 19 inches of annual precipitation) to 74 pounds under wet climatic conditions (i.e., 41 inches annual precipitation). The Highway 312 total phosphorus load represents 5 percent of the total future phosphorus load to Lake Riley under dry climatic conditions (i.e., 19 inches of annual precipitation) and 4 percent under wet climatic conditions (i.e., 41 inches annual precipitation). The additional phosphorus loading from Highway 312 is included in Tables 8 and 11. Treatment of highway runoff waters will minimize phosphorus loading increases to Lake Riley.

Treat Highway Runoff Waters—Construction of four or five wet detention basins meeting MPCA- and NURP-criteria will reduce phosphorus loading from Highway 312 runoff waters by 67 percent under average climatic conditions (i.e., 27 inches annual precipitation). Proposed pond locations are shown on Figure 14. Following treatment, watershed phosphorus loading from Highway 312 runoff waters are expected to range from 16 pounds under average climatic conditions (i.e., 27 inches of annual precipitation) to 25 pounds under wet climatic conditions (i.e., 41 inches annual precipitation). Table 15 presents treatment benefits.

Table 15 Benefits of Wet Detention Basin Treatment of Highway 312 Runoff Waters

	Annual Total Phosphorus Loading		
Climatic Condition (Water Year, Inches of Precipitation)	**No Treatment Pounds/Year**	**Wet Detention Basin Treatment Pounds Removed/Year**	**Percent Reduction from Treatment**
Wet Year (1983, 41 inches)	74	49	66%
Average Year (1995, 27 Inches)	48	32	67%
Dry Year (1988, 19 Inches)	34	17	50%

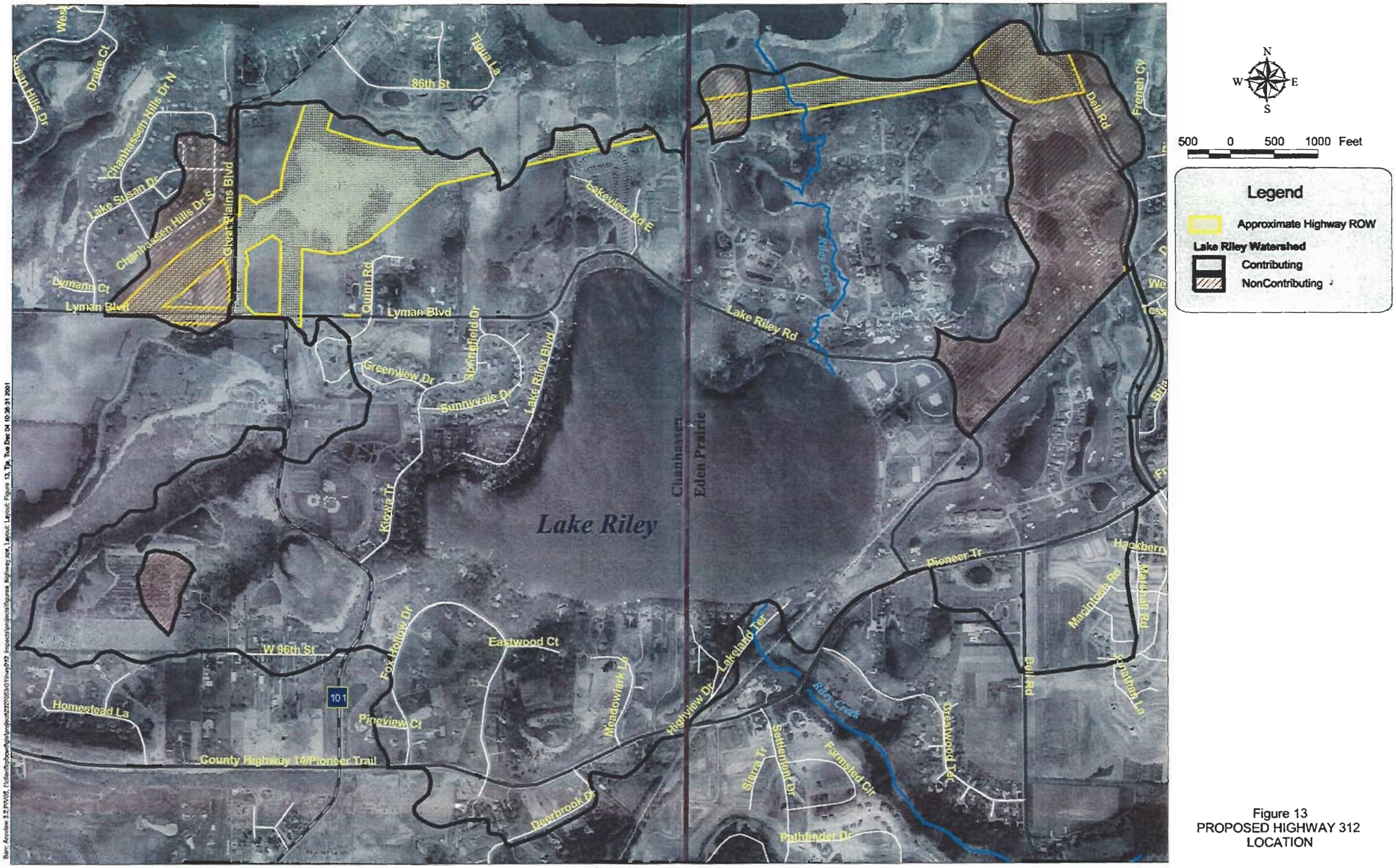


Figure 13
PROPOSED HIGHWAY 312
LOCATION

Figure 14
PROPOSED HIGHWAY 312
TREATMENT POND LOCATIONS
UNDER PROPOSED
CONDITIONS

2.2.4 Public Ditch Systems

There are no known ditch systems affecting Lake Riley.

2.3 Fish and Wildlife Habitat

The current habitat for Lake Riley does not meet the MDNR-criteria for the lake's fishery. The MDNR has established criteria for the support of the lake's fishery, based upon its classification as a Class 24 lake. The MDNR-criteria for Lake Riley is an average TSI_{SD} of 56 or lower (i.e., a summer average Secchi disc transparency of about 4 feet or greater).

AQUATOX model simulations and an MPCA model were used to estimate the lake's TSI_{SD} under varying climatic conditions. As shown in Table 16, the lake's TSI_{SD} is estimated to range from 49 to 64 under existing watershed land use conditions. Under proposed future watershed land use conditions, the lake's TSI_{SD} is estimated to range from 50 to 52. Unless the water quality is improved to meet MDNR-criteria for Lake Riley, the lake will exhibit an impaired habitat for its fishery during wet climatic conditions (i.e., existing watershed land use).

Table 16 Estimated Lake Riley Trophic State Index Secchi Disc Values Under Varying Climatic Conditions

Parameter	District Goal	Trophic State Index (TSI) Value Wet Year (1983, 41")	Dry Year (1988, 19")	Average Year (1995, 27")
Existing Watershed Land Use Conditions				
Secchi Disc	≤56	64	49	53
Proposed Future Watershed Land Use Conditions				
Secchi Disc	≤56	52	50	51

Data collected during 1971 through 1998 were evaluated to determine whether the lake has met MDNR-criteria during the period of record. The evaluation indicates the average summer TSI_{SD} was greater than 56 during 9 of the 16 monitoring years (i.e., 56 percent).

Lake Riley can achieve the water quality needed to meet MDNR-criteria under varying climatic conditions for existing and proposed future land use conditions (See Table 17) by reducing phosphorus loads to the lake. Phosphorus reduction can be attained by implementing the management practice discussed in Section 2.2.1.2—Riley Creek (manage practice). Managing Rice Marsh Lake by

Table 17. Estimated Lake Riley Trophic State Index Secchi Disc Values Following Management of Rice Marsh Lake by Treating the Lake's Sediments With Alum and Lime Slurry

Parameter	District Goal	Trophic State Index (TSI) Value		
		Wet Year (1983, 41")	Dry Year (1988, 19")	Average Year (1995, 27")
Existing Watershed Land Use Conditions				
Treat Rice Marsh Lake Sediments with Alum and Lime Slurry Mixture	≤56	43	45	46
Proposed Future Watershed Land Use Conditions				
Treat Rice Marsh Lake Sediments with Alum and Lime Slurry Mixture	≤56	46	49	48

2.4 Water Based Recreation

Recreation uses of Lake Riley currently include swimming, fishing, canoeing, paddle boating, and aesthetic viewing. Swimming requires a higher water quality than other recreational uses. When a lake's water quality fully supports swimming, other recreational uses are also supported. Hence, the following discussion focuses on the water quality requirements of swimming.

The MPCA has established water quality criteria to determine whether a lake has the water quality required to fully support a swimmable use. According to MPCA-criteria, lakes fully supporting the swimmable use should exhibit "impaired swimming" conditions less than 10 percent of the time and in terms of physical condition should exhibit "high algal levels" less than 10 percent of the time. To put this criteria in measurable terms, the MPCA has specified that lakes with an average Trophic State Index (TSI) ≤ 53 are classified as fully supporting swimmable and aesthetic uses. The trophic state index is calculated from total phosphorus, chlorophyll *a*, and Secchi disc transparency data from a lake (Carlson 1977). When the MPCA-criteria for fully swimmable and aesthetic uses are compared to a standardized lake rating system, a TSI ≤ 53 would correspond to oligotrophic (excellent water quality), mesotrophic (good water quality), and mildly eutrophic (poor water quality) conditions. An evaluation of estimated Lake Riley TSI under wet, dry, and average climatic conditions indicates the lake is currently unable to fully support swimmable use under wet and average climatic conditions and existing watershed land uses (See Table 18). The lake will be unable to fully support swimmable use under all climatic conditions and proposed future watershed land uses (See Table 18). Consequently, the lake exhibits "impaired swimming conditions" under wet and average climatic conditions currently and is expected to exhibit "impaired swimming conditions" under all climatic conditions in the future.

Table 18 Lake Riley Estimated Trophic State Index Values Under Varying Climatic Conditions

Parameter	District Goal	Trophic State Index (TSI) Value Wet Year (1983, 41")	Average Year (1995, 27")	Dry Year (1988, 19")
Existing Watershed Land Use Conditions				
Total Phosphorus	≤ 53	72	51	46
Chlorophyll *a*	≤ 53	69	56	51
Secchi disc	≤ 53	64	53	49
Average TSI	≤ 53	68	53	49
Proposed Future Watershed Land Use Conditions				
Total Phosphorus	≤ 53	53	49	48
Chlorophyll *a*	≤ 53	56	54	54
Secchi disc	≤ 53	52	51	50
Average TSI	≤ 53	54	51	51

Lake Riley can achieve the water quality needed to fully support swimming by reducing phosphorus loads to the lake. Phosphorus reduction can be attained by implementing the management practice discussed in Section 2.2.1.2—Riley Creek (manage practice). Phosphorus reduction is expected to reduce the phytoplankton population and hence improve the lake's water quality. In addition, the following management practice is recommended for rapid attainment of the District's recreation goal.

- **Manage Lake Riley**—Treatment of Lake Riley with alum is recommended to remove excess phosphorus currently present in the lake, thus resulting in rapid attainment of the lake's water quality goal. Although reduction of phosphorus loading to the lake will reduce its phosphorus concentration over the long-term, residual effects of the current phosphorus load may delay the anticipated reduction for several years. As shown in Table 3, the hydrologic residence time of Lake Riley varies with climatic conditions, ranging from 1.4 to 4.3 years. On average, the lake notes a 2.7 year hydrologic residence time. This means that some of the current high phosphorus waters may reside in the lake, on average, for approximately 3 years after completion of the watershed management practice discussed in Section 2.2.1.2—Riley Creek (manage practice). An alum treatment of the lake would quickly remove current high levels of phosphorus, resulting in low phosphorus concentrations following treatment. The watershed management practice discussed in Section 2.2.1.2—Riley Creek (manage practice) would then protect the improved water quality through reduced phosphorus loading to the lake. In addition to rapid attainment of the lake's recreation goal, an alum treatment of the lake is also expected to reduce the lake's internal phosphorus load by approximately 90 percent for a period of around 10 years. Current, approximately 79 pounds of phosphorus are loaded to the lake annually from sediment phosphorus release or internal loading. Hence, alum treatment of the lake is expected to reduce the lake's annual total phosphorus load by approximately 71 pounds annually. An alum treatment of the lake is estimated to cost approximately $200,000.

2.5 Ecosystem Data

The Lake Riley ecosystem is a determining factor in the achievement or non-achievement of Lake Riley's recreation, aquatic communities, and water quality goals. An imbalance in the lake's ecosystem adversely impacts the lake's fish community, water based recreation, and water quality thereby preventing goal achievement. The ecosystem consists of phytoplankton (small aquatic plants), zooplankton (small animals), fish, and macrophytes (large aquatic plants).

An imbalanced phytoplankton community in Lake Riley results in nuisance algal blooms throughout the summer, but particularly during the late-summer period. The profuse phytoplankton cause the lake to have a reduced water transparency and an objectionable green appearance. Water quality degradation and "impaired swimming conditions" result from the overabundant phytoplankton community. As shown in Table 18, current phytoplankton levels in the lake result in non compliance with MPCA-criteria for full swimmable use during wet and average precipitation conditions. Current phytoplankton levels also result in non compliance with MDNR-criteria for the lake's fishery during wet precipitation conditions (See Table 16). Hence, profuse phytoplankton prevent achievement of the lake's recreation, aquatic communities, and water quality goals. The excess phytoplankton are caused by overabundant phosphorus loading to the lake (imbalanced nutrients). A reduction in the lake's phosphorus load will reduce the phytoplankton to acceptable levels.

The lake's problem of excessive phytoplankton is exacerbated by the lack of natural control by the zooplankton community. Lake Riley currently notes low levels of cladocera and copepoda. While the zooplankton community provides food for the lake's fishery, zooplankton have little impact on the lake's water quality. Increased numbers of large zooplankton (primarily cladocera, a type of zooplankton) would help reduce the lake's phytoplankton and improve the lake's water quality.

Fish predation of zooplankton is the assumed cause of the low numbers of zooplankton. Panfish, such as bluegills, eat zooplankton and, hence, fish predation impacts the number of zooplankton in the lake. Fish predation in Lake Riley has reduced larger zooplankton numbers to low levels. The low numbers of larger zooplankton prevent control of the lake's phytoplankton community.

Despite the imbalances noted for phytoplankton and larger zooplankton, the lake's fish community seems balanced. 1995 fisheries survey results indicated Lake Riley exhibited a typical largemouth bass—bluegill—northern pike fishery. However, the phytoplankton imbalance results in a less than ideal habitat for the lake's fishery.

Balance to the lake's ecosystem may be restored by reducing phosphorus loads to the lake. Phosphorus reduction to the lake may be attained by implementing the management practice discussed in Section 2.2.1.2—Riley Creek (manage practice) and Section 2.4—Water Based Recreation (manage practice).

2.6 Water Quality

2.6.1 Baseline/Current Analysis

A comparison of baseline and current trophic state index (TSI) values indicates that Lake Riley has been unable to fully support swimmable use during the baseline and current periods. All but two summer averages exceeded MPCA-criteria (i.e., TSI $\leq$53) for fully support swimmable use. Lake Riley's fishery habitat has failed to meet MDNR-criteria during a portion of the baseline period and during most of the current period. Approximately 36 percent of baseline values and 80 percent of current values failed to meet MDNR-criteria for the lake's fishery (See Table 19).

Table 19 A Comparison of Lake Riley Baseline TSI with Current TSI Based on Summer (June through August) Averages

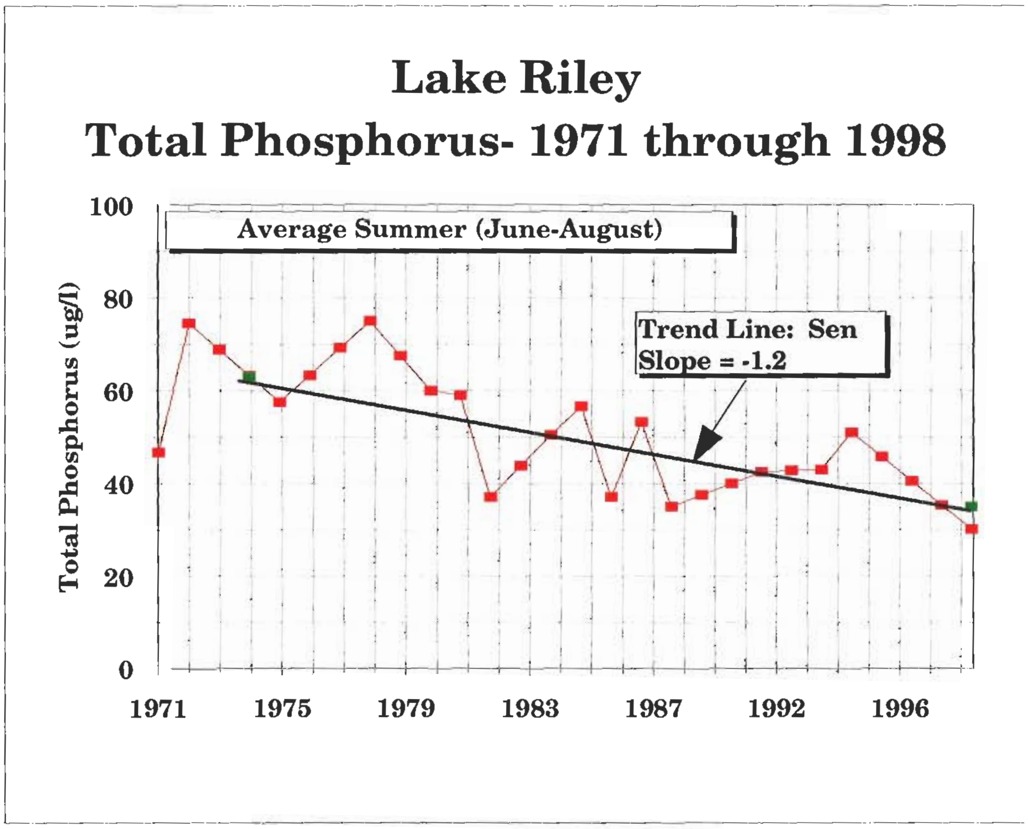
Total Phosphorus TSI		Chlorophyll TSI		Secchi Disc TSI	
Baseline (1971-1987)	Current (1988-1998)	Baseline (1971-1987)	Current (1988-1998)	Baseline (1971-1987)	Current (1988-1998)
Range: 56-66	Range: 55-61	Range: 58-68	Range: 62-66	Range: 49-62	Range: 55-62
Mean: 61	Mean: 58	Mean: 64	Mean: 64	Mean: 55	Mean: 58
1971: 60	1988: 55	1971: 62	1988: 62	1971: 62	1988: 57
1972: 64	1990: –	1972: 60	1990: 66	1972: 55	1990: 59
1975: 63	1991: 58	1975: 66	1991: 64	1975: 57	1991: 55
1978: 66	1994: 61	1978: 61	1994: 63	1978: 49	1994: 57
1980: 63	1998: 57	1980: 65	1998: 64	1980: 60	1998: 62
1981: 63		1981: 62		1981: 49	
1982: 57		1982: 58		1982: 52	
1984: 61		1984: 67		1984: 60	
1985: 62		1985: 68		1985: 52	
1986: 56		1986: 68		1986: 54	
1987: 61		1987: 68		1987: 56	

2.6.2 Historical Water Quality—Trend Analysis

A trend analysis of Lake Riley was completed to determine if the lake had experienced significant degradation or improvement during the years for which water quality data are available. The results of the trend analysis show no significant change in the lake's water quality during the 1974 through 1998 period. The analysis was based upon Secchi disc transparency, total phosphorus, and chlorophyll *a* observations collected since 1974 (24 years of data). Standard statistical methods (i.e., linear regression and analysis of variance) were used to complete the analysis. Plots of the three water quality variables and the fitted regression lines are shown in Figures 15 through 17.

Two criteria must be met to conclude the lake's water quality has significantly improved or declined. First, the trend in a variable was considered significant if the slope of the regression was statistically significant at the 95 percent confidence level. Second, a conclusion of degraded water quality requires concurrent increases in total phosphorus and chlorophyll *a* concentrations, and decreases in Secchi disc transparencies; a conclusion of improvement requires the inverse relationship. The results for the three variables show that phosphorus concentrations have significantly declined (i.e., water quality improvement), Secchi disc transparency has significantly declined (i.e., water quality degradation), and chlorophyll concentrations have not significantly changed. Hence, despite fluctuations in the lake's water quality, the water quality of the lake has remained relatively stable over time.

The results of the regressions indicate that Secchi disc transparency has been declining at an average rate of 0.02 meters per year (less than 1 inch); chlorophyll *a* concentration in the epilimnion (upper 6 feet) has increased at the rate of 0.07 μg/L per year; total phosphorus concentration in the epilimnion (upper 6 feet) has been decreasing at a rate of 1.2 μg/L per year. The changes in Secchi disc and total phosphorus are significantly different from zero statistically, but the chlorophyll changes are not significant. Hence, the data indicate the lake's current water quality problems are unlikely to change unless management practices are implemented to improve the lake's water quality.



Seasonal Kendall Test
Test Statistic = -11.050

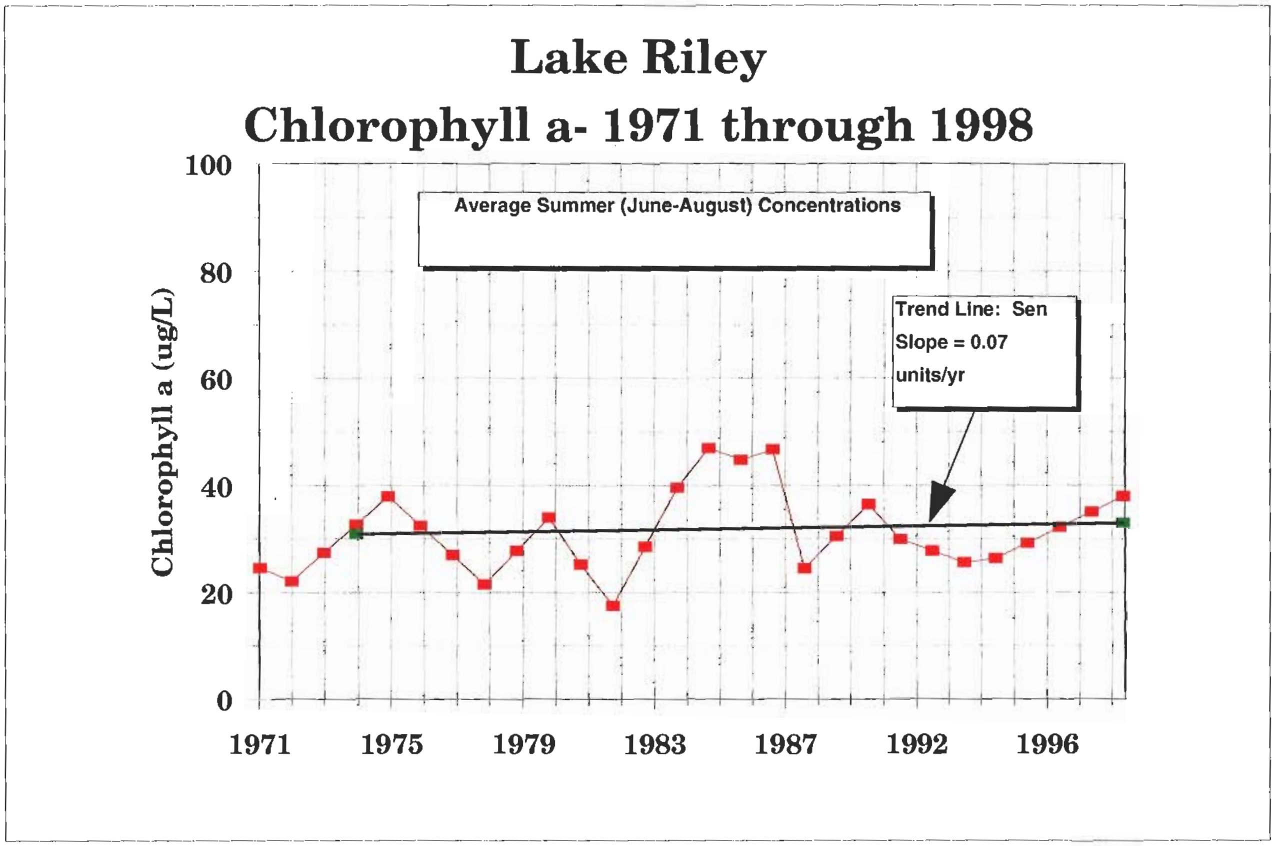
confidence level	test	significance*
95%	-11.050<-1.960	SIGNIFICANT
90%	-11.050<-1.645	SIGNIFICANT
80%	-11.050<-1.282	SIGNIFICANT

*Slope significantly different from zero at the indicated confidence level.

Seasonal Kendall Sen Slope Estimate: Slope = -1.21969 units/year

Seasonal Kendall Trend Analysis of Total Phosphorus
and Time Since 1974 for Lake Riley

Figure 15



Seasonal Kendall Test
Test Statistic = 1.011

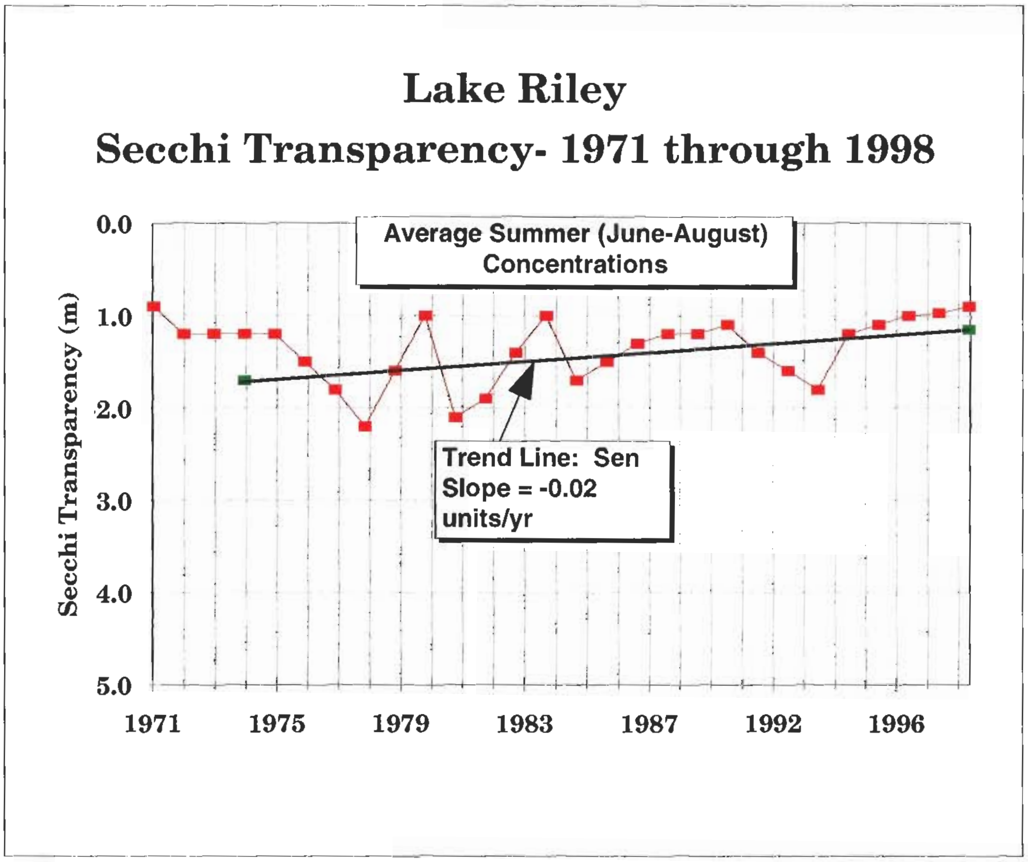
confidence level	test	significance*
95%	-1.960<1.011<1.960	NOT significant
90%	-1.645<1.011<1.645	NOT significant
80%	-1.282<1.011<1.282	NOT significant

*Slope significantly different from zero at the indicated confidence level.

Seasonal Kendall Sen Slope Estimate: Slope = 0.06829 units/year

Seasonal Kendall Trend Analysis of Chlorophyll a and
Time Since 1974 for Lake Riley

Figure 16



Seasonal Kendall Test
Test Statistic = -6.647

confidence level	test	significance*
95%	-6.647 < -1.960	SIGNIFICANT
90%	-6.647 < -1.645	SIGNIFICANT
80%	-6.647 < -1.282	SIGNIFICANT

*Slope significantly different from zero at the indicated confidence level.

Seasonal Kendall Sen Slope Estimate: Slope = -0.02177 units/year

Seasonal Kendall Trend Analysis of Secchi Disc Transparencies and Time Since 1974 for Lake Riley

Figure 17

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2.6.3 Water Quality Modeling Analysis

During preparation of the District water management plan, the Dillon and Rigler model was used to estimate the lake water quality conditions. The model was the best available tool during plan preparation. During 2000, the U.S. EPA released the AQUATOX model, a modular, process-based, fate and effects model for aquatic ecosystems. U.S. EPA has supported the development of AQUATOX, and encourages the use of the model for eutrophication modeling and studies of total maximum daily load (TMDL). AQUATOX has the capability of using the daily time step loading data from the P8 Urban Catchment Model to predict daily or seasonal changes in chlorophyll *a*, and the biomass of algae groups, such as greens and blue-greens. Furthermore, the model calculates daily water transparency (Secchi depth), and dissolved oxygen in the epilimnion and hypolimnion.

The AQUATOX model was found to be the appropriate model to estimate the water quality of Lake Riley under varying climatic conditions. Hence, the AQUATOX model was calibrated to 1998 Lake Riley conditions (i.e., model calibration year). The model was then used to estimate the average summer total phosphorus and chlorophyll concentrations in the upper 6 feet of Lake Riley under wet, dry, and average conditions for existing and proposed future land uses. Secchi disc transparency values (SD) were estimated using AQUATOX model chlorophyll *a* concentrations (CHL) and Heiskary & Wilson's (1990) empirical equation for SD-CHL (mean summer values) for phosphorus limited lakes: $Log_{10}SD = -0.59\ Log_{10}\ CHL + 0.89$.

The modeling analysis indicates the lake currently has poor or very poor water quality under all but dry climatic conditions. A comparison of the lake's modeled total phosphorus and chlorophyll concentrations and Secchi disc transparency measurements with a standardized lake rating system indicates the average summer values were within the:

- **Hypereutrophic** (i.e., very poor water quality) category during wet climatic conditions, under existing watershed land use conditions
- **Eutrophic** (i.e., poor water quality) category during: (1) calibration and average climatic conditions, under existing watershed land use conditions; and (2) all wet, dry, and average climatic conditions, under proposed future land use conditions
- **Mesotrophic** (good water quality) category during dry climatic conditions, under existing watershed land use categories

The modeling analysis confirms that the lake is currently unable to meet the District water quality goal under all but dry climatic conditions, and under virtually all climatic conditions in the future.

The lake's water quality can be improved by reducing phosphorus loaded to the lake from its watershed and by treating the lake with alum. Phosphorus reduction can be attained by implementing the management practice discussed in Section 2.2.1.2—Riley Creek (manage practice). Alum treatment of the lake, discussed in Section 2.4—Water Based Recreation (manage practice) will remove excess phosphorus loads currently present in the lake and reduce internal phosphorus loading by approximately 71 pounds annually for around 10 years. Treatment of Highway 312 runoff, discussed in 2.2.3 Highway 312 Impacts, will facilitate goal attainment by the two lake improvement alternatives discussed in this paragraph.

2.7 Major Hydrologic Characteristics

The major hydrologic characteristics of the lake have changed from the pre-development period. Change continued throughout the development of the watershed. Although the watershed is nearly developed, some additional development will occur to attain proposed future watershed land use conditions. The lake's annual water load is expected to increase by about 12 to 13 percent under proposed future watershed land use conditions. Hence, the lake's hydrologic residence time is expected to decrease by 8 to 18 percent upon attainment of proposed future watershed land use 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. Watershed urbanization is nearly complete. However, future redevelopment within the watershed could result in density increases and increased phosphorus loading to the lake. Increased density in residential development and increased commercial development are both possible in the future. Proposed land use changes within the lake's watershed should be analyzed to determine whether increased phosphorus loading to the lake would result from the changes. Management practices to prevent phosphorus loading increases should be required of land use changes to prevent degradation of the lake's water quality.

- **Add**—Detention basins may be required of developments to remove phosphorus from runoff waters.

3.0 Lake Riley Goals

The approved water management plan of the Riley-Purgatory-Bluff Creek Watershed District articulated five specific goals for Lake Riley. These goals address recreation, aquatic communities, water quality, water quantity, and wildlife. A discussion of the goals follows.

3.1 Water Quantity Goal

The water quantity goal for Lake Riley 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 Lake Riley is predicated upon the lake's recreational goal. The goal is to achieve a water quality that will fully support the lake's swimmable use. The specific District goal is to achieve and maintain a $TSI_{SD} \leq 53$.

The water quality goal has not been achieved, but can be achieved through the implementation of lake and watershed practices. Two different alternatives will achieve or exceed the District water quality goal. Figure 18 compares costs of the two alternatives and Table 20 compares water quality benefits of the two alternatives under varying climatic conditions. The two alternatives are:

- **WQ-1: Manage Rice Marsh Lake** (treat Rice Marsh Lake with alum and lime slurry)
- **WQ-2: Manage Rice Marsh Lake** (treat Rice Marsh Lake with alum and lime slurry); **Manage Lake Riley** (treat Lake Riley with alum); and **Treat Highway Runoff** (treat Highway 312 runoff with four or five ponds meeting MPCA- and NURP-criteria)

Table 20 Benefits of Water Quality Management Alternatives

Alternative	Trophic State Index (TSI) Secchi Disc Value			
	District Goal	Wet Year (1983, 41")	Average Year (1995, 27")	Dry Year (1988, 19")
Existing Watershed Land Use				
Manage Rice Marsh	≤53	43	46	45
Manage Rice Marsh and Lake Riley	≤53	39	39	38
Proposed Future Watershed Land Use				
Manage Rice Marsh	≤53	46	48	49
Manage Rice Marsh and Lake Riley, and Treat Highway Runoff	≤53	40	39	44

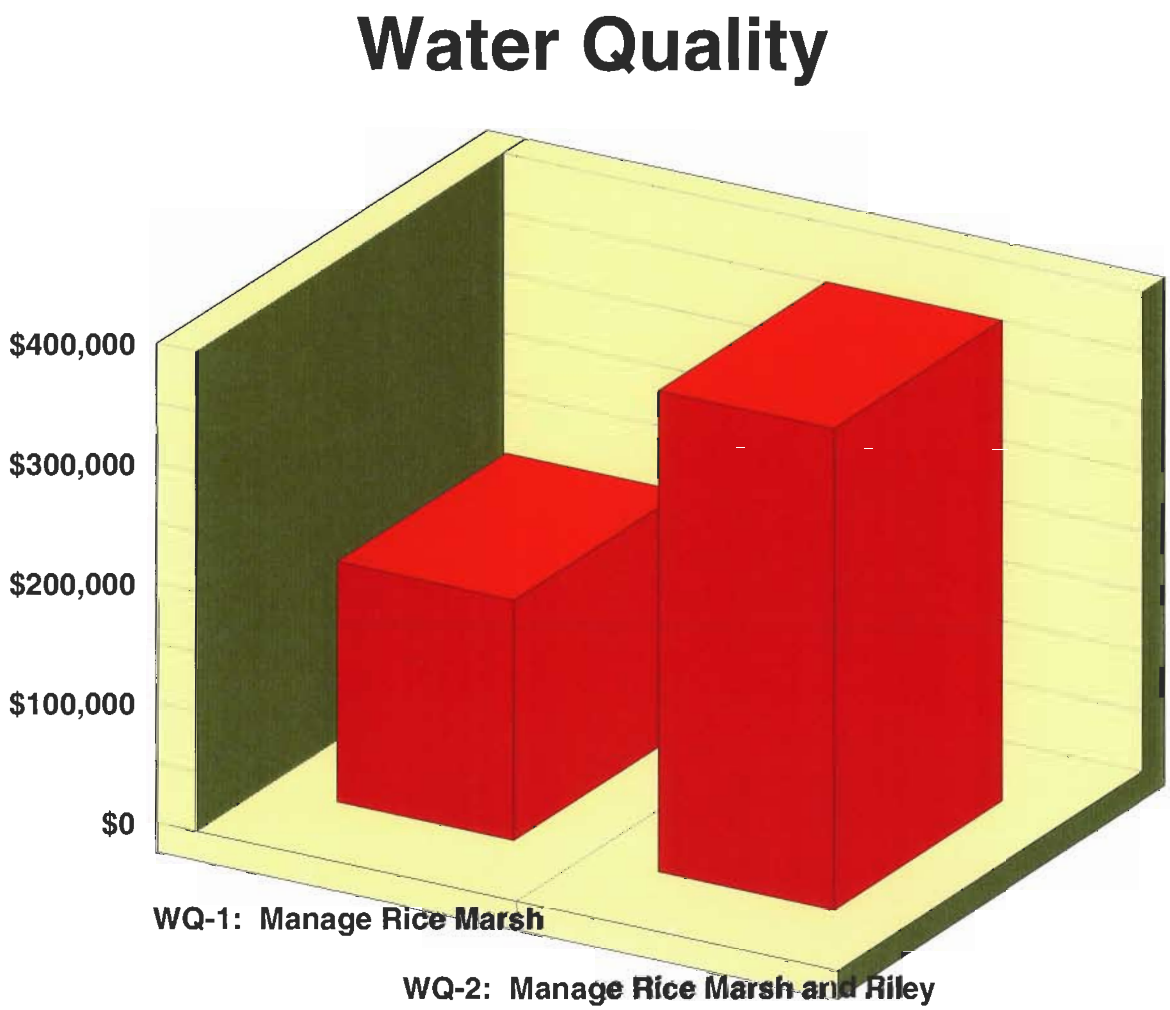

Figure 18

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3.3 Aquatic Communities Goal

The aquatic communities goal of Lake Riley is to achieve and then maintain a water quality that fully supports the lake's fisheries-use classification determined by the MDNR in accord with the MDNR *An Ecological Classification of Minnesota Lakes with Associated Fish Communities.* Specifically, the goal is to achieve and maintain a $TSI_{SD} \leq 56$. The lake currently has a good quality fishery and, hence, the goal is to maintain the lake's current fishery. The lake's current water quality does not provide the desired habitat for the lake's fishery. Hence, the aquatic communities goal has not been achieved. However, the goal can be achieved through the implementation of lake and watershed management practices. Two different alternatives will achieve or exceed the District aquatic communities goal. Figure 19 compares costs of the two alternatives and Table 20 compares water quality benefits of the two alternatives under varying climatic conditions. The two alternatives are the same alternatives described in Section 3.2-Water Quality Goal.

3.4 Recreation Goal

The recreation goal is to fully support the lake's recreational use classification and its MDNR ecological class 24 rating. Goal details follow:

- Lake Riley supports a variety of recreational activities. Swimming, however, requires a higher water quality than other recreational activities. Hence, the recreational goal is to achieve a water quality that fully supports swimming. Achieving this goal will ensure the lake supports all recreational activities. The recreation goal was based upon the MPCA *Use Support Classification for Swimming Relative to Carlson's Trophic State Index by Ecoregion* and the *Minnesota Lake Water Quality Assessment Data: 1997—An Update to Data Presented in the Minnesota Lake Water Quality Assessment Report: 1990* (MPCA 1998). The documents define the water quality criteria required for a full support of swimming. The criteria are based upon a lake's water quality and its location. The MPCA has divided the state into four areas called ecoregions: Northern Lakes and Forests, North Central Hardwood Forests, Northern Glaciated Plains, and Western Corn Belt Plains. The MPCA then established phosphorus criteria (Heiskary and Walker, 1988) for full support of swimming in each ecoregion. The criteria were based upon user opinions regarding a water quality that fully supports swimming. The opinions were expressed as phosphorus concentrations compared with a standardized lake rating system (Carlson's TSI scale to establish a use support threshold for each ecoregion). Because the lakes in the Northern Lakes and Forests were of better water quality than lakes in other ecoregions, user expectations were higher for this ecoregion. Hence, higher criteria were established for full support of swimming for this ecoregion. Phosphorus criteria for the Northern Lakes and Forests ecoregion is $[P] \leq 30$ $\mu g/L$ and a $TSI_{SD} \leq 50$. Lake Riley is in the North Central Hardwood Forests ecoregion. Because

Aquatic Communities

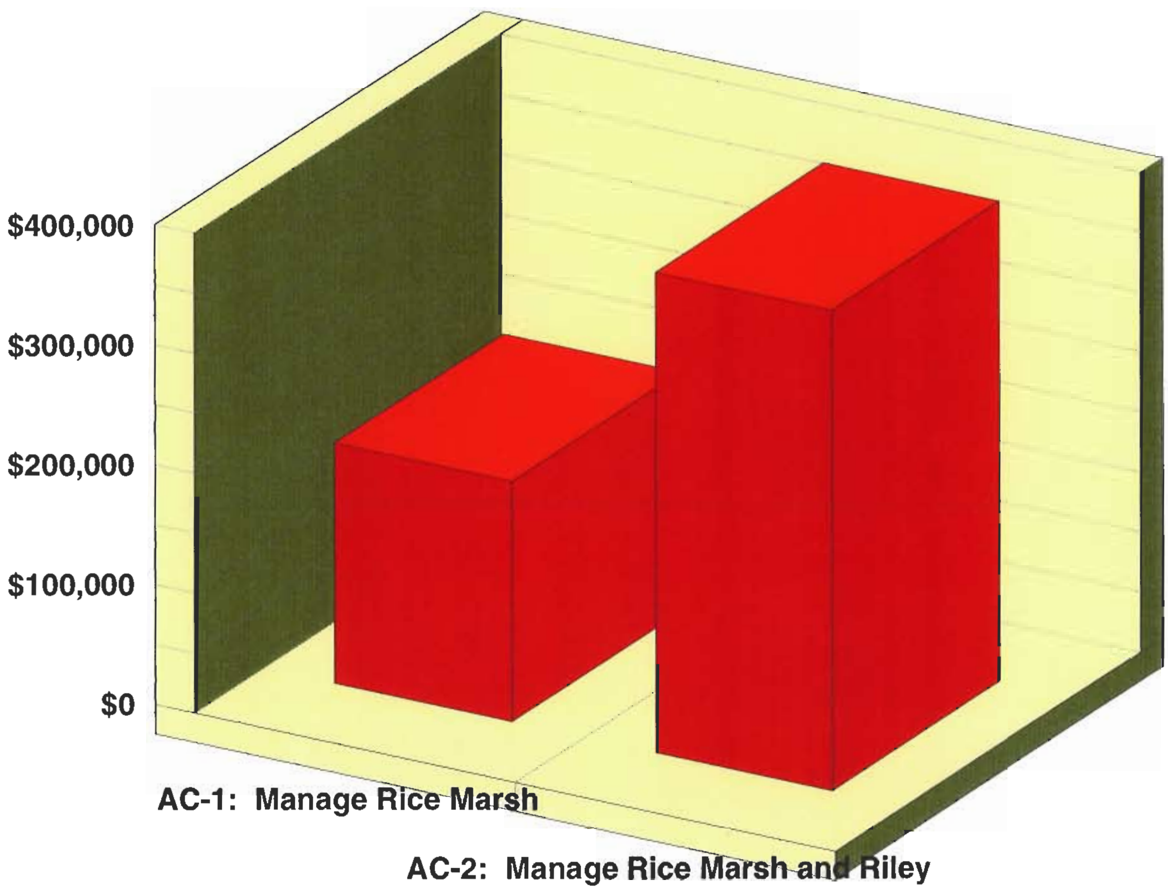

Figure 19

P:\23\27\053\rileyuaa\report\man_cost.wb2:Management Cost lake water quality in the North Central Hardwood Forests ecoregion is lower than lake water quality in the Northern Lakes and Forests ecoregion, user expectations are somewhat lower. Hence, a water quality goal reflective of poorer water quality was established for the North Central Hardwood Forests ecoregion. Phosphorus criteria for the North Central Hardwood Forests ecoregion is [P] $\leq$40 μg/L and a $TSI_{SD} \leq 53$. The criteria ensures that conditions associated with "impaired swimming" would occur less than 10 percent of the summer. Phosphorus concentrations above criteria levels result in greater frequencies of nuisance algal blooms and increased frequencies of "impaired swimming." The upper threshold for partial support of swimmable use was set at 60 μg/L for the lake's ecoregion. As phosphorus concentrations increase from about 10 μg/L to 60 μg/L, summer mean chlorophyll concentrations increase from about 30 μg/L to 60 μg/L, and Secchi disc transparency decreases from about 1.7 meters to 0.8 meters. Over this range, the frequency of nuisance algal blooms and reduced Secchi disc transparency results in a high percentage of the summer (26 to 50 percent) perceived as "impaired swimming." Because a public swimming beach is located on Lake Riley, the District has established a water quality goal to insure the lake fully supports swimming. The goal is to achieve and maintain a $TSI_{SD} \leq 53$.

- Achieve and then maintain a water quality that fully supports the lake's fisheries-use classification determined by the MDNR in accord with the MDNR *An Ecological Classification of Minnesota Lakes with Associated Fish Communities.* Specifically, the goal is to achieve and maintain a $TSI_{SD} \leq 56$. Goal achievement will fully support the lake's WDNR ecological class 24 rating.

The recreation goal has not been achieved. The goal can be achieved through the implementation of lake and watershed management practices. Two different alternatives will achieve or exceed the District water quality goal. Figure 20 compares the costs of the two alternatives and Table 20 compares the water quality benefits of the two alternatives under varying climatic conditions. The two alternatives are the same alternatives discussed in Sections 3.2—Water Quality Goal and 3.3—Aquatic Communities Goal.

Recreation

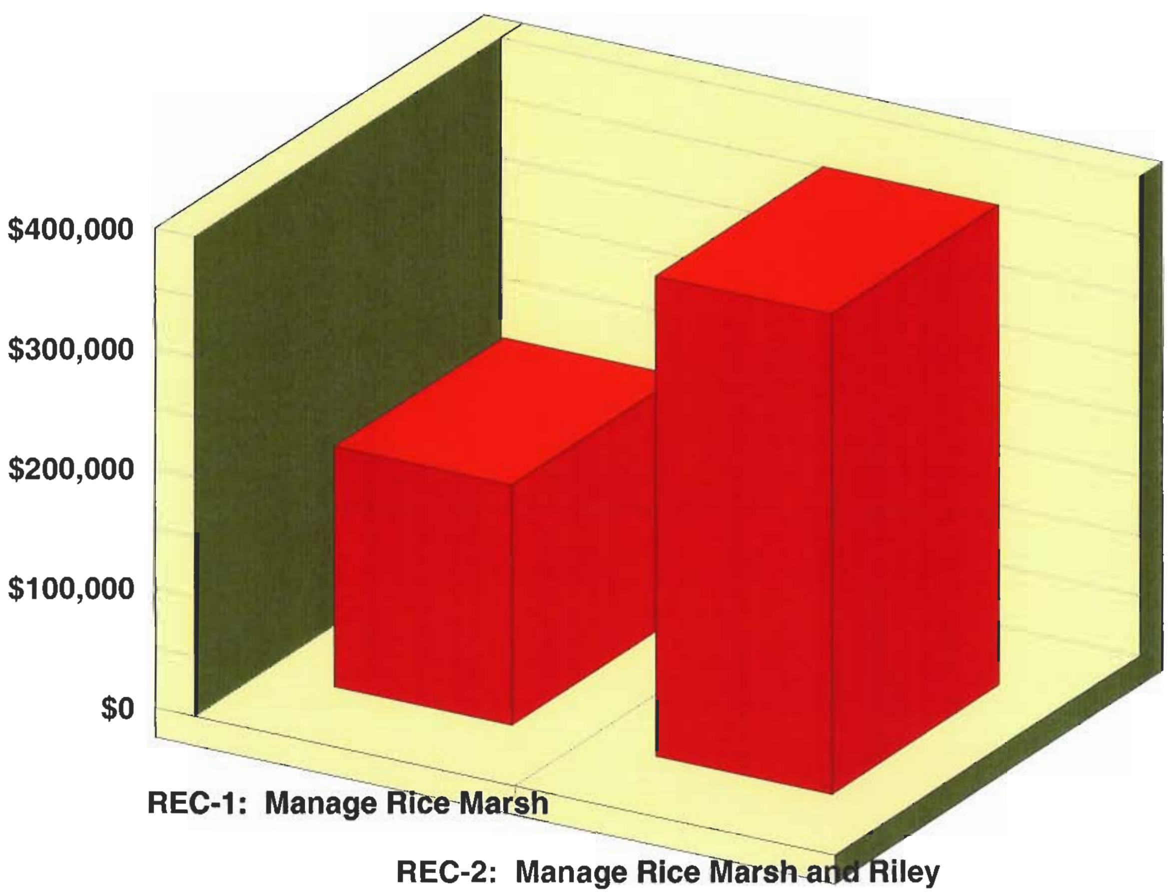

Figure 20

3.5 Wildlife Goal

The wildlife goal for Lake Riley 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 a 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

Two different lake improvement alternatives will achieve or exceed District goals for Lake Riley.

The two alternatives are:

- **Manage Rice Marsh Lake** (treat Rice Marsh Lake with alum and lime slurry)
- **Manage Rice Marsh Lake** (treat Rice Marsh Lake with alum and lime slurry); **Manage Lake Riley** (treat Lake Riley with alum); and **Treat Highway Runoff** (treat Highway 312 runoff with four or five ponds meeting MPCA- and NURP- criteria)

The two alternatives were evaluated to compare cost and benefit differences. Treatment of Rice Marsh Lake with a mixture of alum and lime slurry is expected to achieve the District's water quality goals for Lake Riley. However, displacement of the higher phosphorus waters within Lake Riley with lower phosphorus waters from Rice Marsh Lake following treatment may take several years. Hence, goal achievement may take several years to accomplish. Alternatively, treatment of Lake Riley with alum will result in rapid water quality improvement and rapid goal achievement. Concurrently, an alum treatment of Lake Riley will remove the lake's internal phosphorus load for approximately 10 years, further improving the lake's water quality.

Treatment of runoff waters from proposed Highway 312 by 4 or 5 ponds meeting MPCA- and NURP-criteria will minimize phosphorus loading increases to Lake Riley. Treatment of runoff waters will facilitate goal attainment.

Manage Rice Marsh Lake and Lake Riley and Treat Highway Runoff was selected as the implementation plan to improve the water quality of Lake Riley. The selected plan provides the greatest benefit to Lake Riley and is expected to result in rapid goal achievement. Details of the selected implementation plan follow.

4.1 Treat Rice Marsh Lake With Alum and Lime Slurry

Treatment of Rice Marsh Lake with an alum/lime slurry mixture will include:

- Collection and analysis of Rice Marsh Lake sediment cores
- Lab experiments to determine alum and lime slurry doses
- Treatment of Rice Marsh Lake with alum/lime slurry mixture

The dosing of alum (i.e., aluminum sulfate) will be determined from an evaluation of the quantity of extractable phosphorus found in the upper 5 centimeters of the lake sediment. The method is based upon the findings of Rydin and Welch (1998). Research results indicated that a failure to consider the quantity of extractable phosphorus in the determination of alum dose has resulted in a low alum dose. Reduced effectiveness and/or short-term effectiveness of alum treatment are consequences of low alum doses.

Five sediment core samples will be collected from the center of Rice Marsh Lake using a piston coring apparatus. A 0-1 meter composite lake sample will also be collected.

One sediment core will be extruded and the upper 5 centimeters of the sediment core will be removed and placed in a sample container. The sample (i.e., upper 5 centimeters of the core) will be analyzed for extractable phosphorus. A portion of the composite lake sample will be analyzed for alkalinity to determine whether buffered alum may be needed. The extractable phosphorus content of the lake sediments will be used to determine alum dosage. Dosage will be based upon a ratio of approximately 100 parts aluminum to 1 part extractable phosphorus.

The four remaining cores will be extruded into clear PVC tubes of 4-inch inside diameter. Approximately 6 inches of extruded lake sediment will be overlaid by three liters of lake water in replicate 3-foot tall microcosms. The microcosms will consist of replicate controls and replicate experimental doses of alum/lime slurry. The alum dosage will be determined from the extractable phosphorus content of the sediment, described in the previous paragraph. A lime slurry dose of approximately 100 mg/L will be used. Following addition of the experimental doses, each microcosm will be capped with 1-inch mineral oil seals. Each microcosm will be allowed to go anaerobic after its mineral oil seal is added. The microcosms will then be mixed continuously using a magnetic stirring apparatus which propels a teflon stirring bar positioned 8 inches above the sediment/water interface. The slowly revolving stirring bar will serve to keep the water layer completely mixed without suspending sediment particles. The microcosms will then be incubated in a darkened chamber at 70 degrees for a period of 22 days. Small water samples will be extracted daily from each microcosm through a sampling port at mid-depth in the water column. The concentrations of total phosphorus in each sample will be analyzed. In addition, samples collected from days 1 and 22 will be analyzed for pH to determine whether the pH meets water quality criteria. Cumulative phosphorus mass will be plotted against days of incubation to determine sediment phosphorus release rates using linear regression techniques. An analysis of the sediment-phosphorus release rates will determine whether the selected dose reduces sediment phosphorus release rates by 90 to 100 percent. If the selected dose is unsuccessful in achieving the rate reduction goal, the experiment will be repeated with higher doses of alum and/or lime slurry. When, selection of an effective alum/lime slurry dose has been completed, Rice Marsh Lake will be treated with the selected alum/lime slurry dose.

4.2 Treat Lake Riley with Alum

The dosing of alum (i.e., aluminum sulfate) will be determined from an evaluation of the quantity of extractable phosphorus found in the upper 5 centimeters of Lake Riley sediment. A sediment core sample will be collected from the center of Lake Riley using a piston coring apparatus. A 0-2 meter composite lake sample will also be collected. The sediment core will be extruded and the upper 5 centimeters of the sediment core will be removed and placed in a sample container. The sample (i.e., upper 5 centimeters of the core) will be analyzed for extractable phosphorus. The composite lake sample will be analyzed for alkalinity to determine whether buffered alum is needed to maintain a pH that meets water quality criteria. The extractable phosphorus content of the lake sediments will be used to determine alum dosage. Dosage will be based upon a ratio of approximately 100 parts aluminum to 1 part extractable phosphorus. Lake Riley will then be treated with the selected dosage of alum.

4.3 Treat Highway Runoff

Treatment of runoff waters from proposed Highway 312 by four or five ponds meeting MPCA- and NURP-criteria will minimize phosphorus loading increases to Lake Riley. Proposed pond locations are shown in Figure 14. One or two treatment ponds will treat runoff waters from subwatersheds 5.22a and 5.23a, resulting in a total of four or five treatment ponds. Pond construction will occur concurrently with Highway 312 construction. Hence, treatment pond costs will be included in Highway 312 construction costs.

References

Barr Engineering Company. 1973a. *1971-1972 Water Quality Inventory*. Prepared for Riley-Purgatory Creek Watershed District.

Barr Engineering Company. 1973b. *1972 Engineer's Annual Report*. Prepared for Riley-Purgatory Creek Watershed District.

Barr Engineering Company. 1976. *1975 Engineer's Annual Report*. Prepared for Riley-Purgatory Creek Watershed District.

Barr Engineering Company. 1979. *1978 Lake Quality Inventory*. Prepared for Riley-Purgatory Creek Watershed District.

Barr Engineering Company. 1982. *1981 Lake Quality Inventory*. Prepared for Riley-Purgatory Creek Watershed District

Barr Engineering Company. 1985a. *1984 Lake Quality Inventory*. Prepared for Riley-Purgatory-Bluff Creek Watershed District.

Barr Engineering Company. 1985b. *Lake Riley Diagnostic Study*. Prepared for the City of Chanhassen, City of Eden Prairie, and Riley-Purgatory-Bluff Creek Watershed District.

Barr Engineering Company. 1989a. *1988 Lake Water Quality Inventory: Lakes Ann, Duck, Hyland, Lotus, Lucy, Mitchell, Red Rock, Rice Marsh, Riley, Round, Staring and Susan*. Prepared for Riley-Purgatory-Bluff Creek Watershed District.

Barr Engineering Company. 1989b. *Lake Riley Chain of Lakes Improvement Project Work Plan*. Prepared for Riley-Purgatory-Bluff Creek Watershed District.

Barr Engineering Company. 1993. *1990 and 1991 Lake Water Quality Inventory and Historical Water Quality Trend Analyses*. Prepared for Riley-Purgatory-Bluff Creek Watershed District.

Barr Engineering Company. 1996. *1993 and 1994 Lake Water Quality Inventory, Trend Analysis, and Mass Balance Modeling*. Prepared for Riley-Purgatory-Bluff Creek Watershed District.

Barr Engineering Company. 1999. *Lake Lucy and Lake Ann Use Attainability Analysis*. Prepared for Riley-Purgatory-Bluff Creek Watershed District

Barr Engineering Company. 1999. *Susan and Rice Marsh Lake Use Attainability Analysis*. Prepared for Riley-Purgatory-Bluff Creek Watershed District.

Barr Engineering Company. 2000. *1996-1999 Lake Water Quality Inventory and Assessment—Lakes: Ann, Lotus, Lucy, Mitchell, Red Rock, Rice Marsh, Riley, Round, and Susan*. Prepared for Riley-Purgatory-Bluff Creek Watershed District.

Burley, K.L., E.E. Prepas, and P.A. Chambers. 2001. *Phosphorus Release from Sediments in Hardwater Eutrophic Lake: the Effects of Redox-Sensitive and -Insensitive Treatments.* Freshwater Biology. 46(8): 1061-1074.

Carlson, R.E. 1977. *A Trophic State Index for Lakes.* Limnology and Oceanography 22 (2): 361-369.

Chambers, P.A., E.E. Prepas, M.E. Ferguson, M. Serediak, M. Guy, and M. Holst. 2001. *The Effects of Lime Addition on Aquatic Macrophytes in Hard Water: in situ and microcosm experiments.* Freshwater Biology. 46(8): 1121-1138.

Dillon, P.J. and F.H. Rigler. 1974. *A Test of a Simple Nutrient Budget Model Predicting the Phosphorus Concentrations in Lake Water.* J. Fish. Res. Be. Can. 31: 1771-1778.

Heiskary, S.A. and W.W. Walker. 1988. *Developing Phosphorus Criteria for Minnesota Lakes.* Lake and Reservoir Management. 4:1-9.

Heiskary, S.A. and C.B. Wilson. 1990. *Minnesota Lake Water Quality Assessment Report—Second Edition—A Practical Guide for Lake Managers.* Minnesota Pollution Control Agency.

IEP, Inc. 1990. *P8 Urban Catchment Model.* Version 2.1. Prepared for the Narragansett Bay Project. Providence, Rhode Island.

Madsen, J.D., J.W. Sutherland, J.A. Bloomfield, L.W. Eichler, and C.W. Boylen. 1991. *The Decline of Native Vegetation Under Dense Eurasian Watermilfoil Canopies.* Journal of Aquatic Plant Management 29: 94-99.

Minnesota Department of Natural Resources (MDNR). 1980. *Recreational Use Survey.*

Minnesota Department of Natural Resources (MDNR). 1996. *Fisheries Lake Survey.*

Minnesota Pollution Control Agency. 1998. *Minnesota Lake Water Quality Assessment Data: 1997—An Update to Data Presented in the Minnesota Lake Water Quality Assessment Report: 1990.* Water Quality Division. Prepared for the Environmental Protection Agency.

Minnesota Pollution Control Agency. 1989. *Protecting Water Quality in Urban Areas.*

Nurnberg, G.K. 1984. *The Prediction of Internal Phosphorus Loads in Lakes with Anoxic Hypolimnia.* Limnology and Oceanography 299(1): 111-124.

Osgood, R.A. 1989. *Assessment of Lake Use—Impairment in the Twin Cities Metropolitan Area.* Prepared for the Minnesota Pollution Control Agency. Metropolitan Council Publication 590-89-130. 12pp.

Osgood, R.A. 1983. *Diagnostic-Feasibility Study of Seven Metropolitan Area Lakes—Part 2: Lake Riley.* Metropolitan Council Publication No. 10-83-093E.

Prepas, E.E, B. Pinel-Alloul, P.A. Chambers, T.P. Murphy, S. Reedyk, G. Sandland, and M. Serediak.. 2001. *Lime Treatment and its Effects on the Chemistry and Biota of Hardwater Eutrophic Lakes.* Freshwater Biology. 46(8): 1049-1060.

Prepas, E.E., J. Babin, T.P. Murphy, P.A. Chambers, G.J. Sandland, A. Ghadouani, and M. Serediak. 2001. *Long-Term Effects of Successive $Ca(OH)_2$ and $CaCO_3$ Treatments on the Water Quality of Two Eutrophic Hardwater Lakes.* Freshwater Biology. 46(8): 1089-1103.

Reedyk, S. E.E. Prepas, and P.A. Chambers. 2001. *$Ca(OH)_2$ Doses on Phosphorus Concentration and Macrophyte Biomass of Two Boreal Eutrophic Lakes Over 2 Years.* Freshwater Biology. 46(8): 1075-1087.

RWMWD. 2001. Unpublished Data from RWMWD Tanner's Alum Treatment Facility.

Rydin, E. and Welch, E.B. 1998. *Aluminum Dose Required to Inactivate Phosphate in Lake Sediments.* Water Res. 32(10): 2969-2976.

Schupp, D.H. 1992. *An Ecological Classification of Minnesota Lakes With Associated Fish Communities.* Investigational Report 417, Minnesota Department of Natural Resources.

Walker, W.W. 1987. *Phosphorus Removal by Urban Runoff Detention Basins.* Lake and Reservoir Management: Volume III. North American Lake Management Society.

Valley, R.D. and R.M. Newman. 1998. *Competitive Interactions Between Eurasian Watermilfoil and Northern Milfoil in Experimental Tanks.* Journal of Aquatic Plant Management. 36(2): 121-126.

Zhang, Y., A. Ghadouani, E.E. Prepas, B. Pinel-Alloul, S. Reedyk, P.A. Chambers, R.D. Robarts, G. Methot, A. Raik, and M. Holst. 2001. *Response of Plankton Communities to Whole-Lake $Ca(OH)_2$ and $CaCO_3$ Additions in Eutrophic Hardwater Lakes.* Freshwater Biology. 46(8): 1105-1119.