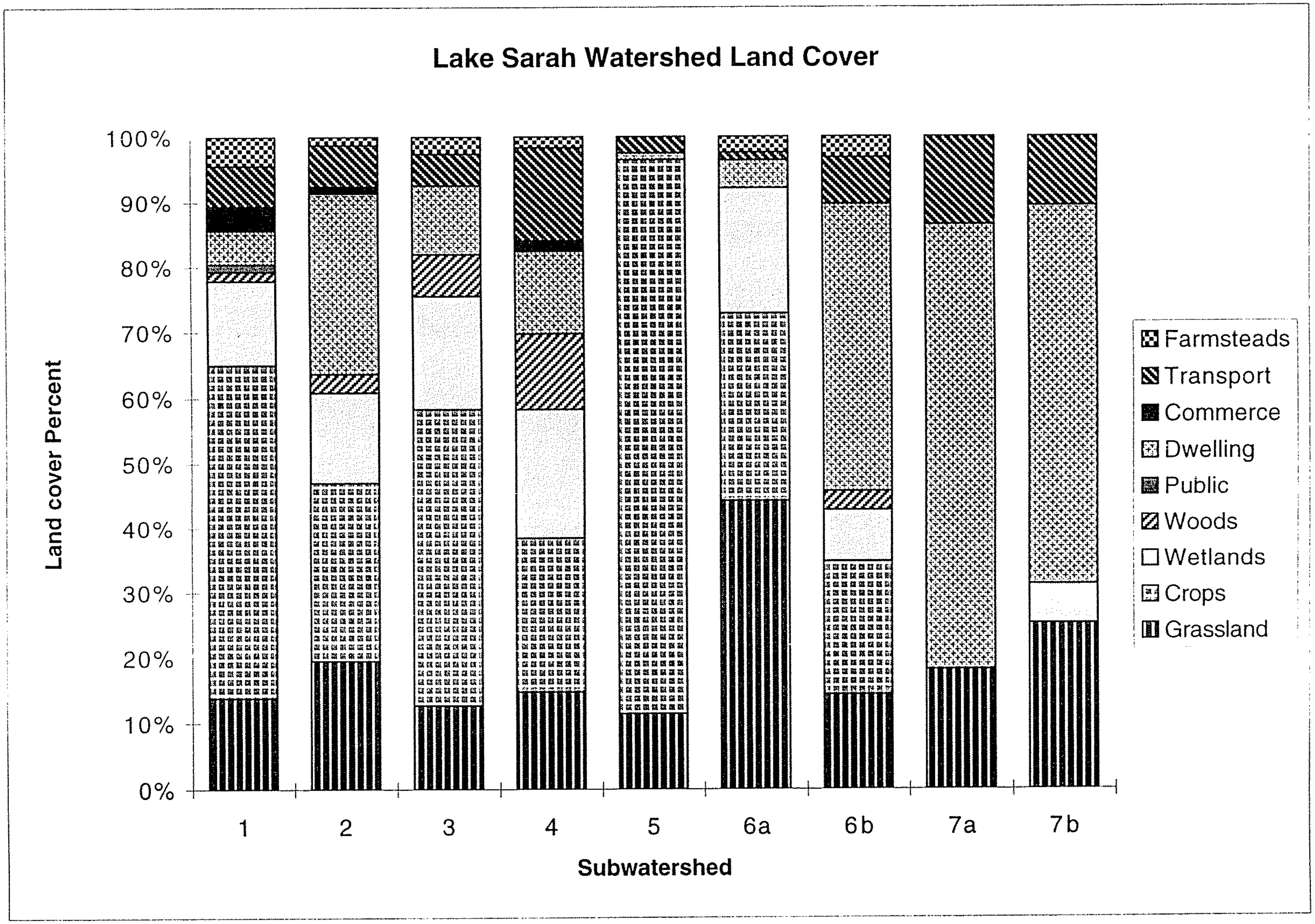
Figure 21. Land Cover by Subwatershed



2.4.3 Subwatershed 3

Subwatershed 3 is the largest of the 7 delineated for evaluation purposes. The subwatershed is 2289 acres in size with 46 percent of the area in crops. The majority of the 400 acres of wetlands have been ditched extensively. Two feedlots are located within this subwatershed. A large wetland just north of the lake through which Dance Hall Creek (Rush Creek) runs serves as pasture for about 30 head of cattle. A feedlot located adjacent to Townhall Road has about 45 cattle and 2 pigs. The feedlot includes an area on both sides of a ditch which is tiled and ditched to Dance Hall Creek. The animals have free access to the water. The feedlot north of Rebecca Park Trail is located at the very northern part of the watershed. This is a horse farm. Drainage from this site is overland to a culvert under Rebecca Park Trail and into a series of wetlands which flow about two miles down to the lake. A 114 acre area is now under development in this subwatershed. The 120 acre area will be converted to 24 lots. Another development, Rush Creek Farm, is proposed just north of Lake Sarah adjacent to Dance Hall Creek (Rush Creek). Fourteen building sites are proposed. For these developments, Nationwide Urban Runoff Program (NURP) ponds will be installed to treat runoff.

2.4.4 Subwatershed 4

Subwatershed 4 is 252 acres with a mixture of land uses. One small feedlot drains by culvert under Lake Sarah Drive and downhill to the lake. An open grass field provides filtration of the runoff before it reaches the lake. The largest two land uses are 24% cropland and 20% wetland. The Lake Rebecca County Park is located in this subwatershed. This area is not considered a pollutant source. This subwatershed includes approximately 30-35 homes adjacent to the lake. A wetland fringe surrounding the lake near the outlet has prevented extensive development in this area. An area of the wetlands around Sarah Creek, the outlet, are included in this subwatershed because there is at times flow back into the lake.

2.4.5 Subwatershed 5

Subwatershed 5 is the smallest subwatershed at 48 acres. This area is 85% cropland which is tiled directly to the lake. Plumes of sediment have been observed flowing from the tile into the lake during rain storms. This area also was spread with Metropolitan Waste Control Commission's nutralime which is high in phosphorus. A grab sample at the tile outlet into the lake showed a high phosphorus concentration. The remainder of this area is drained wetland on

Hennepin Parks property. In 1995, part of this land was developed into average 5 acre residential lots. Some homes are now under construction in this development. The agricultural land is still tiled into the lake. However, it is now routed through a pond. The Commission is cooperating with the developer to convert the pond into a larger 2-cell NURP pond which will treat the water from the majority of the agricultural land as well as from a 6 acre area of the development.

2.4.6 Subwatershed 6

Subwatershed 6 is a 191 acre area with the western half primarily residential lake lots with single family homes. The eastern half of this subwatershed included a dairy farm that is located directly adjacent to the lake. This farm has recently been converted to a small beef cattle operation. A description of this site can be found in part 2.3.2 under agricultural watershed assessment. This area included the Shady Beach Resort which was sold off in August 1993. The area down by the resort is flat and has experienced flooding. A small pond where the campsites were located was tiled to the lake to help alleviate flooding in that area. Erosion is evident along this stretch of shoreline which is located at the narrows of the lake where wave action from boats contributes to the erosion.

2.4.7 Subwatershed 7

Subwatershed 7 consists of 105 acres of which approximately 80% is residential and roadway on the north side of Lake Sarah. This subwatershed consists of all direct drainage to the lake through drainage-ways and the slope to the lake. Culverts under Lake Sarah Heights Drive permit drainage from the area between the road and the railroad tracks to reach the lake. Loading from this subwatershed consists of pollutants from lawn care, residential activities and road runoff.

2.5 Resource Water Quality Goals

The water quality goals for the lake differ depending upon whom is asked. The present lake uses are primarily fishing and boating. The desired uses include more body-contact recreation which is presently not possible due to the algal blooms and more recently the infestation of Eurasian watermilfoil which occur during the growing season. Lake Sarah users would like to see water quality improved to swimmable levels. In order to reach a condition of low frequency of nuisance algal conditions, a phosphorus goal of 35 μg/l is needed. However, this may not be a realistic goal for a lake with a substantially higher phosphorus concentration. Fishing is an important use of the lake. The fishery should be maintained or improved. A TP of no greater than 40 - 60 μg/l is needed to meet these desired conditions.

The water quality of Lake Sarah has been decreasing over a period of many years. Several methods were used to estimate a water quality goal for Lake Sarah. The goal was determined based on total phosphorus concentration since Lake Sarah is normally phosphorus limited.

2.5.1 Method 1 Natural Lake Conditions

In order to determine what the condition of the lake was before the influence of humans, the equation of Vighi and Chiaudani was used (Vighi and Chiaudani, 1985). This equation relates the phosphorus concentration to alkalinity and conductivity. Alkalinity and conductivity provide an indication of natural trophic level as calculated by the Morphoedaphic index (MEI). This index can be used to determine what trophic condition a lake would reach based on its morphometry and natural characteristics of the watershed. This would provide an estimate of potential water quality or a goal for a lake. In the case of Lake Sarah, the MEI was calculated for both alkalinity and conductivity. Alkalinity is less influenced by anthropogenic inputs. However, only three alkalinity values for Lake Sarah were available. Twenty-eight conductivity values were used to calculate the MEI for conductivity.

MEI alk = 0.47

MEI cond = 68.7

Total Phosphorus concentration:

Log [P] = 1.48 +.33 Log MEIalk = 23.4 μg/l (21.9 - 25.1)

Log [P] = .75 + .27 Log MEIcond = 17.6 μg/l (11.1 - 28.1)

These equations indicate that the potential water quality for Lake Sarah, as estimated by phosphorus concentration, is about 20 - 25 μg/l phosphorus.

2.5.2 Method 2 MINLEAP

A phosphorus concentration was calculated using the computer model, MINLEAP (Wilson and Walker, 1989). The estimated TP value indicates potential water quality based upon minimally impacted lakes in the ecoregion. The MINLEAP model predicted a phosphorus concentration of 34 μg/l (Table 14 and 15).

Table 14. MINLEAP Printouts Summer 1991

```
Minnesota Lake Eutrophication Analysis Procedure
ENTER INPUT VARIABLES
LAKE NAME ? Lake Sarah 1991
ECOREGION NUMBER 1=NLF,2=CHF,3=WCP,4=NGP ? 2
WATERSHED AREA (HA)           ? 1812
LAKE SURFACE AREA (HA)        ? 212.7
LAKE MEAN DEPTH (M)           ? 5.5
OBSERVED MEAN LAKE TP (UG/L)  ? 112
OBSERVED MEAN CHL-A (UG/L)    ? 25
OBSERVED MEAN SECCHI (M)      ? 1.11

INPUT DATA:
LAKE NAME =Lake Sarah 1991    ECOREGION=CHF
LAKE AREA = 212.7  HA
WATERSHED AREA (EXCLUDING LAKE) = 1812  HA
MEAN DEPTH = 5.5  METERS
OBSERVED MEAN TP = 112  UG/L
OBSERVED MEAN CHL-A = 25  UG/L
OBSERVED MEAN SECCHI = 1.11  METERS

<press ENTER to view results>



LAKE = Lake Sarah 1991                   ECOREGION = CHF
AVERAGE INFLOW TP = 168.9852  UG/L       TOTAL P LOAD        = 412.4388  KG/YR
LAKE OUTFLOW      = 2.44068   HM3/YR     AREAL WATER LOAD    = 1.147475 M/YR
RESIDENCE TIME    = 4.793132  YRS        P RETENTION COEF    = .7987835

VARIABLE  UNITS        OBSERVED PREDICTED STD ERROR  RESIDUAL    T-TEST
TOTAL P   (UG/L)        112.00     34.00     13.00      0.52       2.86
CHL-A     (UG/L)         25.00     11.38      7.53      0.34       1.10
SECCHI    (METERS)        1.11      1.85      0.81     -0.22      -1.11
NOTE: RESIDUAL = LOG10(OBSERVED/PREDICTED)
      T-TEST FOR SIGNIFICANT DIFFERENCE BETWEEN OBS. AND PREDICTED

CHLOROPHYLL-A INTERVAL FREQUENCIES (%)
CHL-A             PREDICTED PREDICTED PREDICTED
  PPB  OBSERVED     CASE A    CASE B    CASE C
   10     95.25      51.25     51.16     50.74
   20     58.95       7.85      9.57     20.96
   30     26.73       1.19      1.85      9.86
   60      1.95       0.01      0.03      1.73
CASE A = WITHIN-YEAR VARIATION CONSIDERED
CASE B = WITHIN-YEAR + YEAR-TO-YEAR VARIATION CONSIDERED
CASE C = CASE B + MODEL ERROR CONSIDERED
Ok
```

Table 15. MINLEAP Printouts Annual 1991

```
Minnesota Lake Eutrophication Analysis Procedure
ENTER INPUT VARIABLES
LAKE NAME ? Lake Sarah 1991
ECOREGION NUMBER 1=NLF,2=CHF,3=WCP,4=NGP ? 2
WATERSHED AREA (HA)           ? 1812
LAKE SURFACE AREA (HA)        ? 212.7
LAKE MEAN DEPTH (M)           ? 5.5
OBSERVED MEAN LAKE TP (UG/L)  ? 123
OBSERVED MEAN CHL-A (UG/L)    ? 19.85
OBSERVED MEAN SECCHI (M)      ? 1.34

INPUT DATA:
LAKE NAME =Lake Sarah 1991    ECOREGION=CHF
LAKE AREA = 212.7  HA
WATERSHED AREA (EXCLUDING LAKE) = 1812  HA
MEAN DEPTH = 5.5  METERS
OBSERVED MEAN TP = 123  UG/L
OBSERVED MEAN CHL-A = 19.85  UG/L
OBSERVED MEAN SECCHI = 1.34  METERS

<press ENTER to view results>



LAKE = Lake Sarah 1991                     ECOREGION = CHF
AVERAGE INFLOW TP = 168.9852  UG/L         TOTAL P LOAD        = 412.4388  KG/YR
LAKE OUTFLOW      = 2.44068  HM3/YR        AREAL WATER LOAD    = 1.147475 M/YR
RESIDENCE TIME    = 4.793132  YRS          P RETENTION COEF    = .7987835

VARIABLE  UNITS        OBSERVED PREDICTED STD ERROR  RESIDUAL    T-TEST
TOTAL P   (UG/L)         123.00     34.00     13.00      0.56      3.09
CHL-A     (UG/L)          19.85     11.38      7.53      0.24      0.78
SECCHI    (METERS)         1.34      1.85      0.81     -0.14     -0.70
NOTE: RESIDUAL = LOG10(OBSERVED/PREDICTED)
      T-TEST FOR SIGNIFICANT DIFFERENCE BETWEEN OBS. AND PREDICTED

CHLOROPHYLL-A INTERVAL FREQUENCIES (%)
CHL-A               PREDICTED PREDICTED PREDICTED
  PPB  OBSERVED      CASE A    CASE B    CASE C
   10     88.28       51.25     51.16     50.74
   20     39.85        7.85      9.57     20.96
   30     13.54        1.19      1.85      9.86
   60      0.55        0.01      0.03      1.73
CASE A = WITHIN-YEAR VARIATION CONSIDERED
CASE B = WITHIN-YEAR + YEAR-TO-YEAR VARIATION CONSIDERED
CASE C = CASE B + MODEL ERROR CONSIDERED
Ok
```

2.5.3 Method 3 Ecoregion

The 25th - 75th percentile summer phosphorus concentration for minimally impacted lakes in the North Central Hardwood Forests ecoregion is 23 - 50 µg/l (Table 16).

2.5.4 Method 4 User Perception

It is important to consider lake user perception when setting goals. A numerical water quality indicator means little to the average lake user. Rather, lake users want to know how green will it be, how weedy will it be, can I use it for swimming and what type of fish does is support? A lake is considered fully supporting of swimming when impaired swimming conditions or "high algal levels" are estimated to occur less than 10% of the summer (Heiskary and Wilson, 1990). Lakes with an average trophic state index (TSI) < 50 will generally fully support swimming. A TSI of 50 indicates mesotrophic conditions and corresponds to a phosphorus concentration of $\leq$ 24 µg/l. Lakes which exhibit impaired swimming conditions 11-25% of the summer are classified as fully supporting-threatened. These lakes have a TSI of 51-59, corresponding to a phosphorus concentration of approximately 25-45 µg/l, chlorophyll *a* concentration of 8-20 µg/l and Secchi disk transparency of 1.1 - 1.9 meters.

2.5.5 Method 5 Fisheries

Lake Sarah is a popular fishing lake in the metropolitan area. Maintenance of the fishery is important to lake users. Fish species present are dependent upon a number of factors including nutrient concentration. The nutrient concentration also affects the dissolved oxygen present in the water column. Poor dissolved oxygen conditions may result in loss of game fish and survival of the more tolerant rough fish. The bass-panfish ecological class is found in a total phosphorus range of approximately 30-75 µg/l (25th - 75th percentile) (Heiskary, 1990). Bass-panfish-walleye lakes have a slightly lower mean phosphorus concentration, 25-70 µg/l (25th - 75th percentile). Rough fish are common in phosphorus concentrations of 80-240 µg/l (25th - 75th percentile). Lake Sarah is presently managed as a Centrarchid (largemouth bass) lake. This management classification should be maintained or improved. Lake Sarah is classified as Schupp's Lake Type 24. The mean TSI for class 24 is 50.4. This correlates to a TP concentration of about 25 µg/l.

The values calculated for each method were compared to determine an appropriate goal for Lake Sarah:

	Mean
Method 1: 20 - 25 µg/l total phosphorus	23.0
Method 2: 34 µg/l total phosphorus	34.0
Method 3: 23 - 50 µg/l total phosphorus	36.5
Method 4: 24 - 45 µg/l total phosphorus	35.0
Method 5: 30 -75 µg/l total phosphorus	52.5
Mean	36.2

The long term numerical total phosphorus goal for Lake Sarah is 35-40 µg/l.

2.6.6 Pollutant reduction

The 1991 condition of Lake Sarah compared to ecoregion values is listed in Table 16.

Table 16. Ecoregion Lake Data Base Water Quality Summary* (summer average values)

Parameter	Lake Sarah	North Central Hardwood Forests Ecoregion
Total Phosphorus (µg/l)	104	23 - 50
Chlorophyll *a* mean (µg/l)	22	5 - 22
Chlorophyll maximum (µg/l)	38	7 - 37
Secchi disk (feet)	4.5	4.9 - 10.5
TKN (mg/l)	0.72	<0.6 - 1.2
Nitrite + Nitrate (mg/l)	0.47	< 0.01
Alkalinity (mg/l)	129	75 - 150
Color (Pt-Co units)	45	10 - 20
pH (SU)	8.5	8.6 - 8.8
Chloride (mg/l)	11 (1994 data)	4 - 10
Total Suspended Solids (mg/l)	6.5	2 - 6
Total Suspended Inorganics Solids (mg/l)	5.6	1 - 2
Conductivity (µmhos/cm)		300 - 400
TN:TP ratio	12:1	25:1 - 35:1

*Based on interquartile range (25th-75th percentile) for ecoregion reference lakes. Derived in part from Heiskary and Wilson (1990).

Since the intensive monitoring period in 1990-1991, Lake Sarah has been sampled by the Pioneer-Sarah Creek Watershed Management Commission in 1992 and 1994 (Table 17). Hennepin Parks also conducted some monitoring in 1992-1995. The results of these studies and the 5 year average water quality for Lake Sarah are summarized in Table 18. Phosphorus concentrations have decreased since the 1991 intensive monitoring program. Transparency has increased even though chlorophyll *a* concentrations have also shown an increase. The 1994 transparency was skewed by very high spring transparency.

Based upon recent data, it appears that the phosphorus concentration for 1991 was unusually high and is not indicative of present conditions. The TN:TP ratio was also lower than usual. In 1992, a TN:TP ration of 24:1 was calculated (mean TP = 93 µg/l). A ratio of 41:1 was found in 1994 (mean TP = 51 µg/l). The high load of TP in 1991 apparently provided enough phosphorus to shift the lake closer to a nitrogen limited situation. The substantial changes in phosphorus concentration indicate a fairly rapid response to changes in watershed runoff and pollutant loading. As a short term goal for Lake Sarah, phosphorus concentrations should be reduced or maintained at 50-60 µg/l. Because of the response of the lake to changes in the watershed, reductions in pollutant loading to the lake should be noticeable over a period of several years. A hydraulic residence time of approximately two years suggests an approximate two year response time.

Table 17. Lake Sarah Water Quality 1992 & 1994

Lake Sarah 1992	SDT	TP	CHL	NO2+ NO3	NH3	TKN	TN	Lab	COND µmhos/	ALK	CL
	feet	µg/l	µg/l	mg/l	mg/l	mg/l	mg/l	pH	cm	mg/l	mg/l
May	6.2	50	11.9	0.13	0.03	1.14	2.23	8.85	320	139	11.9
June	4.5	71	14.1	0.05	0.47	1.47	1.50	8.45	328		
July	3.0	112	59.2	0.03	0.54	1.02	1.68	8.85	280		
August	2.5	78	21.8	0.12	0.71	1.16	2.95	8.70	282		
September	2.0	153	25.0	0.49	0.76	4.82	2.65	7.75	282		
Mean	3.6	93	26.4	0.16	0.50	1.92	2.20	8.52	298		
Median	3.0	78	21.8	0.12	0.54	1.16	2.23	8.70	282		
Std. Deviation	1.7	40	19.1	0.19	0.29	1.63	0.62	0.46	24		
TSI 63.6	58.7	69.5	62.7								

Lake Sarah 1994	SDT	TP	CHL	NO2 + NO3-N	NH3-N	TKN	TN	Lab	COND µmhos/	ALK.	CL
	feet	µg/l	µg/l	mg/l	mg/l	mg/l	mg/l	pH	cm	mg/l	mg/l
May-18	12.0	41	0.3	0.0705	0.45	1.22	1.67	7.92	347	152	10
Jun-11	9.8	75	9.8	<.030	0.48	2.51	2.99	8.39	377	92	
Jul-12	2.4	12	84.0	<.030	0.39	2.38	2.77	9.40	403	131	
Aug-16	3.3	97	22.1	<.030	0.38	1.75	2.13	8.24	386	125	
Sep-15	2.6	58	121.1	<.030	0.20	1.89	2.09	8.97	367	125	
Mean	6.0	57	47.5		0.38	1.95	2.33	8.58	376	125	10
Median	3.3	58	22.1		0.39	1.89	2.13	8.39	377	125	
Std. Deviation	4.5	33	52.5		0.11	0.52	0.54	0.59	21	22	
TSI 60.7	51.3	62.5	68.5								

Table 18. Lake Sarah Water Quality
5 year summer average (May - Sept)

	TP µg/l	SDT feet	CHL µg/l	TN mg/l
1991	104	4.5	25	1.23
1992	93	3.9	26.4	2.2
1993		5.7		
1994	57	5.6	47.5	2.33
1995		8.8		
Mean	84.7	5.7	33.0	1.9

A comparison of data for samples collected mid month from May - September was conducted to determine if the higher TP concentration found in 1991 was due to the more intensive sampling schedule compared to the Watershed Commission's 5 samples/year program. Values found in this simulation were comparable to that observed for the more intensive monitoring (see Table 19). This indicates that in 1991, the lake water quality was impacted by higher pollutant loading from the watershed or internally. A long term TP goal of 35-40 µg/l seems much more attainable if the phosphorus concentration in the lake is closer to that measured in 1994 rather than the high TP measured in 1991.

Table 19. Comparison of Results Based Upon Sampling Frequency

Parameter	**1991 (10 samples)**	**1991 (5 samples)**
TP µg/l	104	118
SDT feet	4.5	4.6
CHL µg/l	25	18.8

2.6.7 Modeled Lake Response

The BATHTUB model (Walker, 1986) was used to simulate potential future water quality conditions in Lake Sarah with reductions in nutrient loading. Input parameters were adjusted to reflect potential reductions in nutrient loading to the lake. The lake water quality conditions were also altered to model more recent conditions. The results of the various simulations are shown in Table 20.

Several potential concentration values were used as input to the BATHTUB model to simulate reduced pollutant loading to the lake. Using the 1991 lake water quality concentration and reductions in tributary phosphorus concentrations, the lake water quality remained above the 1994 values. Additional model simulations were completed based on the 5 year mean and the 1994 mean water quality data for the lake values. The above scenarios with 50 % reduction in phosphorus concentration and with and without internal loading were modeled. In addition, tributary concentrations were replaced with the mean values of minimally impacted streams for the ecoregion. A value of 145 μg/l TP was used with an estimated soluble reactive phosphorus (SRP) of 50 μg/l.

A 50% reduction in tributary TP concentrations and little to no internal load was needed to reduce in-lake phosphorus concentrations below the 5 year average value of 85 μg/l. The only simulations that resulted in lake phosphorus concentrations near the goal level of 35 μg/l were obtained using the 5 year average lake phosphorus or 1994 mean phosphorus with significant reductions in tributary loading. The model results indicate that tributary phosphorus concentrations will have to be reduced to match that of minimally impacted streams and internal loading must be reduced. For the two major tributaries, a reduction of 75% to 80% of the total phosphorus concentration is indicated.

Table 20. Computer Model Simulations

Parameter	1991 Values	Simulation 1	Simulation 2	Simulation 3	Simulation 4	Simulation 5	Simulation 6	Simulation 7	Simulation 8	Simulation 9
model input										
Tributary TP conc.	measured	25% reduct.	150 - 300	50% reduct.	85	145	measured	300	300	300
Tributary SRP conc.	measured	25% reduct.	100 - 200	50% reduct.	37	50	measured	200	200	200
Lake TP (μg/l)	124.6	124.6	124.6	124.6	85	57	85	85	85	57
Internal load TP (mg/m²/day)	1	0	0.1	0	0	0	1	1	0	0
model output										
Tributary TP Load kg/yr	5614.7	4174.7	2591.1	2751.5	574.2	477.5		2809.6	2809.6	
Internal Load kg/yr	814.5	0	81.5	0	0	0		814.5	0	
Total Load kg/yr	6607	4335.1	2834.1	2912.5	734.3	637.6		3784.5	2970	
Estimated lake TP (μg/l)	126.1	100.8	80.7	77	37.4	34.7	126.1	93.7	82.2	82
Estimated Chl a (μg/l)	19.1	16.2	11.9	12.6	8.9	5.6	21.5	14.5	14.1	12.6
Estimated SD (meters)	1.3	1.3	1.4	1.4	1.5	1.6	1.6	1.8	1.8	1.4
Inflow TP export (kg/km²)	258	192.7	119.6	127	26.5	22		129.7	129.7	

1991 Values: values measured and/or estimated during study
Simulation 1: tributary nutrient concentrations reduced by 25%, no internal load
Simulation 2: 300 μg/l TP on main tributaries, 150 μg/l TP on smaller tributaries, reduced internal load
Simulation 3: tributary nutrient concentrations reduced by 50%, no internal load
Simulation 4: using mean tributary TP based upon Omernik (1977), no internal load
Simulation 5: using mean tributary TP from ecoregion minimally impacted streams, no internal load
Simulation 6: using measured tributary concentrations with 5 year average lake TP
Simulation 7: using reduced tributary concentrations with 5 year average lake TP
Simulation 8: using reduced tributary concentrations with 5 year average lake TP, no internal load
Simulation 9: using reduced tributary concentrations with 1994 average lake TP, no internal load

SECTION 4
CONCLUSIONS

The Lake Sarah Project began with an intensive monitoring program of the lake and its major inlets and outlet. The major data collection was completed in 1991 and 1992. Since that time the Watershed Commission and Hennepin Parks have conducted routine monitoring of the lake. The results indicate that the lake water quality in 1991 was not representative of conditions occurring in most years. The data from more recent years was included in the discussion and recommendations to offset the unusually high phosphorus results for 1991.

The inlet monitoring and computer modeling showed that the majority of the loading comes from the two major inlets, Dance Hall Creek and Loretto Creek. Internal loading was also determined to be a significant source of phosphorus to the lake. The lake retains the majority of the phosphorus carried into it. Several sources of pollutants to the creeks were identified to be addressed in the implementation plan.

Lake Sarah is beyond the need for protection and requires restoration to meet the recreational needs of its users and restore it to its previous state. Water quality goals for the lake were determined using several methods. A long term (5-10 years) phosphorus goal of 35-40 µg/l was recommended. A short term goal (2-5 years) of 50-60 µg/l should be possible considering the more recent lake phosphorus concentrations. Significant reductions in tributary phosphorus concentrations and internal loading are needed to meet the long term water quality goal.

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