WATER QUALITY MODEL STUDY

FOR

LAKE REDSTONE, SAUK COUNTY

Prepared for:

The Lake Redstone Protection and Rehabilitation District

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Conclusions

Based on the results of the monitoring and modeling analysis the following can be concluded.

1. The FLUX model did an adequate job of estimating the tributary flow and loading from Big Creek and Swallow Bay to Lake Redstone.

2. The BATHTUB model did an adequate job of estimating Lake Redstone's pool water quality.

3. The seasonal watershed water loading to Lake Redstone is about 93% of the total and is therefore the largest single source.

4. The seasonal watershed phosphorus loading to Lake Redstone is about 63% of the total and is therefore the largest single source.

5. Of the subwatershed areas monitored, the subarea with the highest seasonal unit area phosphorus export was Swallow Bay at 0.23 Kg/Ha followed by the West Branch at 0.17 Kg/Ha and the East Branch at 0.16 Kg/Ha.

6. The May through September 1996 rainfall at Lake Redstone was slightly below the 30 year normal, however if not for a large storm in June the seasonal total would be significantly below normal.

7. The internal recycling of phosphorus in Lake Redstone comprises about 29% of the seasonal total, but likely is not contributing significantly to algal growth.

8. Dissolved oxygen levels are a problem in Lake Redstone during both the summer and winter. Decomposition of organic sediments results in a "sediment oxygen demand" and reduction in the lake's oxygen levels. Periodic monitoring, especially during the winter, will provide valuable information about these conditions.

Recommendations

1. Continue cooperative efforts in working with watershed farmers to reduce sources of phosphorus to the lake. This effort can include roof drains, grassed waterways, buffer strips or other "low-cost" options. Reductions in loading have occurred and source prevention.should be a high priority of the district.

2. Although the study estimates the contribution of phosphorus from septic systems to be low, management effort should continue in this area. Lake Redstone is heavily developed and poor soils or steep slopes have required the use of holding tanks or septic systems other than conventional septic tanks. Prevention of ground water contamination (and possibly lake discharge) should be a high priority. The use of low or no phosphorus fertilizers and lake shore buffers can minimize site runoff of nutrients and should be encouraged.

3. Develop and implement an education program that informs lake residents about issues related to water quality and lake protection. This program should also discuss realistic goals and expectations about Lake Redstone's water quality.

4. Work with Sauk County to ensure periodic maintenance and yearly operation of the dam's emergency bypass. Keeping the bypass functional is important to the safety and well being of the dam.

5. Continue monitoring the occurrence and distribution of Eurasian water milfoil (an exotic nuisance plant). Spot treatment with selective herbicides will protect native plants and perhaps minimize the expansion of this invasive species.

6. Purchase a dissolved oxygen meter and begin periodic winter monitoring to track conditions and provide information for future planning.

7. Record information such as ice cover dates, ice and snow thickness and water column dissolved oxygen levels at a variety of locations.

8. The Lake Redstone District should continue coordination with the Department's Fisheries Manager on issues related to fish management. Specific fisheries related recommendations are not a part of this document.

Introduction

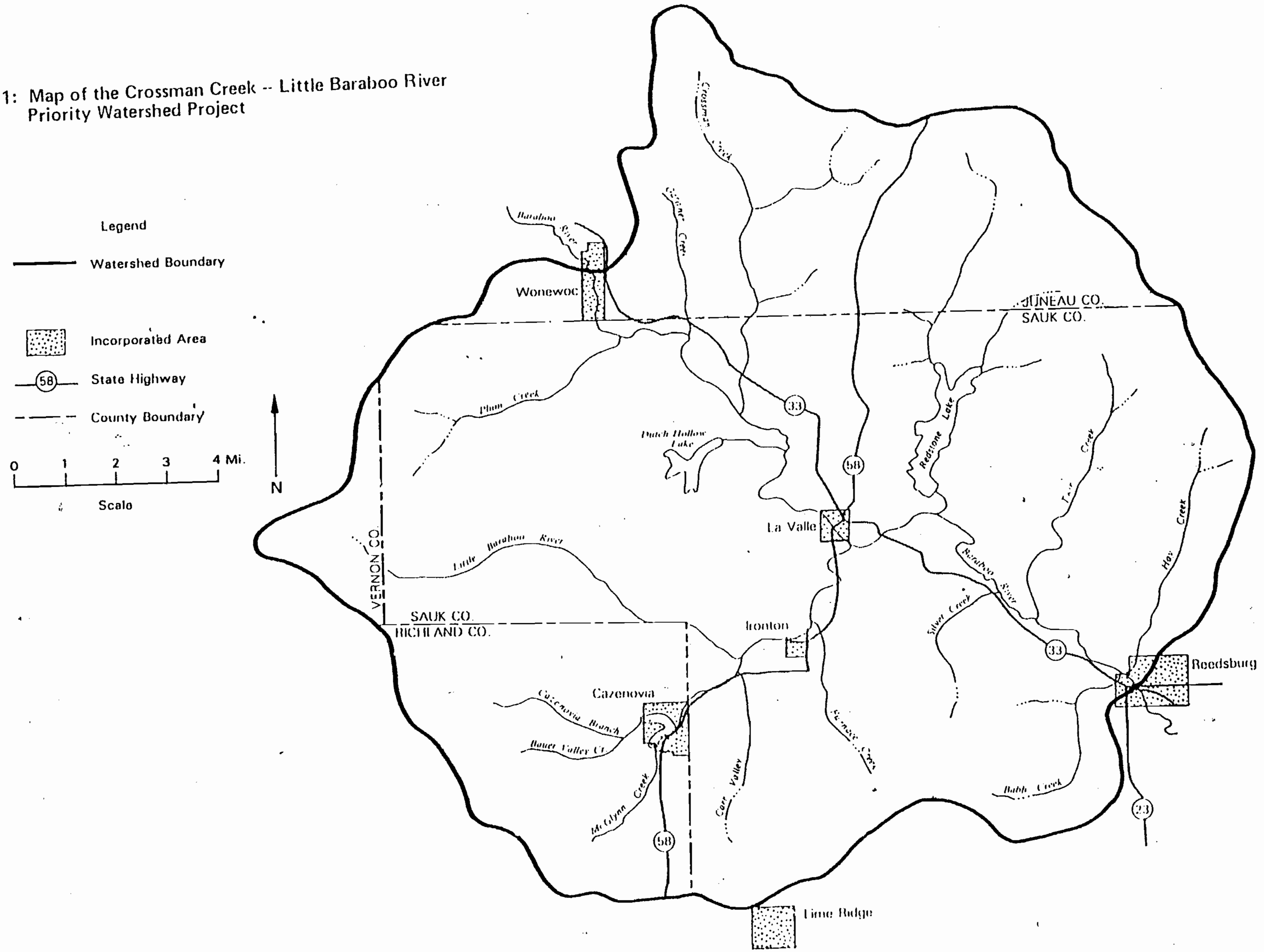
The purpose of this document is a discussion of the water quality and watershed monitoring.

The Lake Redstone District was awarded the Lake Stewardship Award at the 1997 Wisconsin Association of Lakes (WAL) annual convention. This award reflects the dedication and concern of the district about issues related to the lake. These efforts are to be commended and the progressive proactive approach should continue.

Lake Redstone is a 612 acre impoundment located in Sauk County, Wisconsin, near the town of LaValle (see figure 1). The lake was created in 1965 by impounding the lower reach of Big Creek, a tributary of the Baraboo River. The project was undertaken by a real estate developer with the intent of making Lake Redstone the recreational focus of a large residential development. Once the project was completed, over 1,600 lots (450-550 homes have been constructed) were platted around the 16.4 mile shoreline. The lake began to experience degraded water quality shortly after its filling in 1966 and still experiences extensive algal blooms during the summer months, low dissolved oxygen levels and sedimentation. In an effort to better direct management efforts, the Lake Redstone Management District requested planning grant assistance from the Wisconsin Department of Natural Resources. During the summer of 1996 detailed inflow and in-lake sampling was conducted in an attempt to develop water and nutrient budgets for use in a lake response model. This report presents the methods, assumptions and results of the monitoring and modeling effort.

It is important to realize that the model study was done using a seasonal (May-September) time frame and therefore all flow and loading values represent seasonal and not annual values. The modeling was done using a seasonal time period primarily for two reasons, the first being the difficulty in operating and maintaining the stream flow gages over the winter. The second reason is summer water quality in Lake Redstone is most directly influenced by phosphorus loading occurring during the growing season. This seasonal response behavior is not uncommon for reservoirs and is the result of the controlling influence the watershed has on Lake Redstone's water residence time and nutrient loading.

Figure 1: Map of the Crossman Creek -- Little Baraboo River Priority Watershed Project



Methods

Flow Monitoring.

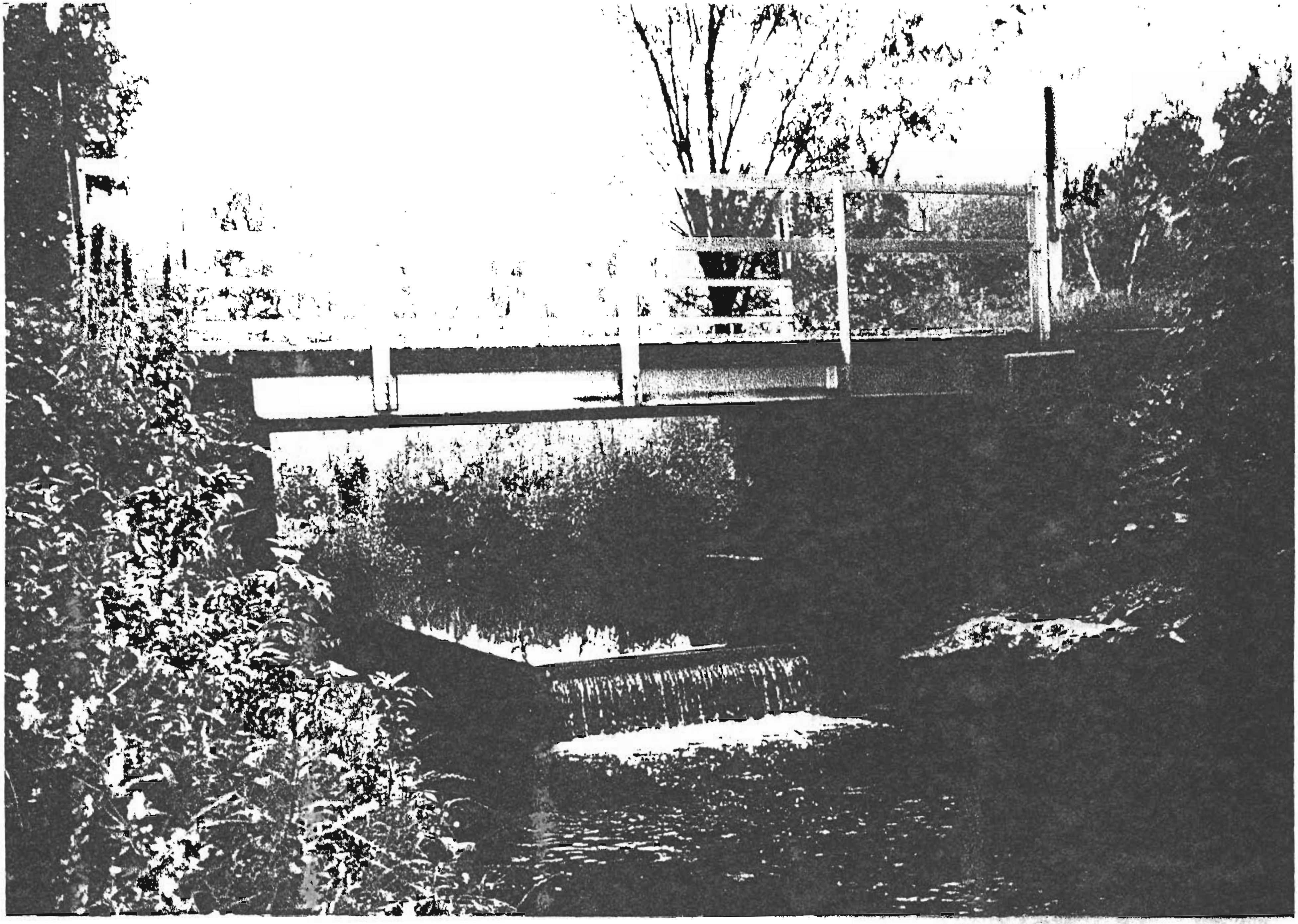
In order to develop water and nutrient budgets for Lake Redstone it was necessary to collect flow and water quality data. Automatic flow recording stations were activated in April of 1996 at Clark Road to monitor the West Branch of Big Creek and at East Redstone Drive to monitor the East Branch of Big Creek. The monitoring equipment was operated and maintained through the end of October 1996. Permanent manhole structures were installed at each site to house equipment and a steel weir was installed at the East Branch site (see figure 2). The flow at the East site was determined using a bubbler flow meter. An area velocity meter was used at the West Branch site and therefore no weir or primary device was needed. ISCO automatic flow recorders and samplers were installed at each site. Continuous flow measurements were taken, averaged and recorded every 15 minutes by an electronic data logger and also on a chart recorder as backup. Storm event samples were flow composited into a single bottle and collected by volunteers from the Lake Redstone Management District. These samples were prepared and shipped immediately to the Wisconsin State Laboratory of Hygiene (SLOH) in Madison for analysis of total and ortho phosphorus. A total of 10 flow composited storm event and 12 inter-event samples were collected at each site.

In addition, ten storm event grab samples and instantaneous flow measurements were taken at the Swallow Bay weir. These samples were shipped to the SLOH for analysis of total and ortho phosphorus. A staff gage was installed on the southeast wing wall of principal spillway on the dam and read daily by a volunteer. A rating curve developed during the 1981 study (IES, 1981) was verified and used to calculate daily flow outflow.

Lake Monitoring.

Three lake monitoring stations were established in Lake Redstone. The upper station was located mid lake approximately 500 feet south of the confluence of the East and West Branches, the middle station was located mid lake approximately 3,500 feet down stream of East and West Branch confluence and the lower station was located mid lake approximately 6,600 feet downstream of the East and West Branch confluence. Surface and bottom samples were collected at each site and analyzed for total phosphorus. Secchi depth, dissolved oxygen and chlorophyll a samples were also collected by DNR staff at the deep hole site approximately 600 feet upstream of the dam. Lake Redstone is one of 50 statewide Long Term Trend (LTT) lakes. Samples are collected 5 times per year including a late winter sample, ice out sample and one each in June, July and August. All samples were sent to the SLOH for analysis. To summarize, samples collected at the most downstream site were collected by WDNR staff, all other samples were collected by volunteers from the Lake Redstone Management District.

Figure 2.



Development of a Water Budget.

The total growing season (May - September) flow volume was calculated using the US Army - Corps of Engineers (USACE) tributary loading model FLUX (Walker, 1996). The 15 minute flow values monitored at the East and West Branch sites were averaged into daily values and entered into FLUX. The flow values calculated at each monitoring site were translated from the gage to the lake using drainage area ratios. The instantaneous flows observed at Swallow Bay were entered into FLUX along with a synthesized continuous flow record developed using the East Branch flow record. The runoff volume from the direct tributary watershed was calculated using a unit area runoff volume of 6.91 inches multiplied by the drainage area. The unit area runoff volume was determined from the tributary monitoring data. The contribution of precipitation on the lake's surface to the water budget was calculated using bulk precipitation data collected at Lake Redstone and the evaporation was calculated using observed pan evaporation data from the Arlington Agricultural Experiment Station. The groundwater flow volume was estimated as the difference between all sources and the observed outflow.

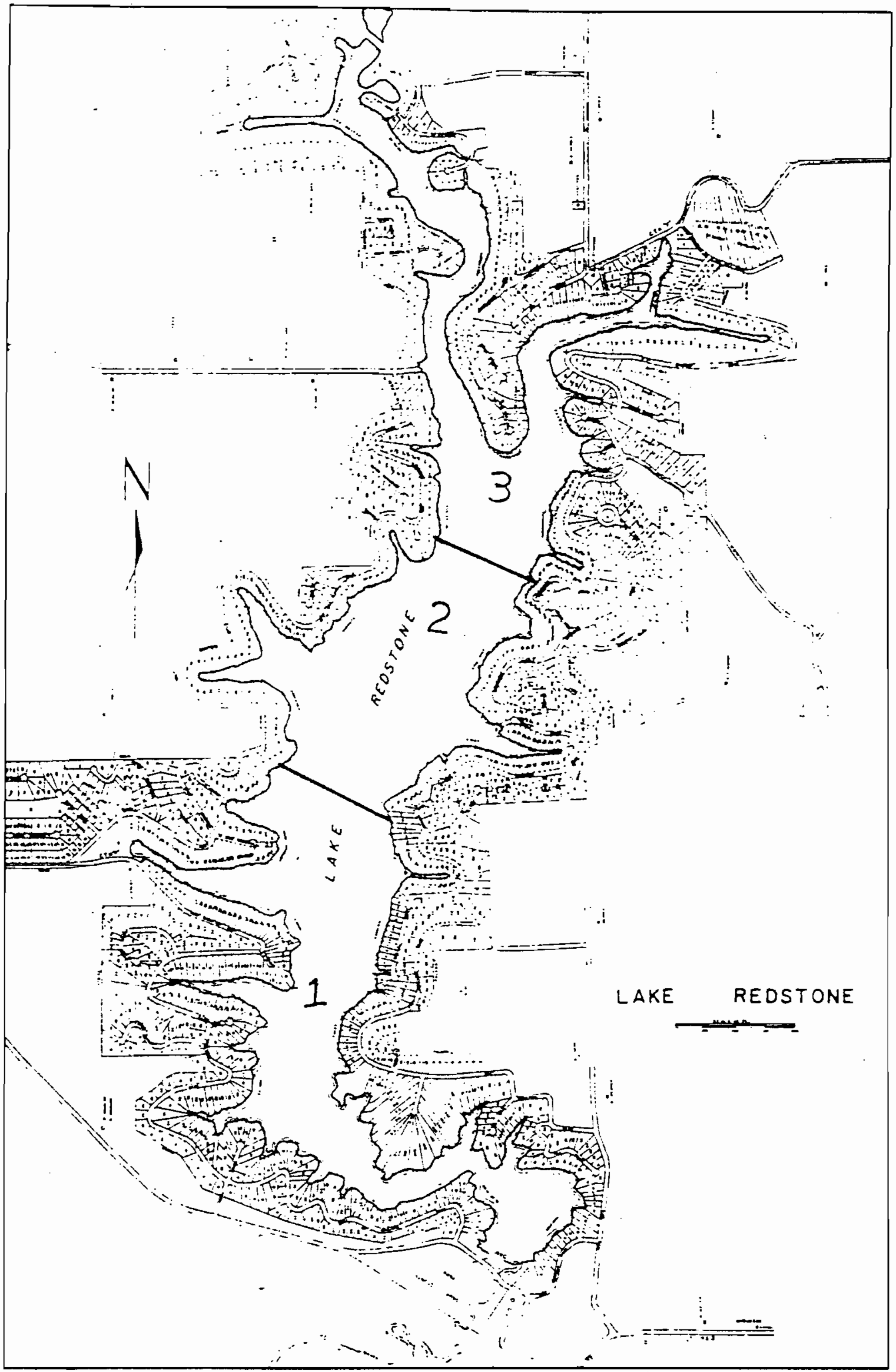
Development of a Phosphorus Budget.

The nutrient of principal water quality concern for Lake Redstone is phosphorus (IES, 1981). It was therefore necessary to know the phosphorus loading to the lake for input into the lake response model. The total growing season phosphorus loading was also calculated using the USACE tributary loading model FLUX (Walker, 1996). The storm event and inter-event sample concentrations were entered directly into FLUX. The total and ortho phosphorus load values calculated at each monitoring site were then translated from the gage to the lake using drainage area ratios. The load entering the lake at Swallow Bay was also calculated using FLUX in conjunction with the concentration of grab samples collected at the weir and a synthesized daily flow record. Phosphorus loading from the direct tributary watershed was determined by multiplying a unit area export of 0.23 Kg/Ha as monitored at Swallow Bay by the direct watershed area. The atmospheric deposition of phosphorus on the lake's surface from precipitation and "dry fall" was determined based on an annual phosphorus atmospheric loading of 0.30 Kg/Ha/Yr. The groundwater phosphorus loading was estimated using a mean phosphorus concentration of 39 ug/l observed in IES (1981) multiplied by the flow volume.

Reservoir Response Modeling.

The USACE BATHTUB model (Walker, 1996) was used to model Lake Redstone's pool water quality and also its response to changes in loading. The reservoir was divided into 3 segments, upper, middle and lower as shown in Figure 3. After all inflow and phosphorus loading sources were entered into BATHTUB, the model was calibrated to the observed in-lake conditions. The calibration was done by setting the phosphorus settling calibration coefficient to 1.0 and adjusting the internal loading to match the observed conditions. For the purpose of modeling it was assumed that the internal loading occurs in the middle segment and a loading value of 2.5 mg/m^2/day was used. Table 1 summarizes the phosphorus,

Figure 3.



chlorophyll a and secchi depth models and calibration values used within BATHTUB.

TABLE 1
Summary of models and calibration coefficients

Parameter	Model	Calibration Coefficient
Phosphorus Retention	No. 3; 2nd Order, Fixed	1.0
Chlorophyll a	No. 5; Jones & Bachmann	1.25
Secchi Depth	No. 1; vs Chl a & Turb.	1.0
Dispersion	Fischer - Numeric	1.0

Evaluation of Watershed Loading Reduction Options.

Crossman Creek - Little Baraboo River, which includes Lake Redstone, was a Priority Watershed project in the mid 1980's. As a part of that priority non-point source protection control project various sites were identified and targeted for corrective measures to reduce nutrient loading to the lake. In Lake Redstone's case, high and medium priority sites were selected for corrective actions. Participation in the voluntary program did not satisfy the recommended goals and nutrient reductions were not met. It has been over 10 years since the watershed project was originally evaluated. Since completion of the watershed project inventory, the priority sites identified in the non-point project may have expanded in size, or may not even be operational. In order, to evaluate the impacts of nutrient reductions it is necessary to update the watershed inventory. Thus, the water quality modelling study was "piggy-backed" with a re-evaluation of the watershed (Midstate, 1997). This watershed re-evaluation looked at the previously identified high and medium priority sites to see if they are still major contributors to the lake. It also looked at other operations to see if they have expanded and what their impact may be. These efforts were also done with a Lake Planning Grant awarded to the lake district. Watershed estimates on nutrient loading were compared to the estimates from the original project to quantify any changes that may have occurred. The model is not designed to identify corrective actions since it operates in a water quality predictive capacity.

Results and Discussion

Runoff.

The seasonal inflows to Lake Redstone are summarized in Figure 4 and the time series graph of flow for the East and West Branch gages are shown in Figure 5. Review of Figure 4 indicates that 93% of the seasonal water input to the lake is from watershed runoff with about 8% from groundwater and a net loss of about 1% from evaporation off the lake's surface. The West Branch of Big Creek produces the largest portion of the runoff with 48% followed by the direct tributary area at 27% and the East Branch with 18%. The unit area seasonal runoff volume from the East and West Branch watersheds was 4.92 and 6.96 inches, respectively. In general, the seasonal rainfall was 4.01 inches below normal with the largest May through September runoff volume on June 17th. As shown in Table 2, the monthly rainfall total for June was 9.56 inches which is 5.6 inches above normal due primarily to the 4 inch storm that occurred on June 17. This 4 inch storm was part of a long rainfall event that lasted June 16th through 19th. The May through September rainfall totals for Lake Redstone are shown in Table 2.

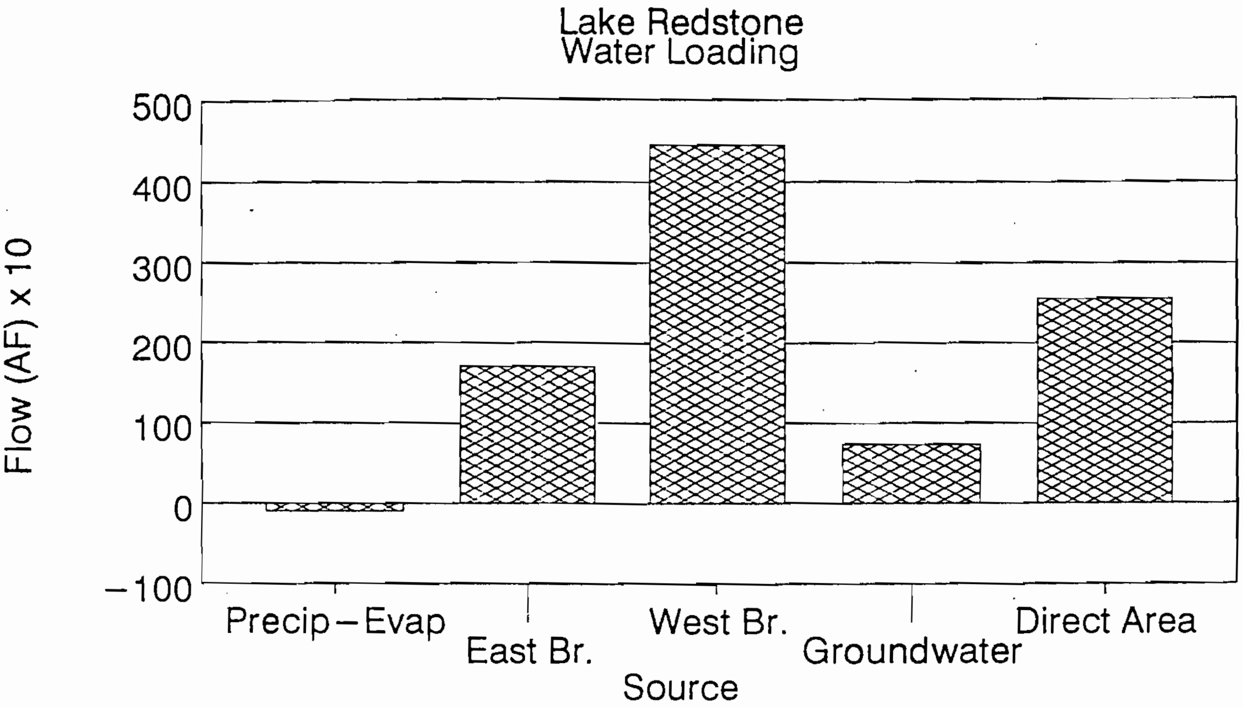
TABLE 2
Seasonal Rainfall in inches for Lake Redstone

Month	Observed Precipitation	30 Year Normal Precipitation *	Departure from Normal
May	0.35	3.4	-3.05
June	9.56	3.96	5.6
July	2.75	3.75	-1.0
August*	1.32	4.37	-3.05
September*	1.38	3.89	-2.51
Total	15.36	19.37	-4.01

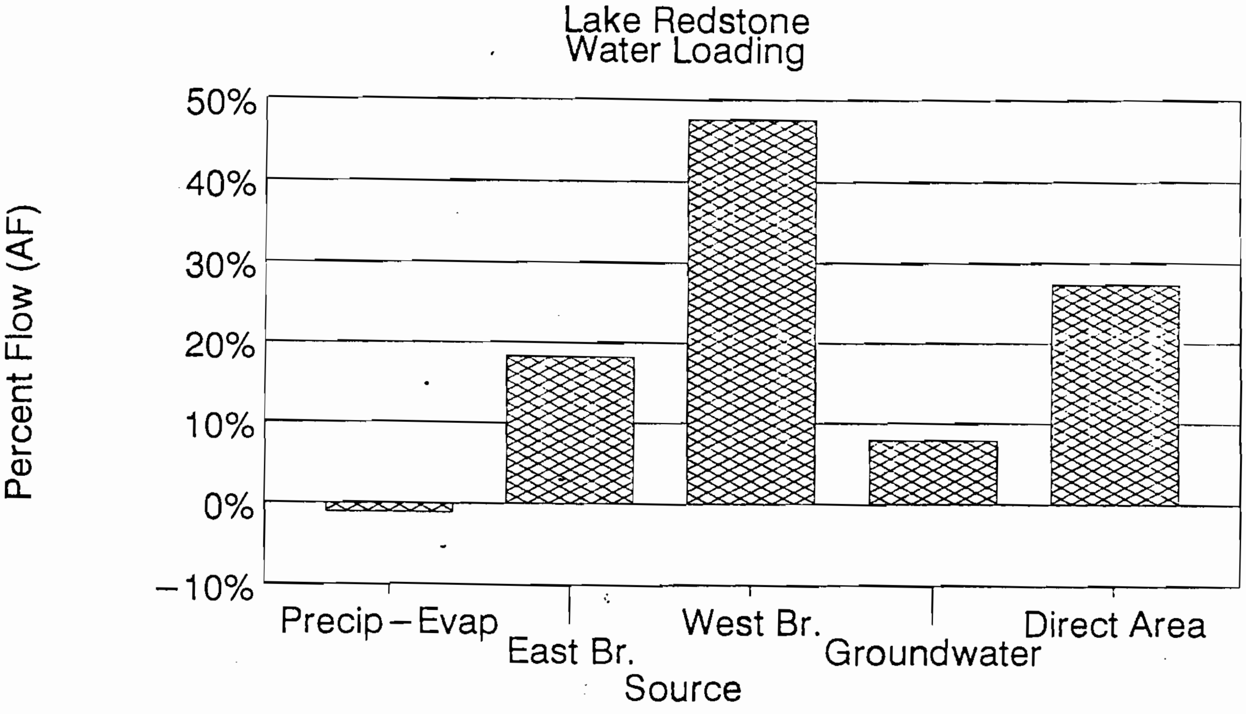
* Used WI Dells observed rainfall for normals and when data was missing.

The growing season phosphorus loads to Lake Redstone are summarized in Figure 6. Review of Figure 6 indicates that about 66% of the seasonal phosphorus loading to the lake is from watershed runoff, 29% from internal recycling and about 2% from groundwater. Considering the overall watershed sources, the West Branch is the highest followed by the direct tributary area. The seasonal unit area loads for the West Branch, East Branch and Swallow Bay are 0.17 Kg/Ha, 0.16 Kg/Ha and 0.23 Kg/Ha, respectively. The ratio of total phosphorus to orthophosphorus for the West Branch, East Branch and Swallow Bay were 40%, 30%, and

Figure 4.

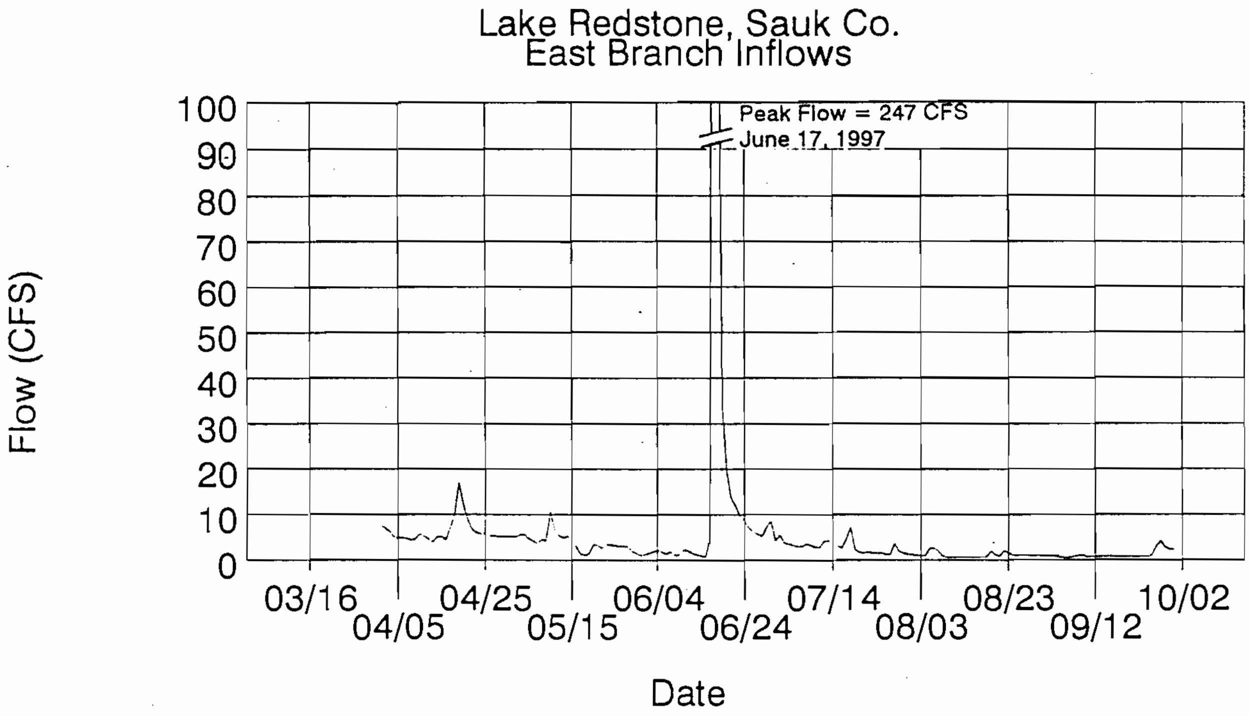


Lake Redstone
Water Loading
Flow (AF) x 10
500
400
300
200
100
0
−100
Precip−Evap
East Br.
West Br.
Groundwater
Direct Area
Source



Lake Redstone
Water Loading
Percent Flow (AF)
50%
40%
30%
20%
10%
0%
−10%
Precip−Evap
East Br.
West Br.
Groundwater
Direct Area
Source

Figure 5.


Lake Redstone, Sauk Co.
East Branch Inflows
Peak Flow = 247 CFS
June 17, 1997
Flow (CFS)
100
90
80
70
60
50
40
30
20
10
0
03/16
04/05
04/25
05/15
06/04
06/24
07/14
08/03
08/23
09/12
10/02
Date

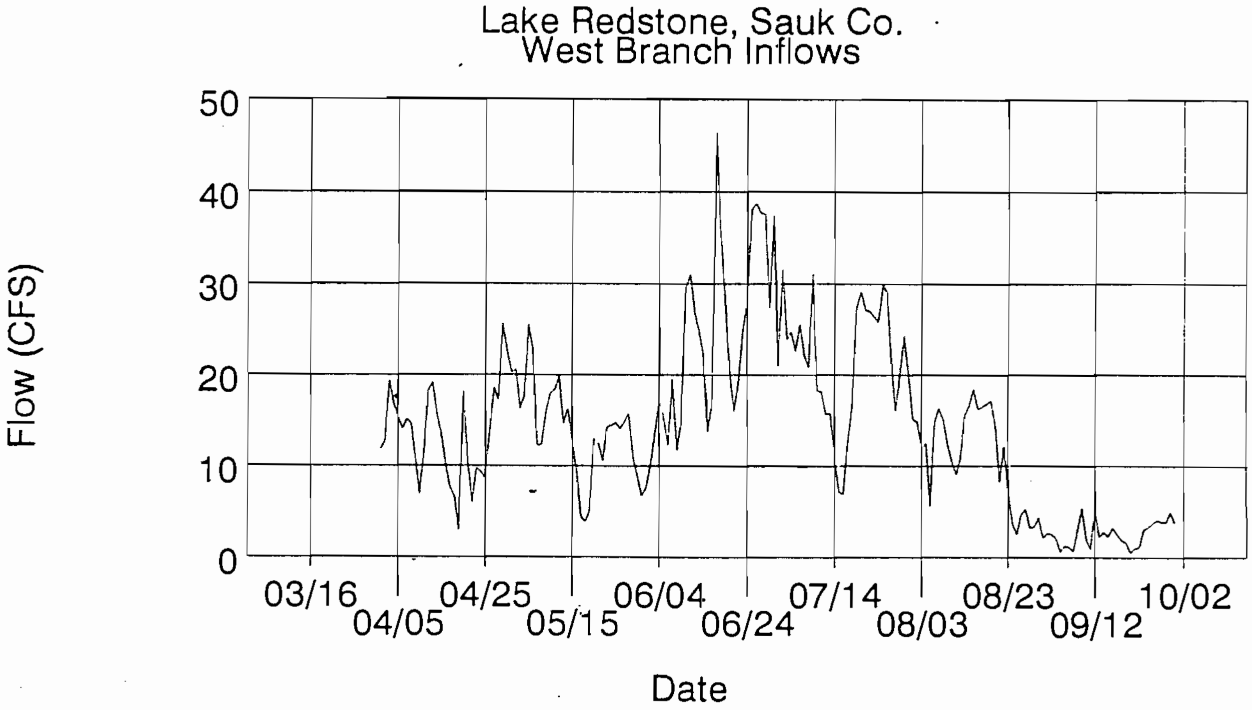
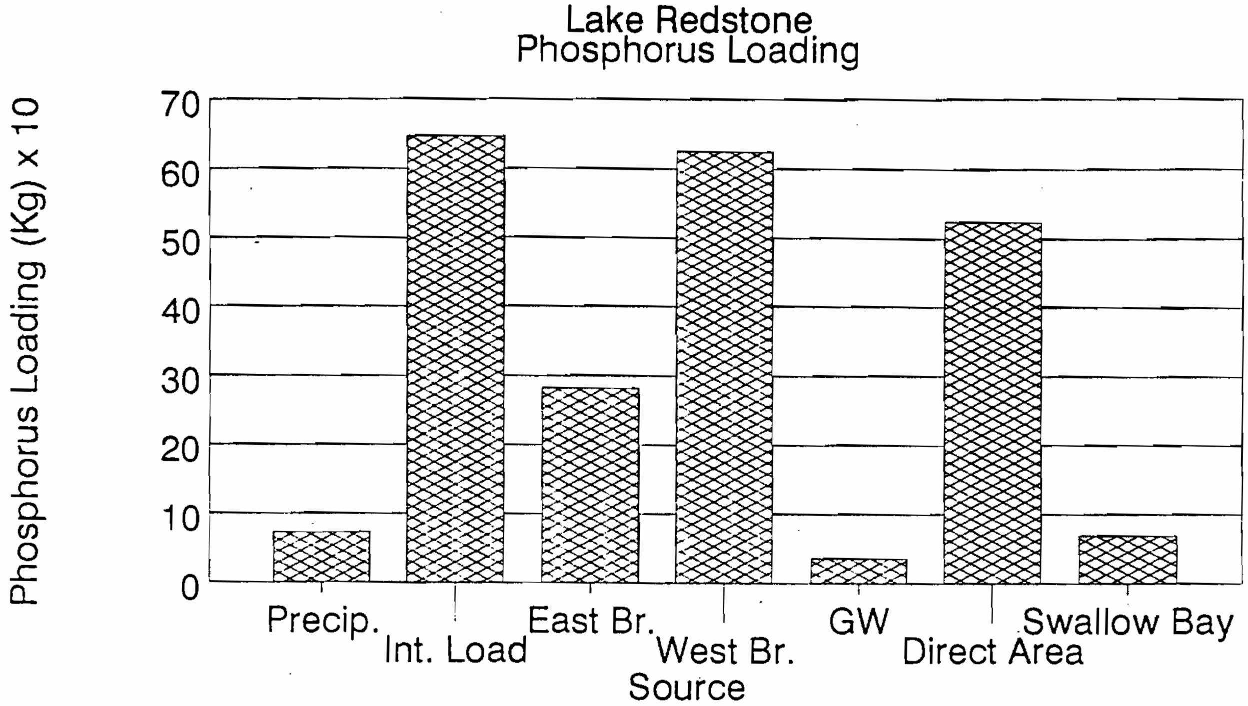
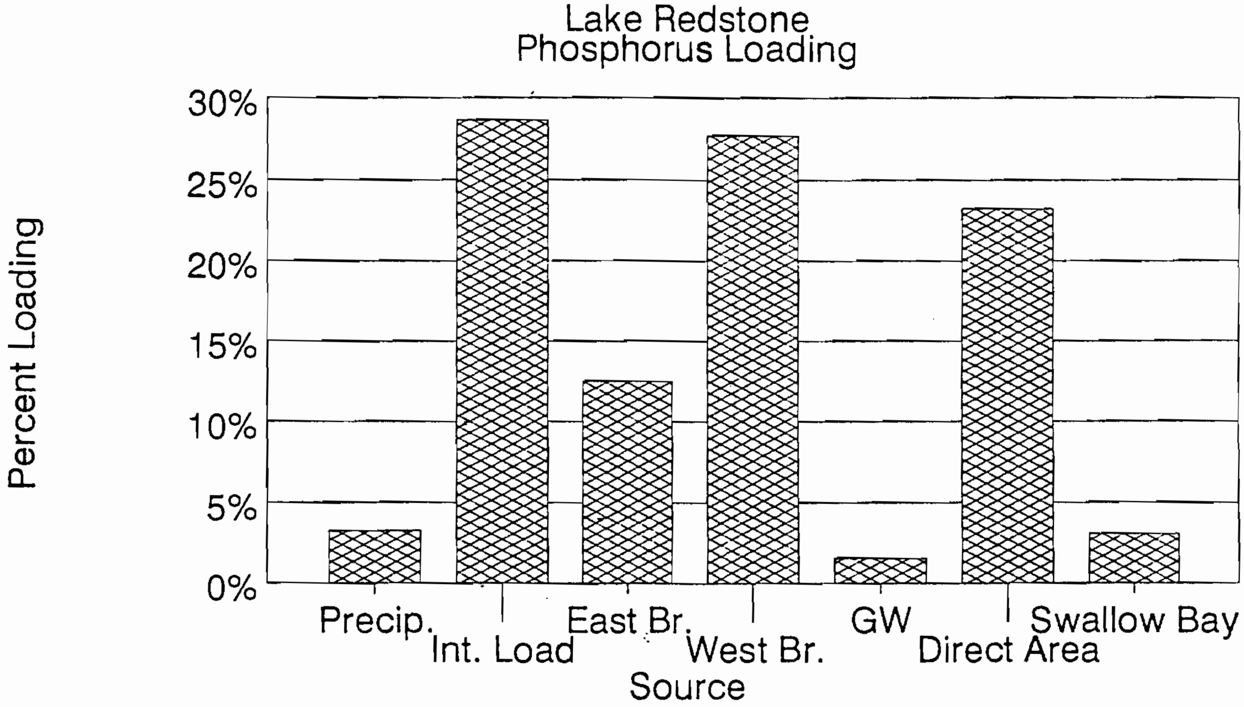

Lake Redstone, Sauk Co.
West Branch Inflows
Flow (CFS)
50
40
30
20
10
0
03/16
04/05
04/25
05/15
06/04
06/24
07/14
08/03
08/23
09/12
10/02
Date

Figure 6.


Lake Redstone
Phosphorus Loading
Phosphorus Loading (Kg) x 10
70
60
50
40
30
20
10
0
Precip.
Int. Load
East Br.
West Br.
GW
Direct Area
Swallow Bay
Source


Lake Redstone
Phosphorus Loading
Percent Loading
30%
25%
20%
15%
10%
5%
0%
Precip.
Int. Load
East Br.
West Br.
GW
Direct Area
Swallow Bay
Source

41%, respectively. The ratios observed here are well within range of values observed elsewhere by Walker (1996). The 1996 seasonal phosphorus loading generally followed the local rainfall patterns and as such the June 17 storm accounted for about 40% the total seasonal phosphorus load.

Internal Recycling.

Clearly watershed runoff contributes the greatest share of phosphorus to the lake. Internal recycling of phosphorus was determined to be 29% of the load but in a water quality sense may not be a significant part of the problem.

The discussion of lake conditions identifies the concentration of phosphorus in bottom (hypolimnetic) waters. The data shows high phosphorus concentrations during the stratified summer period. However, other factors may mitigate the impact of this phenomenon on surface water quality. Most of the phosphorus in the bottom water isn't available for algal use during the growing season but does become available in the fall when lake stratification is breaking down with the cool weather. The frequency and duration of algal blooms during this period is low and not as noticeable as during the summer period. Lake Redstone's flushing rate, or amount of time it takes one lake volume to pass through the lake, is 1.8 times during the growing season. Thus, with a "change" of water about twice a year, a good deal of phosphorus released in early to mid autumn flows out of the lake during late autumn and winter.

The enriched lake bottom sediments do have an impact on the lake's dissolved oxygen levels. During the summer, oxygen levels are low in a large portion of the lake deeper than 10 feet which limits the available habitat for aquatic organisms. Late winter dissolved oxygen levels are also low in the lower section of the lake, where the DNR does the long-term monitoring. It is not known what the dissolved oxygen levels are in other parts of the lake during the winter time period. Additional dissolved oxygen monitoring would provide more complete information about any potential risks of winterkill conditions on the lake.

Lake Conditions.

The observed and predicted surface mean total phosphorus, chlorophyll a and secchi depth for each segment and area-weighted average are summarized in Table 3. The predicted values represent the best model fit to the observed conditions using the method of least squares.

TABLE 3

Summary of predicted and observed conditions

T STATISTICS COMPARE OBSERVED AND PREDICTED MEANS
USING THE FOLLOWING ERROR TERMS:

1 = OBSERVED WATER QUALITY ERROR ONLY
2 = ERROR TYPICAL OF MODEL DEVELOPMENT DATA SET
3 = OBSERVED AND PREDICTED ERROR

SEGMENT: 1; South Site No. 1

	OBSERVED		ESTIMATED		T STATISTICS			
VARIABLE	MEAN	CV	MEAN	CV	RATIO	1	2	3
TOTAL P MG/M3	36.0	.30	38.6	.21	.93	-.23	-.26	-.19
CHL-A MG/M3	21.0	.20	20.9	.41	1.00	.01	.01	.01
SECCHI M	1.1	.20	1.1	.34	1.00	-.01	-.01	.00
ORG N MG/M3	.0	.00	663.3	.32	.00	.00	.00	.00
T-ORT-P MG/M3	.0	.00	42.3	.41	.00	.00	.00	.00
HOD-V MG/M3-DAY	.0	.00	553.2	.24	.00	.00	.00	.00
MOD-V MG/M3-DAY	.0	.00	293.3	.33	.00	.00	.00	.00

SEGMENT: 2; Middle Site No.2

	OBSERVED		ESTIMATED		T STATISTICS			
VARIABLE	MEAN	CV	MEAN	CV	RATIO	1	2	3
TOTAL P MG/M3	45.0	.31	42.8	.19	1.05	.16	.19	.14
CHL-A MG/M3	25.0	.26	24.4	.38	1.03	.10	.08	.06
SECCHI M	1.1	.10	1.2	.36	.98	-.18	-.07	-.05
ORG N MG/M3	.0	.00	731.9	.32	.00	.00	.00	.00
T-ORTHO-P MG/M3	.0	.00	45.4	.41	.00	.00	.00	.00
HOD-V MG/M3-DAY	.0	.00	553.2	.24	.00	.00	.00	.00
MOD-V MG/M3-DAY	.0	.00	293.3	.33	.00	.00	.00	.00

SEGMENT: 3; North Site No.3

	OBSERVED		ESTIMATED		T STATISTICS			
VARIABLE	MEAN	CV	MEAN	CV	RATIO	1	2	3
TOTAL P MG/M3	47.0	.40	44.7	.19	1.05	.12	.18	.11
CHL-A MG/M3	26.0	.38	26.0	.38	1.00	.00	.00	.00
SECCHI M	.8	.30	.8	.41	1.00	.00	.00	.00
ORG N MG/M3	.0	.00	798.6	.31	.00	.00	.00	.00
T-ORTHO-P MG/M3	.0	.00	57.6	.39	.00	.00	.00	.00

SEGMENT: 4; AREA-WTD MEAN

```
                          OBSERVED              ESTIMATED                T STATISTICS
VARIABLE             MEAN          CV     MEAN           CV     RATIO    1        2        3
-----------------------------------------------------------------------------------------------
TOTAL P MG/M3        41.9         .34     41.6          .20     1.01    .02      .02      .02
CHL-A MG/M3          23.6         .28     23.4          .39     1.01    .03      .03      .02
SECCHI M              1.0         .19      1.0          .29      .99   -.04     -.02     -.02
ORGANIC N  MG/M3       .0         .00    723.0          .31      .00    .00      .00      .00
T-ORTHO-P MG/M3        .0         .00     47.6          .38      .00    .00      .00      .00
HOD-V  MG/M3-DAY       .0         .00    553.2          .24      .00    .00      .00      .00
MOD-V  MG/M3-DAY       .0         .00    293.3          .33      .00    .00      .00      .00
-----------------------------------------------------------------------------------------------
```

The average hypolimnetic, or bottom water total phosphorus, concentration for the lower, middle and upper segments are 106 ug/l, 141 ug/l and 50 ug/l, respectively. In the middle and lower segments, the hypolimnetic total phosphorus can be seen to build from 40 to 243 ug/l and 48 to 164 ug/l, respectively over the May through July time period. In addition, the upper segment which does not stratify does not exhibit a build up of hypolimnetic phosphorus. This increase in concentration after anoxia is a clear indication that internal recycling of phosphorus is taking place in Lake Redstone.

Comparison of Past and Present Conditions.

Lake Redstone's water quality was modelled at various times in the past using a variety of computer models. In 1981 the lake was evaluated by the University of Wisconsin (Water Resources Management Workshop). The model used during that evaluation was Carlson's Trophic State Index. Results from the study classified Lake Redstone an a meso-eutrophic or eutrophic lake. In 1986 a non-point source priority watershed project study was done (WDNR, 1985) on the Crossman Creek - Little Baraboo River Watershed, which includes Lake Redstone. The calculated Trophic State Index (TSI) for the lake at that time was 65.

Analysis of the lake's water quality and loading during this effort, using the BATHTUB model, resulted in an estimated TSI value of 58 (see Figure 7). Table 8, Page 27, of the 1985 non-point source watershed study (WDNR, 1985) is included as Appendix A. As shown in Appendix A the goal of the non-point project was to reduce phosphorus loading from runoff by 70% which would result in a post project an estimated TSI value of 58.

At the same time the in-lake and tributary sampling was being done as a part of the BATHTUB modelling effort, a watershed inventory was also performed. The purpose of the watershed inventory was to re-evaluate the "high" and "medium" priority sites identified in the non-point source project. The goal of this evaluation was to document the existing usage and potential of these sites to continue to be phosphorus sources to Lake Redstone. Midstate Engineering, Inc., was contracted by the Lake Redstone District to do this watershed inventory. A lake planning grant was the primary funding source and the two efforts were "piggy-backed" so that loading estimates from the watershed evaluation could be compared to

Figure 7.

Existing Conditions

```
SEGMENT: 4 AREA-WTD MEAN
                      ----- VALUES -----  --- RANKS (%) ----
VARIABLE              OBSERVED ESTIMATED  OBSERVED ESTIMATED
----------------------------------------------------------
TOTAL P      MG/M3       41.88     41.61      44.1      43.8
CHL-A        MG/M3       23.64     23.43      88.5      88.2
SECCHI           M        1.01      1.02      46.7      47.0
ORGANIC N   MG/M3         .00    723.00        .0      79.6
TP-ORTHO-P MG/M3          .00     47.63        .0      68.7
HOD-V   MG/M3-DAY         .00    553.15        .0      99.6
MOD-V   MG/M3-DAY         .00    293.32        .0      98.0
ANTILOG PC-1            591.92    582.95      75.0      74.6
ANTILOG PC-2             11.55     11.54      86.7      86.7
TURBIDITY      1/M        .42       .42      34.0      34.0
ZMIX * TURBIDITY          .86       .86       4.8       4.8
ZMIX / SECCHI            2.02      2.00       6.9       6.8
CHL-A * SECCHI          23.97     23.91      88.6      88.6
CHL-A / TOTAL P           .56       .56      95.2      95.1
FREQ(CHL-a>10) %        85.95     85.61        .0        .0
FREQ(CHL-a>20) %        48.40     47.80        .0        .0
FREQ(CHL-a>30) %        24.38     23.92        .0        .0
FREQ(CHL-a>40) %        12.34     12.04        .0        .0
FREQ(CHL-a>50) %         6.45      6.26        .0        .0
FREQ(CHL-a>60) %         3.50      3.39        .0        .0
CARLSON TSI-P           58.01     57.91        .0        .0
CARLSON TSI-CHLA        61.63     61.54        .0        .0
CARLSON TSI-SEC         59.80     59.70        .0        .0
----------------------------------------------------------
```

25% reduction in all watershed loads

```
SEGMENT: 4 AREA-WTD MEAN
                      ----- VALUES -----  --- RANKS (%) ----
VARIABLE              OBSERVED ESTIMATED  OBSERVED ESTIMATED
----------------------------------------------------------
TOTAL P      MG/M3       41.88     38.96      44.1      40.9
CHL-A        MG/M3       23.64     21.27      88.5      85.6
SECCHI           M        1.01      1.08      46.7      50.0
ORGANIC N   MG/M3         .00    673.82        .0      75.5
TP-ORTHO-P MG/M3          .00     43.79        .0      65.5
HOD-V   MG/M3-DAY         .00    527.07        .0      99.5
MOD-V   MG/M3-DAY         .00    279.50        .0      97.7
ANTILOG PC-1            591.92    504.75      75.0      70.9
ANTILOG PC-2             11.55     11.30      86.7      85.8
TURBIDITY      1/M        .42       .42      34.0      34.0
ZMIX * TURBIDITY          .86       .86       4.8       4.8
ZMIX / SECCHI            2.02      1.89       6.9       5.6
CHL-A * SECCHI          23.97     22.96      88.6      87.4
CHL-A / TOTAL P           .56       .55      95.2      94.6
FREQ(CHL-a>10) %        85.95     81.79        .0        .0
FREQ(CHL-a>20) %        48.40     41.65        .0        .0
FREQ(CHL-a>30) %        24.38     19.36        .0        .0
FREQ(CHL-a>40) %        12.34      9.19        .0        .0
FREQ(CHL-a>50) %         6.45      4.56        .0        .0
FREQ(CHL-a>60) %         3.50      2.37        .0        .0
CARLSON TSI-P           58.01     56.96        .0        .0
CARLSON TSI-CHLA        61.63     60.59        .0        .0
CARLSON TSI-SEC         59.80     58.90        .0        .0
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the stream and lake modelling efforts. The results of the watershed inventory indicated that an approximately a 66% reduction in phosphorus loading has occurred since 1985. This estimate is for manure or nutrient related loading not phosphorus associated with sediment run-off. As discussed previously, the 1985 watershed project had limited success in implementing Best Management Practices (BMPs), and reducing phosphorus loading to the lake. However, as identified in the Midstate Engineering study, attrition and changes in farming operations has resulted in an overall reduction of loads to the tributaries of Lake Redstone. In effect, phosphorus loads have been reduced and the lake has responded in accordance with what was predicted in the 1985 modelling effort.

The watershed, lake and stream evaluation have shown that Lake Redstone has "reached" the original watershed project goal of a 70% reduction in phosphorus loading resulting in a TSI value of 58. The District is committed to working with the farming community in looking at options that would be mutually beneficial to both the farmers and the District. Thus, methods such as roof drains, grassed waterways , buffers and other BMPs will be evaluated and implemented to further reduce phosphorus loads.

To facilitate the comparison of the Lake Redstone monitored loads with loadings from other watersheds it is necessary to provide a means to convert the monitored seasonal values into estimated annual values. A conversion factor was developed for use with the Lake Redstone data using the monthly distribution of flows monitored from the gage on the South Branch of the Baraboo River during the same time period. This flow distribution was then used to partition a seasonal value into an annual value. To convert the seasonal values to annual values, the seasonal values should be multiplied by 2.3. This conversion is approximate but does give a reasonable estimate for an annual export to use for comparative purposes. The results for Lake Redstone compared with values from other Wisconsin watersheds are summarized in Table 4. In reviewing these values it is significant to note that the Lake Redstone values are on the low end of the range of unit area export values for Agricultural lands. This indicates that the Lake Redstone watershed may be close to the lower limit typically observed for phosphorus export from southern Wisconsin agricultural watersheds.

Table 4
Summary of Seasonal and Annual Unit Area Loads

Watershed	Seasonal Unit area Load (Kg/Ha)	Estimated Annual Value (Kg/Ha)
E. Branch	0.16	0.37
West Branch	0.17	0.39
Swallow Bay	0.23	0.53

Baseline Unit Area Phosphorus Export from Agricultural Lands in Wisconsin (Kg/Ha)*

Low = 0.20	Most likely = 1.00	High = 3.00

* Typical values for agricultural lands in southern Wisconsin watersheds from (Panuska and Lillie, 1995).

REFERENCES

Institute for environmental studies. 1981. Lake Redstone: A water quality and management study - water resources management workshop. IES Report No. 115. 250p.

Midstate Engineering. Watershed Agricultural Inventory. Lake Redstone Protection and Rehabilitation District. Wisconsin Department of Natural Resources Lake Planning Grant. July 1997.

Panuska, J.C. and R.A. Lillie, 1995. Phosphorus loadings from Wisconsin watersheds: recommended phosphorus export coefficients for agricultural and forested watersheds. research management findings No. 38. publication No. PUBL-RS-738 95. 8p.

Walker, William W. 1995. Simplified procedures for eutrophication assessment and prediction: users manual. USA-COE Instructional report No. W-96-2, September 1996. 270p.

WDNR. October 1985. A Non-point Source Control Plan for the Crossman Creek - Little Baraboo River Priority Watershed.

Appendix A.

Table 8: Measured and Predicted Water Quality Conditions in Redstone Lake

Management Alternative	Total Phosphorus Loading to Lake ** (lbs/yr)	Spring In-Lake Phosphorus (mg/l)	Summer Secchi Depth (feet)	Summer Chlorophyll "a" (ug/l)	Trophic Status Index +	Qualitative Trophic Conditions
CURRENT CONDITIONS						
Average Measured Values (DNR-Bu. Research 1971-1980)	Not Avail.	0.067	4.9	25.3		
Calculated Values * (Based on measured phos.)	4,398	--	3.3	32.1	65	Eutrophic
PREDICTED CONDITIONS *						
Reduce P from runoff by 50%	3,188	0.048	4.2	20.2	60	Eutrophic
Reduce P from runoff by 70%	2,705	0.041	4.7	15.9	58	Eutrophic
Reduce P from runoff by 80%	2,462	0.037	5.0	13.9	56	Eutrophic

* All calculated and predicted values are based on a DNR model called DNR*ILR.TROPHIC which uses the Dillon and Rigler, 1974B equations to predict a phosphorus loading to phosphorus concentration relationship.

** This column is calculated based on the measured in-lake phosphorus using Dillon and Rigler 1974B

\+ After Carlson (1977)

Recognition

A lot of volunteer activity and enthusiasm was expended by many members of the Lake Redstone Protection and Rehabilitation District. Volunteers gathered samples and monitoring data which was used to help prepare this report. Not only did this help make this effort possible, it saved the District many hundreds of dollars. It is always difficult to specifically recognize volunteers since there is a risk in omitting others who also contributed. However, we are aware that Art Deschamps, Riney Nowack, Lou Trepto and Al Baade devoted much time and effort. To all the others not specifically mentioned we also extend our appreciation for your fine effort and dedication.

Thank-you