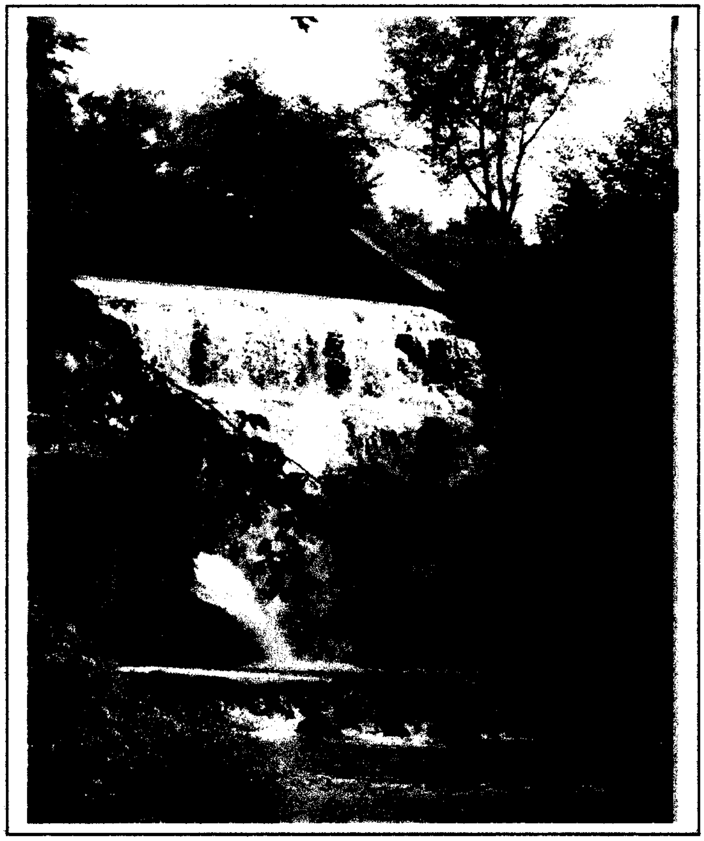
LPL-684

Feasibility of Releasing Hypolimnetic Water to Reduce Internal Phosphorus Loading in Lake Redstone

WDNR Lake Planning Grant and
Baraboo River Restoration and Research Project



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In cooperation with Lake Redstone Protection District and Sauk County Parks Dept.

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Abstract

During the summer and fall of 2000, we investigated the efficacy of improving the water quality in a 612-acre reservoir by releasing nutrient rich bottom water. The Lake Redstone Protection District has proposed hypolimnetic withdrawal to reduce internal phosphorus loading and complement ongoing efforts at reducing watershed nutrient sources. Recent lake modeling predicted that internal phosphorus loading contributes about 29% of the annual load, but direct links to seasonal blooms are not clear. During the summer of 2000, weekly lake sampling at four locations indicated that the area close to the dam is the only part of the lake that stratifies long enough to mobilize and sustain high phosphorus concentrations above the bottom sediment. Phosphorus levels close to the dam reached 1,500ug/l at 0.5 m off the bottom. In the greater reservoir basin, significant fetch and relatively shallow water depth prevent stable stratification and partial mixing occurred. Based on weekly Secchi depth measurements, the small thermally stratified bay near the dam displayed the best water quality while weak stratification and mixing in the rest of the impoundment fueled greater algal blooms. Pronounced thermal stratification near the dam prevented significant internal phosphorus flux during the growing season. Internal phosphorus loading was a greater factor in the weakly stratified large basin that is remote from the outlet. A proposed hypolimnetic withdrawal would at best provide modest water quality benefit given that phosphorus reduction would only occur near the dam. Additionally, effluent limits would be required to protect diverse downstream fisheries in Big Creek due to the very high hypolimnetic hydrogen sulfide and ammonia concentrations. Protecting downstream uses would either limit hypolimnetic discharge rates or necessitate some form of wastewater treatment. Without wastewater treatment, low hypolimnetic discharge rates would not have a significant effect on the overall phosphorus budget. Very high hydrogen sulfide concentrations (>1 mg/l sulfide) further complicate the issue since significant nuisance odors would be generated within a popular county park that encompasses the dam. During two test hypolimnetic discharge experiments, field staff and park users detected nuisance hydrogen sulfide odors near the dam and up to ¼ mile away.

Introduction

Hypolimnetic siphoning or bottom withdrawal has been used to reduce internal phosphorus loading in European lakes since 1961 and North American lakes since 1983 (Cooke 1986, Nurnberg 1987). Both sources reported some successes when thermal stratification was maintained. Nurnberg (1987) reported that optimum effectiveness can occur when the withdrawal pipe is located near the bottom in the deepest location of a lake and high discharge rates are sustained without destratifying or lowering the lake levels. Other factors that will influence the success of a hypolimnetic withdrawal include the lake morphometry and balance of phosphorus inputs versus outputs (Cooke, 1986).

Numerous sources have identified the threats and impacts of anoxic hypolimnetic discharges to downstream fisheries and water quality, whether the release is designed to reduce sediment phosphorus pools or to maintain a desired temperature regime. Due to low dissolved oxygen levels in the hypolimnion of eutrophic lakes, special precautions are needed to protect downstream fisheries (Cooke, 1986). Nurnberg (1987) reported that wastewater treatment is required in some cases to prevent adverse effects downstream. Below several North American impoundments, including Twin Valley Lake in Wisconsin, hypolimnetic discharges significantly reduced macroinvertebrate (Young, et al. 1976, Hilsenhoff 1971, Lehmkulm 1972) and fish populations (Edwards 1978). Tailwater discharges from reservoir hypolimnions often contain toxic levels of hydrogen sulfide and ammonia and can adversely effect downstream ecology, while epilimnetic discharges are generally less disruptive to tailwater biota (Walburg et al. 1981). Minute hydrogen sulfide concentrations can generate nuisance odors, of particular concern in populated areas. Efforts to reduce the "rotten egg" odors have included construction of baffles and fountains to dissipate hydrogen sulfide or enclosures to dilute hypolimnetic water with epilimnetic water (Nurnberg, 1987).

Hypolimnetic withdrawal was listed along with numerous other potential management alternatives for Lake Redstone as part of a University of Wisconsin Madison Water Resources Workshop (1981). At that time, Lake Redstone was considered one of the most eutrophic lakes in Wisconsin. Changes since that time include 66% watershed phosphorus loading reduction and improved water quality. Recent lake modeling estimated that internal loading contributes approximately 29% of the annual phosphorus load but links to seasonal algal blooms may not be significant (Leverance and Panuska 1997). The Lake Redstone Protection District has proposed hypolimnetic withdrawal in an effort to reduce internal phosphorus source and complement ongoing efforts to reduce watershed nutrient loads.

As part of a Wisconsin Department of Natural Resources Lake Planning Grant and the Baraboo River Restoration Project, WDNR and the Lake Redstone Protection District collected additional information needed to evaluate hypolimnetic withdrawal as a potential management option.

Goals of the Planning Grant Study were to:

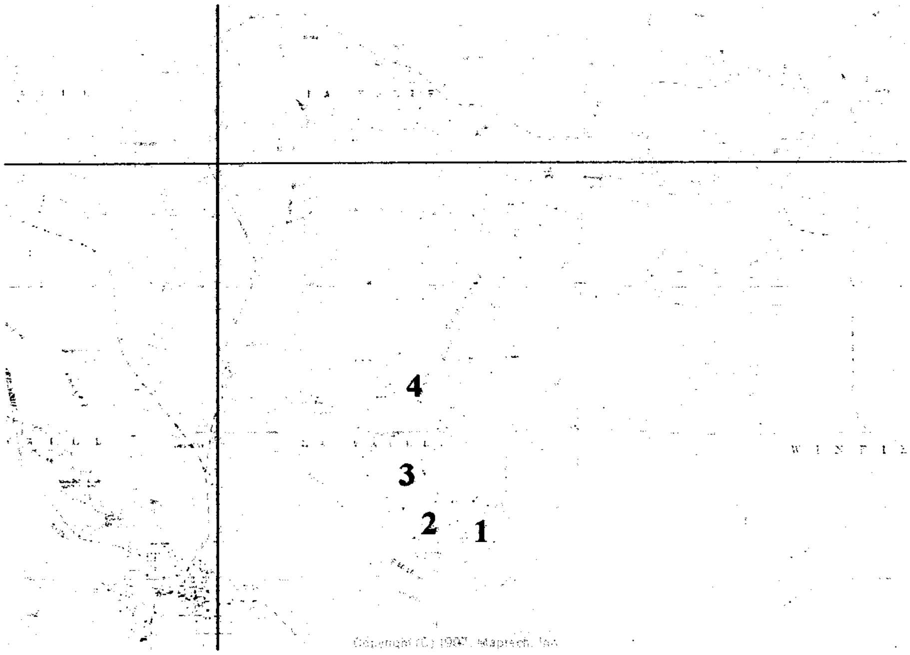
1. Determine maximum hypolimnetic phosphorus concentrations. (Biweekly samples were collected near the lake bottom at two locations when stratification and anoxia were measured.)
2. Determine spatial and temporal limits of thermal stratification in the lake. (Weekly dissolved oxygen and temperature profiles determined the limits of the anoxic zone and potential for mobilizing phosphorus and other reduced substances from the bottom sediment.)
3. Evaluate potential toxic effects of a proposed hypolimnetic discharge on downstream fisheries. (Two experimental hypolimnetic releases were conducted and stream responses were measured. Bioassay tests were conducted on hypolimnetic water. Effluent limits were calculated based on predicted low flows and measured contaminant levels.)
4. Identify fish and macroinvertebrate populations below the reservoir that could be affected by a proposed hypolimnetic withdrawal.

Methods

Lake Sampling

Four sampling locations (Figure 1) were monitored weekly during the summer and fall of 2000. The Lake Redstone Protection District members and WDNR staff alternated weekly sampling. The combined effort generated weekly dissolved oxygen and temperature profiles and secchi measurements during the entire growing season. Air calibrated Yellow Springs Instrument meters were used for all discrete temperature and dissolved oxygen measurements. Every other week, WDNR staff collected water samples with particular emphasis at Station 1. Station 1 was a long term monitoring site with TSI data generated from 1986-96. Parameters at Station 1 included surface (0.5 m) chlorophyll-a, pH, conductivity, total phosphorus and bottom (10.5 m) pH, conductivity and total phosphorus. Coinciding with mid-summer hypolimnetic anoxia, the chemical parameter list was expanded to include ammonia, five-day BOD and sulfide to determine the organic strength of a proposed bottom withdrawal. Water sampling at the other three stations was determined by the degree of thermal stratification. All water lake and stream samples were analyzed at the State Laboratory of Hygiene.

Figure 1: Map of Lake Redstone monitoring sites



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Stream Monitoring

Coinciding with biweekly WDNR lake sampling, Big Creek was sampled below the Lake Redstone dam to include pH, conductivity, total phosphorus, ammonia, and five-day

BOD. Flow was measured with either Swoffer or Marsh McBurney meters. Stream macroinvertebrates were sampled below the dam in the spring with a d-frame net and were submitted to UW-Stevens Point for identification. Fish were sampled with a towed stream shocker in June. The entire (700 meter) stretch of Big Creek below the dam was electrofished and all game and nongame species were identified and counted.

In an effort to measure potential effects of a hypolimnetic withdrawal on downstream water quality, fisheries and macroinvertebrates, two six-hour test releases were conducted on August 15 and September 20, 2000. The experimental test releases were designed primarily to evaluate potential impacts of low dissolved oxygen and high ammonia concentrations. Composite water chemical samples were collected from the surface outlet, bottom gate release, mid-way downstream, at the mouth of Big Creek, upstream in the Baraboo River and downstream in the Baraboo River. Flow rates were measured to calculate pollutant loads and percent dilution. In addition to the parameters listed above, State Laboratory of Hygiene analysis included long term BOD and nitrogen series. All samples below the bottom gate were composited according to estimated travel times. Yellow Spring Instrument 600XLM data loggers were deployed at the Big Creek and Baraboo River sampling stations to measure conductivity, pH, temperature and dissolved oxygen at 10 minute intervals during the two release studies. Manual dissolved oxygen meters and Winkler titrations were used as system backups and quality control.

Biomonitoring and Proposed Effluent Limits Calculations

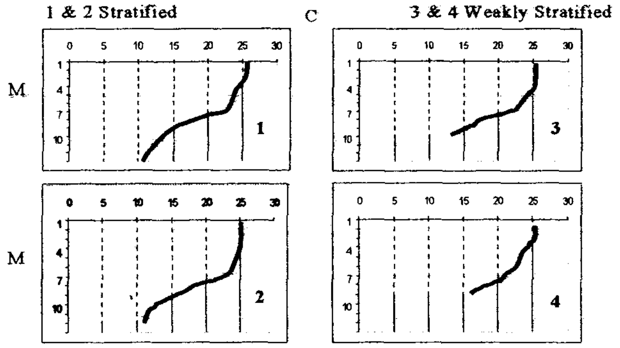
Biomonitoring was conducted to determine the potential toxic effects of a hypolimnetic release on downstream aquatic organisms. On September 11, 12 and 14, hypolimnetic water was collected, iced and transported to the State Laboratory of Hygiene for bioassay tests. On each date, 20 liters of hypolimnetic water was collected 0.5 m off the bottom and 20 liters of test control water from the lake surface. Five bioassay tests were conducted: acute fathead minnow survival, acute *Ceriodaphnia dubia* survival, chronic fathead minnow growth, chronic *C. dubia* growth and *R. subcapitata* growth. The hypolimnetic samples were aerated and dissolved oxygen levels were sustained between 40 and 100% saturation during the tests. Effluent limitations were calculated for BOD, ammonia, phosphorus, dissolved oxygen, total suspended solids and pH. Effluent limitations can be used for planning and/or permit issuance and the standard equations are attached.

Results

Limnology

Weekly dissolved oxygen and temperature profiles at Stations 1 and 2 revealed thermal stratification throughout the growing season. Maximum and mean bottom temperatures at Stations 1 were 11.8 C and 10.9 C (standard deviation = .169) and at Station 2 were 12.5 C and 11.4 C (standard deviation = .203) respectively. These sites are located in the deepest part of the reservoir (11 and 10 meters) and are the most protected from prevailing winds. Stations 3 and 4 are located within the main reservoir basin that is oriented from southwest to northeast and more affected by prevailing winds. Maximum depths are shallower at these stations (9 and 8 meters) and gradually decrease northward. Profile data from these locations indicated that the lake is weakly stratified beyond the protected area of the small basin close to the dam and narrow channel. Maximum and mean of bottom temperatures at Station 3 were 14 C and 13.2 C (standard deviation = .199), and at Station 4 were 20.2 C and 17.3 C (standard deviation = 1.407). Figure 2 displays temperature profiles measured on August 2, 2000 at the four sampling stations. Stations 1 and 2 display pronounced thermal stratification, while Station 4 is weakly stratified. Thermal stratification at Station 3 is intermediate relative to the other stations.

Figure 2: Lake Redstone Depth - Temperature Profiles, Sta. 1 - 4, August 2, 2000



Figures 3 and 4 compare anoxic zones at the four sampling stations throughout the growing season. Station 1 displayed the greatest area and most stable anoxic zone during the mid-summer. Anoxic zones were less stable throughout the summer at the other sampling sites and reflect greater mixing than at Station 1. Station 4 displayed the smallest area consumed by anoxia and the greatest amount of mixing.

Figure 3: Comparative Anoxic Zones at the Four Sampling Stations

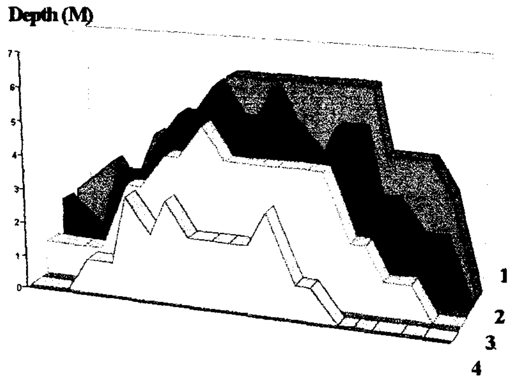


Figure 4: Extent of Aerobic and Anaerobic Zones Throughout the Summer and Early Fall, 2000

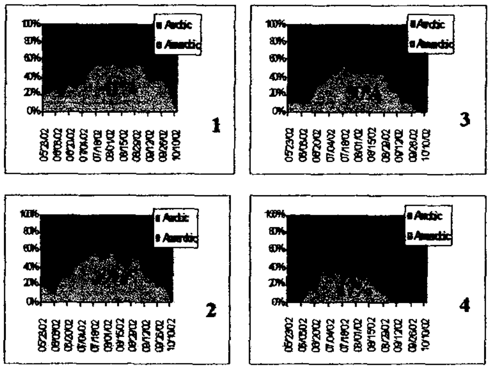
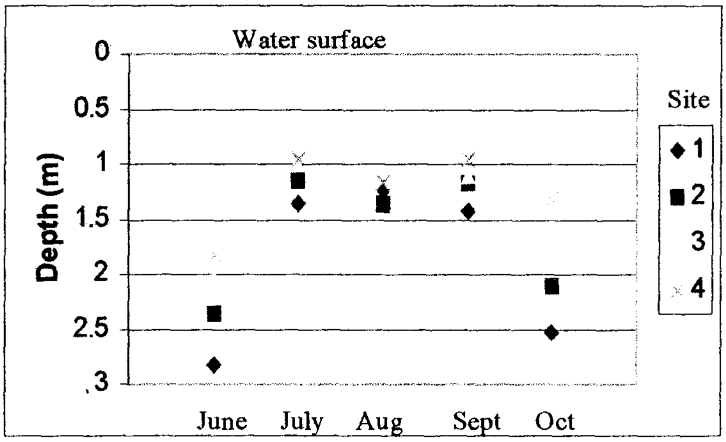


Figure 5 summarizes the weekly Secchi depths that were measured at the four stations from May 23 through October 21. Stations 1 and 2 displayed the best water clarity with mean measurements of 1.84 and 1.61 meters respectively. Measurements at Stations 3 and 4 were generally lower and averaged 1.36 and 1.24 meters respectively. At Station 1, the mean growing season (June-August) Secchi depth was 1.81 meters, with calculated a Carlson's TSI value of 51. This value was better than the LONG-TERM TRENDS database (monthly June, July and August measurements from 1986 through 1996) mean secchi depth of 1.35 meters.

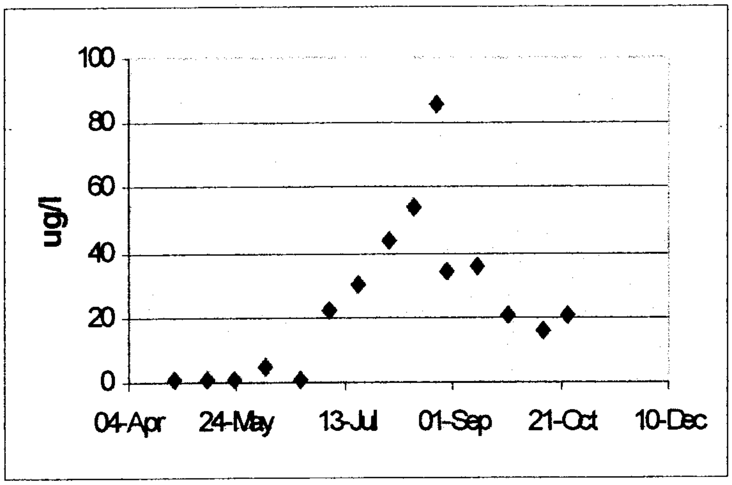
Figure 5: Lake Redstone Monthly Secchi Means



Every other week throughout the summer and fall of 2000, water samples were submitted to the State Laboratory of Hygiene for additional parameter tests. These included surface chlorophyll-a (Station 1), hypolimnetic ammonia (Station 1), hypolimnetic sulfide (Station 1), hypolimnetic BOD (Station 1), hypolimnetic total iron (Station 1) and surface and bottom total phosphorus (Station 1-4). Figure 6 displays biweekly chlorophyll-a sampling results from Station 1. Concentrations peaked in August and ranged from 44 to 86 µg/l that month. The growing season (June-August) mean concentration of 28 µg/l (TSI=63) was better than the 1986-96 long term mean of 40 µg/l. 86 ug/l is the highest chlorophyll-a concentration on record at that Station and was detected at that level only one other time (August 1992).

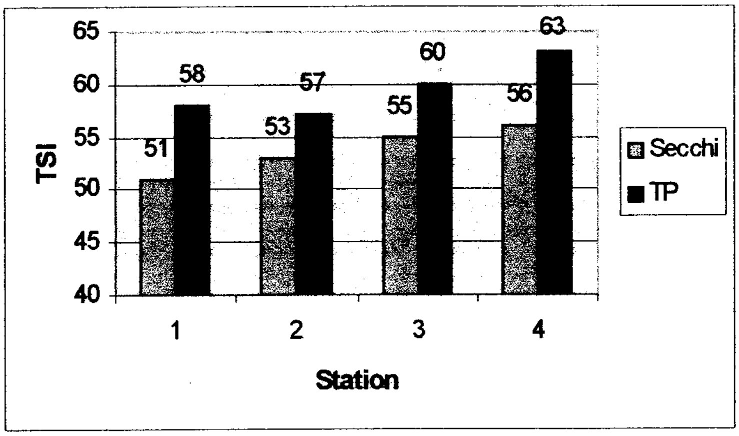
Total phosphorus concentrations near the surface averaged 42 µg/l at Station 1 and 39 µg/l at Station 2 from June through September. The Carlson's TSI values for these concentrations are 58 and 57 respectively. From June 6 through August 2nd, surface phosphorus samples were collected from all four stations. In Figure 7, these phosphorus data, along with the Secchi depth results, are converted to Carlson's TSI values and demonstrate better water quality in the thermally stratified areas of the lake.

Figure 6: Lake Redstone Chlorophyll a Trend at Site 1



The mean growing season (June, July and August) concentration found at Station 1 mirrored the long term growing season mean of 42 µg/l. At 0.5 meters off the bottom, phosphorus concentrations rapidly increased throughout the summer near the bottom of the anoxic hypolimnion (Figure 8). Maximum concentration at Station 1 reached 1500 µg/l on September 27and 1200 µg/l at Station 2 on September 12. By October 13, bottom phosphorus concentrations declined substantially as turnover had occurred. Since very high iron concentrations were found in the bottom water and reached 3.5 mg/l by September 27, most of the hypolimnetic phosphorus likely returned to the sediments as ferric phosphate. Slightly higher surface phosphorus concentrations after turnover suggest that the remainder of the phosphorus mixed throughout the water column.

Figure 7: Carlson's Trophic State Index Values for Total Phosphorus and Secchi at Stations 1 - 4



In addition to phosphorus, other hypolimnetic parameters of concern include BOD, ammonia and hydrogen sulfide. Five day BOD levels were variable (range 7-84 and mean of 29 mg/l) but could pose a significant organic loading to downstream fisheries. Maximum sulfide concentration was 2 mg/l. In several other samples concentrations were indeterminate but all exceeded 1 mg/l. These concentrations indicate that hydrogen sulfide levels are very high and reflect the organic enrichment within the anoxic hypolimnion. Sulfide concentrations exceeding .002 mg/l can cause nuisance odors and concentrations exceeding .02 mg/l can threaten fisheries. Figure 9 displays the ammonia trend with a peak concentration of 5.74 mg/l. Ammonia mirrored the phosphorus pattern of mobilizing above the sediments in the anoxic water and rapidly decreasing after turnover. Acute and chronic ammonia toxicity will vary with pH and temperature.

Figure 8: Lake Redstone Surface and Hypolimnetic TP Trend at Site 1 & 2 (.5 m below the surface and .5 m above bottom)

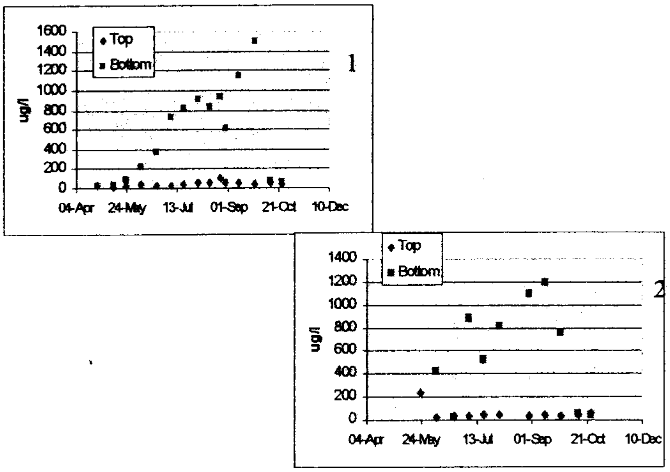
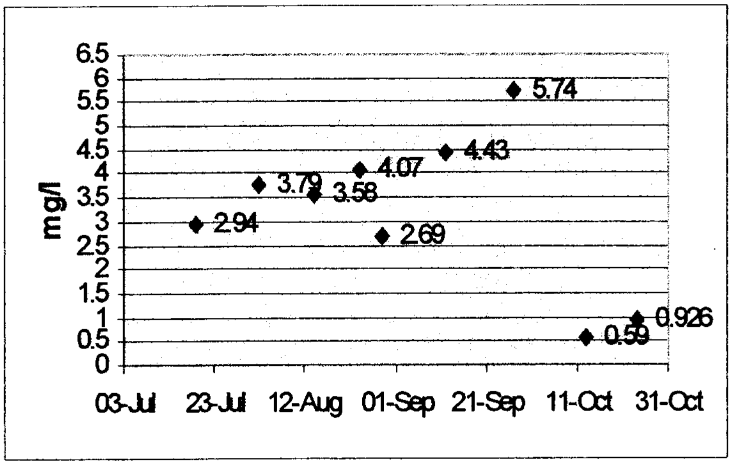


Figure 9: Lake Redstone Hypolimnetic NH3 concentrations at Station 1



Stream Monitoring

Biweekly chemical and flow monitoring was conducted on Big Creek a short distance below the Lake Redstone spillway (cover photo). Flow measurements ranged from 6.3 to 60.9 cubic feet per second (cfs) and a mean of 20 cfs. Water quality below the dam is good and the stream benefits from substantial aeration as water plunges approximately 30 feet over the spillway. All continous and discrete dissolved oxygen measurements exceeded 7 mg/l, well above the water quality standards limit of 5 mg/l. Total phosphorus concentrations ranged from 18 to 76 µg/l with a mean concentration of 41 µg/l. The average phosphorus discharge from the lake was 2 kg/day or approximately 13% of the seasonal phosphorus load from May through September. Table 1 below summarizes Big Creek water chemistry results.

Table 1

Parameter	Minimum	Maximum	Mean	Standard Deviation
Dissolved oxygen	7.6 mg/l	9.7 mg/l	8.7 mg/l	.193
Total phosphorus	18 µg/l	76 µg/l	41 µg/l	4.365
Ammonia	.015 mg/l	.38 mg/l	.11 mg/l	.031
BOD_5	1.3 mg/l	5.5 mg/l	3.2 mg/l	.468
Specific conduct.	.233 ms/cm	.272 ms/cm	.252 ms/cm	.003
pH	8.1 su	8.7 su	8.3 su	.043

The biweekly water chemical monitoring indicated favorable conditions for supporting fisheries. Results of the fish shocking and macroinvertebrate sampling directly support this finding. Five aquatic insect families were found below the dam (Hydropsychidae, Chaoboridae, Empididae, Simulidae, Chironimidae). The taxa representing these insect families resulted in a Hilsenhoff Biotic Index (HBI) value of 5.45, indicating "good" water quality (Hilsenhoff, 1987). Surprisingly, the water quality based on the HBI was actually better below the dam than above the lake in the East Branch Big Creek. At LaValle Road, representative aquatic insect (Heptageniidae, Elmidae, Athericidae) and crustacean (Gammaridae) families indicated cool water habitat. However, the HBI value of 5.81 indicated only "fair" water quality and "fairly signficant organic pollution". The results suggest that the East Branch Big Creek is not meeting water quality potential and sources of runoff pollution are affecting it.

Fish shocking results from July 10 indicated that Big Creek supports diverse fisheries below the dam. Twenty-four species were collected during a survey that encompassed most of the 700-meter stream. The environmental evaluation from the shocking results indicate "good" conditions based on a warmwater IBI (Lyons, 1992) score of 53. Walleye and musky were also observed in the stream during other surveys that summer but were not included in the IBI calculation. The combined fisheries and macroinvertebrate information dictates that management objectives must support warm water fish and aquatic life standards (NR 102). Table 2 contains a list of species and numbers found during the stream shocking survey.

Table 2

Species	Number	Species	Number
Mudminnow	1	Yellow bullhead	4
Common carp	14	Pumpkinseed sunfish	77
Common shiner	159	Bluegill sunfish	95
Hornyhead chub	5	Warmouth sunfish	1
Spotfin shiner	112	Green sunfish	14
Golden shiner	2	Rock bass	3
Bluntnose minnow	81	White crappie	1
Shorthead redhorse	3	Black crappie	1
White sucker	18	Yellow perch	7
Tadpole madtom	2	Banded darter	12
Black bullhead	3	Johnny darter	7

Hypolimnetic release tests were conducted on August 15 and September 20, 2000. The purpose of the releases was to test the effects of bottom water on downstream water quality in Big Creek and Baraboo River. In addition to understanding the potential impacts of a hypolimnetic withdrawal at Lake Redstone, this type of analysis could be applied to similar projects around the state.

On August 15, flow over the spillway was measured at 13.2 cfs. Flow measured near the mouth of Big Creek was 11.2 cfs and indicated some loss to groundwater with no additional flow inputs. (This flow pattern was observed during several surveys that summer.) At 9:45 am, the bottom gate was opened enough to accommodate a flow rate of approximately 1.3 cfs and ultimate stream dilution factor of 10:1. The hypolimnetic water was septic and dark with strong hydrogen sulfide odor. Even though the entire hypolimnion in Lake Redstone was anoxic, aeration at the valve and within the pipe generated an effluent dissolved oxygen concentration of 6 mg/l and temperature of 14 degrees C. Nix et al. (1991) reported that non-hydroelectric dams often introduce aeration by the release structure. Upstream dissolved oxygen and temperature measurements were 7.8 mg/l and 25.5 degrees C. On September 20, upstream flow below the spillway was measured at 15.5 cfs. The bottom gate was opened at 10:00 am to a flow rate of approximately 5.7 cfs. Effluent dissolved oxygen and temperature were measured at 3 mg/l and 18 degrees C compared to upstream levels of 8.4 mg/l and 19 degrees C.

On August 15, a modest (~1 cfs) flow rate sustained colder temperatures and higher ammonia and phosphorus concentrations than what was observed on September 20 when the effluent discharge rate was higher. This was unexpected since pollutant levels should be greater late in the stratification period, and indeed were in Lake Redstone (Figures 8 & 9). Table 3 compares August 15 and September 20 effluent and stream chemical results. To the surprise of both the Lake Redstone Protection District and WDNR, a 15' high submerged clay dam surrounds the outlet structure and diverts water from shallower lake depths into the bottom gate. Based on the two surveys, a higher discharge rate will draw more less-polluted water from shallower depths in the hypolimnion and deeper epilimnion zone. This structure was apparently constructed as an emergency measure to contain flooding when the bottom gate was constructed.

Big Creek's response to the test hypolimnetic releases was similar on both dates but slightly more pronounced on September 20th due to much higher effluent flow rate. In each case, the effluent slug rapidly reached the midway point (15 minutes on August 15 and 10 minutes on September 20) and the mouth of Big Creek (35 minutes on August 15 and 30 minutes on September 20). The short travel time resulted in limited waste assimilation based on the test releases. Table 3 reveals that ammonia and other State Laboratory of Hygiene test results did not change significantly between the midpoint and end point in Big Creek. Table 3 also presents sampling results from the Baraboo River. Since flow rates exceeded 190 cfs and dilution was significant, effects of the hypolimnetic discharge were less. Some parameters such as ortho and total phosphorus and nitrates were less in Big Creek during the discharge than in the Baraboo River. This caused a slight reduction in Baraboo River concentrations due to dilution. However, ammonia levels were higher in Big Creek during the bottom releases, causing increases in the Baraboo River.

Table 3 (all parameters expressed as mg/l)

Site	**BOD_5**	**Ortho P**	**Tot. P**	**NH_3**	**TKN**	**NO_3-NO_2**
August 15						
Spillway	4.7	No detect	.048	.017	1.08	No detect
Effluent	5.2	.129	.551	2.48	3.07	No detect
Midway	4.2	.003	.096	.263	1.08	.017
Endpoint	4.8	.004	.093	.247	1.14	.02
Up Baraboo	2.5	.068	.189	.023	.87	.519
Down Baraboo	2.7	.061	.188	.043	.95	.483
Down Baraboo	3.1	.061	.169	No detect	.89	.488
Site	**BOD_5**	**Ortho P**	**Tot. P**	**NH_3**	**TKN**	**NO_3-NO_2**
Sept. 20						
Spillway	2.5	.003	.045	.06	.73	No detect
Effluent	6.3	.046	.114	1.28	1.94	No detect
Midway	3.3	.017	.105	.521	1.31	No detect
Endpoint	4	.017	.095	.529	1.35	No detect
Up Baraboo	1.6	.064	.212	.063	.77	.808
Down Baraboo	2.1	.054	.159	.149	.75	.657
Down Baraboo	2.1	.057	.173	.146	.64	.728

Figures 10 – 13 summarize YSI data logger results for the hypolimnetic test releases. Dissolved oxygen and temperature recordings were also manually collected at the same 10-minute interval as a backup. The response of temperature, dissolved oxygen, pH and conductivity were similar during both tests but were slightly more pronounced on September 20 (again due to the significantly higher effluent flow). On both dates and at both Big Creek sampling stations downstream of the bottom gate, pronounced changes pH, conductivity and temperature coincided with the initial arrival of the effluent slug.

Field staff had also visually observed arrival of the effluent slug and water quality change due to increased dissolved organic matter. This immediate response was followed by a gradual return toward pretest conditions. Since true bottom water is pooled near the bottom gate, the initial slug contains chemical characteristics more similar to maximum depth hypolimnetic water. As more water is pulled through the gate, the 15' high clay berm directs shallower water with lower pollutant concentrations through the bottom gate. Dissolved oxygen did not respond similarly to the other three parameters because anoxia advances ahead of other chemical changes in the hypolimnion and actually expands into the deeper region of the Lake Redstone epilimnion. Therefore, dissolved oxygen levels did not return to pre-test conditions until the effluent slug had exited the stream. All of the responses measured with the data loggers were not a function of significant waste assimilation, but were rather mixing of surface spillway flow with bottom gate flow. Table 4 displays the maximum chemical changes measured by the YSI 600 XLM data loggers during the two test hypolimnetic releases.

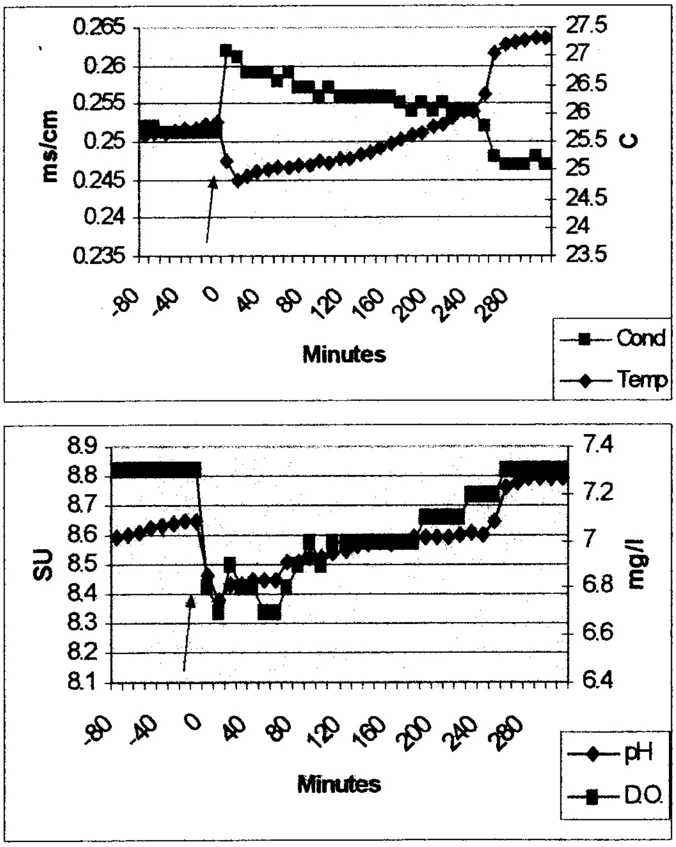


Figure 10: Aug 15 Test Release. Big Creek Midpoint

Fig. 11: Aug 15 Test Release.
Endpoint Big Creek.

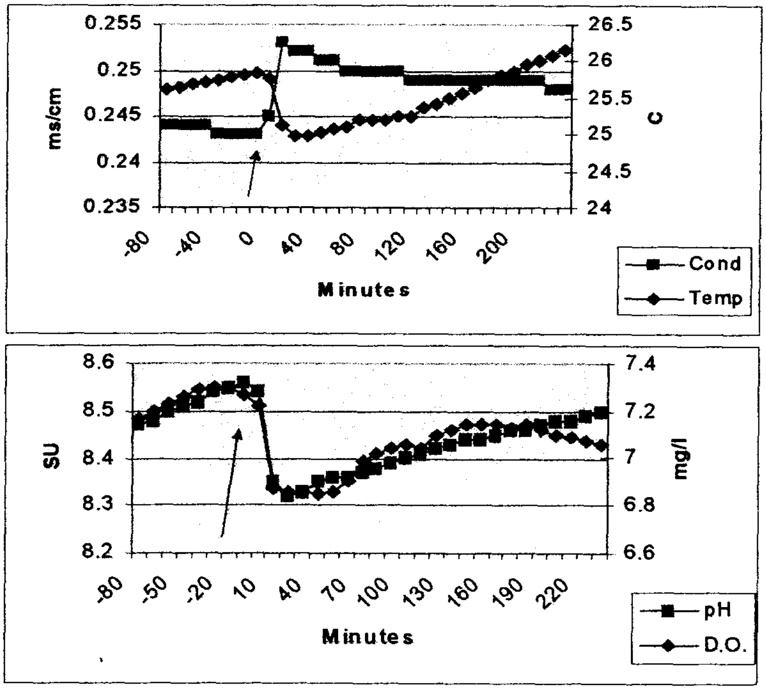


Figure 13: Sept. 20 Test Release. Big Creek Endpoint

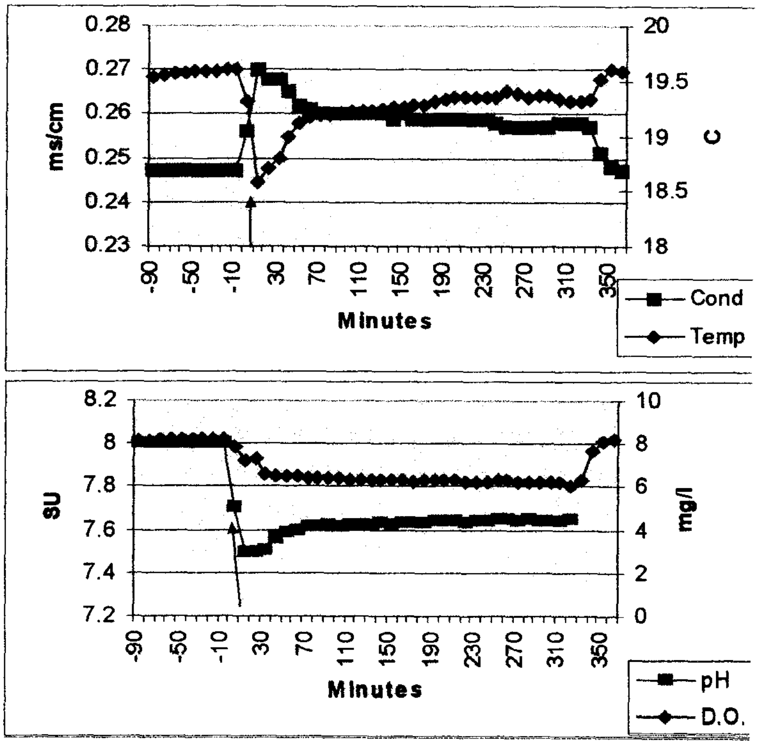


Figure 12: Sept. 20 Test Release Mid-way

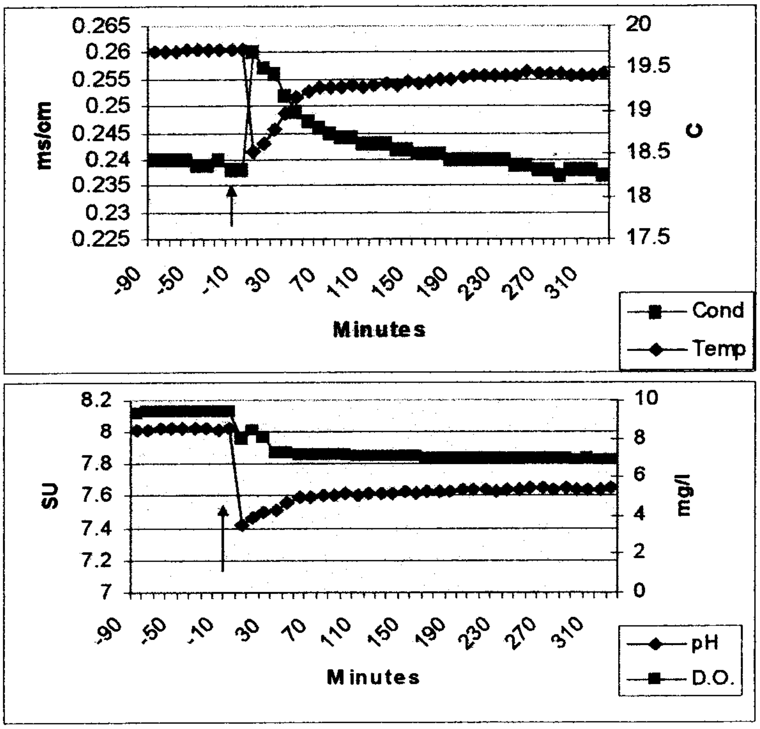


Table 4: Big Creek Responses to Test Hypolimnetic Releases. YSI 600XLM Data Loggers

	Dissolved Oxygen	pH	Specific Cond.	Temperature
August 15				
Midway	-0.6 mg/l	-0.3 su	+11 µs/cm	-1 C
Mouth	-0.4 mg/l	-0.3 su	+10 µs/cm	-1 C
September 20				
Midway	-2.2 mg/l	-0.6 su	+22 µs/cm	-1 C
Mouth	-2.1 mg/l	-0.5 su	+21 µs/cm	-1 C

Biomonitoring (Laboratory Bioassay)

Acute and chronic test temperatures were maintained at 20 ± 1 C and 25 ± 1 C respectively. Mean pH and ammonia values at the start of the tests were 7.5 su and 5.2 mg/l. Since the hypolimnetic samples were anoxic to begin with, aeration was required to maintain dissolved oxygen saturation between 40 and 100% throughout the tests. Aeration would have reduced the ammonia levels during the tests. Bioassay results (attached) indicated no acute toxicity to the test organisms, but chronic toxicity was reported for *Ceriodaphnia*. Chronic toxicity suggests that hypolimnetic water could cause significant reduction in population growth and reproduction, depending on dilution rates.

Based on a combination of the toxicity test results and high levels of hypolimnetic pollutants, effluent limits (attached) were calculated to protect downstream uses and can be used for lake management planning. Since wastewater treatment has not been proposed, the effluent limitations were flow restricted using measured hypolimnètic BOD_5, total phosphorus, ammonia, dissolved oxygen, and pH values. Maximum allowable discharge rates to Big Creek and Baraboo River are 0.12 cfs and 3.1 cfs respectively. For a hypolimnetic discharge to Big Creek, permit authority would fall under Chapter 30 Wisconsin State Statutes. A proposed direct siphon discharge to the Baraboo River would require both Chapter 30 and Wisconsin Pollutant Discharge Elimnination (WPDES) permit approvals.

Discussion

Lake sampling in 2000 indicates that Lake Redstone behaves as two contiguous lakes. The large shallow basin (~480 acres) encompassing Station 4 is weakly stratified. This finding is not surprising given that most of the reservoir is also affected by a significant wind fetch. Weak or non-stratification is predicted by an equation developed by Lathrop and Lillie (1980). Stratification values generated from the equation predict non-stratification within the large basin and within 84% of southwest Wisconsin impoundments. Water quality implication of weak stratification is a net increase of phosphorus during the growing season due, in part, due to internal mixing (Lillie and Mason, 1986). The poor water quality observed at Station 4 was largely due to frequent mixing coupled with relatively close proximity to external phosphorus sources. These factors along with the remote location of the large basin from the dam minimize any potential benefits from a proposed hypolimnetic withdrawal.

Lillie and Mason (1983) emphasized the water quality benefits of thermal stratification and large hypolimnetic volumes. Pronounced stratification was detected in the lower more sheltered area of the reservoir throughout the growing season. Rapid phosphorus release and accumulation occurred near the bottom of the hypolimnion. Significant hypolimnetic phosphorus loading also coincided with the best epilimnetic water quality within the reservoir. Pronounced thermal stratification in the lower basin isolated internal phosphorus sources from the photic zone and did not fuel algal blooms during the warm growing season. While hypolimnetic withdrawal could deplete phosphorus from the lower basin sediments, effects on algal blooms would be insignificant due to the seasonal isolation of hypolimnetic nutrients from phytoplankton populations.

Recent lake modeling (Leverance and Panuska, 1997) predicted that internal phosphorus loading contributes about 29% of the total phosphorus budget. Regardless of the morphometric factors that affect thermal stratification and nutrient cycling, external sources still contribute most of the phosphorus to Lake Redstone. Therefore, significant internal phosphorus loading reduction can not be guaranteed. Lathrop (1994) evaluated hypolimnetic withdrawal to improve Devil's Lake in Sauk County. The Devil's Lake Project will be the first hypolimnetic withdrawal to reduce internal phosphorus loading in Wisconsin. The project is expected to be successful since most of the watershed has been restored to natural conditions, the lake sustains a large hypolimnetic volume, and over 90% of the phosphorus load is now internal.

Assessing potential downstream impacts of a hypolimnetic withdrawal is just as important as assessing potential lake response. Effluent limits were calculated and a WPDES permit was issued to Devil's Lake State Park to protect downstream uses. The effluent limits did not limit the project scope since pollutant levels in Devil's Lake are relatively low compared to fertile impoundments such as Lake Redstone. Maximum ammonia concentrations in Devil's Lake were 1.3 mg/l compared to 5.7 mg/l in Lake Redstone. And while Big Creek below Lake Redstone supports a diverse fishery, the receiving stream below Devil's Lake is intermittent and does not support fish. Therefore, less stringent effluent limits are required in streams classified as intermittent and "Limited Aquatic Life" (NR 104).

The two test hypolimnetic releases provided an intial screening of the potential impacts to Big Creek. But due to problems caused by the submerged berm and limitations of the relative short test period, impacts assessment was inconclusive. During the initial release on both dates, nutrient enriched cold bottom water became diluted with warmer less polluted water shortly after the gate was opened. The dilution of bottom water was both visually apparent and detected with monitoring instruments. The reason for the water quality shift became clear after The Lake Redstone Protection District hired divers to inspect the bottom gate. The divers observed a 15' high clay berm that entirely encompasses the bottom gate. The U. S. Army Corps of Engineers has tested submerged dams in selected impoundments. The structures have been used to prevent thermal destratification by diverting shallower water over the berms and into the bottom gates (Price and Meyer, 1992). The submerged dam in Lake Redstone currently presents a structural obstacle to effective hypolimnetic phosphorus reduction.

In addition to the submerged dam, the relatively short duration of the test releases further limited our ability to assess impacts to the stream. Downstream dissolved oxygen levels in Big Creek remained high during the test releases for a number of reasons. The bottom discharge was not effective at withdrawing the most polluted hypolimnetic water, so the BOD_5 and ammonia levels during the release were lower than what is actually measured near the bottom of the hypolimnion in Lake Redstone. In addition, some aeration occurred at the valve and in the discharge pipe. Once reaching Big Creek, the bottom release mixed with spillway water that was nearly saturated with oxygen. Long-term releases can cause more severe effects. Over a longer period, sustained high nutrient levels would significantly alter the stream ecology and threaten fisheries. Below White Mound Lake in Sauk County, a continuous bottom release has caused significant downstream pollution and nuisance hydrogen sulfide odors. The bottom gate was constructed to sustain cold temperatures for trout management below the dam and was not designed for phosphorus reduction. However, the permanent hypolimnetic release had caused poor water quality including toxic ammonia and low dissolved oxygen levels. Only pollution tolerant fish and macroinvertebrates are now found within several hundred meters below the dam. The stream substrates are covered with filamentous bacteria and other "sewage fungus" microorganisms. The "sewage fungus" microorganisms typically thrive in untreated or poorly treated sewage and create a significant oxygen demand (Ball and Marshall, 1978). Just as we observed below the White Mound dam, and Hilsenhoff (1971) observed below the Twin Valley dam, we would expect these types of organisms would become established in Big Creek following several days of hypolimnetic release. An effort is currently underway to re-evaluate and potentially modify the White Mound Lake outlet structure to discharges from an intermediate depths in an effort to balance surface warm temperatures and poor water quality near the bottom.

Due to the very high hydrogen sulfide concentrations in the hypolimnion, a proposed hypolimnetic discharge is not recommended until after Labor Day to reduce public exposure to nuisance odors. The bottom gate is located a short distance from the spillway, that is a public attraction. Hypolimnetic hydrogen sulfide concentrations up to 2 mg/l far exceed the nuisance odor threshold of .002 mg/l (Walburg, et al, 1981). Waiting until after the summer and Labor Day holidays are over would limit the hypolimnetic discharge period to a maximum of about 45 days.

Phosphorus concentrations during the first and second test releases were only 551 μg/l and 114 μg/l respectively, even though maximum concentrations reached 1500 μg/l in the hypolimnion. With the submerged dam in place, the projected phosphorus reductions over a 45-day period were approximately 61 kg at 1 cfs on August 15 and 72 kg at 5.7 cfs on September 20. These would represent only 2% and 3% of the seasonal phosphorus load duration predicted in the Lake Restone modeling report (Leverance and Panuska, 1997). Based on these test results, increasing the bypass flow rates will not significantly improve phosphorus removal rate due to the vortex effect of drawing greater amounts of relatively shallow water that contains lower phosphorus. Assuming a siphon can be constructed to bypass the submerged dam, effluent limits would restrict flow rates due to very high pollutant concentrations near the bottom. Assuming a mean phosphorus concentration of 1,325 μg/l over a 45-day period, phosphorus reduction would be 18 kg or less than 1% of the seasonal phosphorus load estimated during the 1997 lake modeling effort. This amount is modest compared to the existing spillway discharge of 300 kg during the seasonal five month period or equivalent to 13% of the seasonal phosphorus load. Alternatively, a direct discharge to the Baraboo River could accommodate a flow rate of 3.1 cfs and much greater phosphorus load reduction. The projected phosphorus reduction would be about 452 kg or 20% of the seasonal phosphorus load. The reduction could reduce the sediment phosphorus source near the dam, but a source that is largely non-reactive with the seasonal algal blooms. This alternative would require constructing a ~2300' siphon to the Baraboo River. Flow monitoring would be required for both the discharge pipe and Big Creek. A minimum low flow of 1.5 cfs would have to be sustained in Big Creek to protect existing fisheries.

Based on the potential for downstream impacts and associated conservative effluent limits, a hypolimnetic discharge to Big Creek would have negligable impact on the Lake Redstone phosphorus budget. A WPDES permit would allow for a greater discharge rate if the discharge bypasses Big Creek directly to the Baraboo River and take advantage of substantially more dilution. A greater effluent flow rate to the Baraboo River would still not be sufficient to significantly reduce productivity in Lake Redstone.

MSA Professional Services, Inc. (Paul McGinley, 1998) predicted three factors that may affect the feasibility of a hypolimnetic withdrawal:

1. "removal rates which are likely to provide mixing downstream of the discharge to reduce potential negative effects of bottom water, may result in a discharge which is less than optimal for achieving long term benefits"
2. "any benefits of the bottom draw are likely to be observed in the segment of the lake nearest the dam"
3. "benefits of the continuous bottom draw to other portions of the lake would require bottom water movement towards the dam, which may or may not be achieved with moderate mixing in the lake or at relatively low release rates"

Results of this study have largely confirmed these predictions and support recommendations of the 1997 Lake Redstone Protection District-WDNR "Water Quality Model Study" that suggests controlling internal loading is less important than controlling significant external phosphorus sources.

Summary of Findings

1. Lake Redstone behaves as two contiguous lakes; the upper lake is mixed and lower lake is thermally stratified.
2. Internal phosphorus loading is a significant water quality factor within the mixed upper lake and poor water quality resulted. Due to a combination of weak thermal stratification, close proximity to external phosphorus sources and the remote location from the dam, hypolimnetic withdrawal would not improve the water quality in this part of the lake.
3. Pronounced thermal stratification in the smaller basin near the dam allows for sediment phosphorus reduction if outputs exceed inputs. However, this part of the lake displays the best water quality and indicates that internal phosphorus sources are not affecting surface water quality.
4. Big Creek supports diverse fisheries and aquatic life. A hypolimnetic discharge could pose a serious threat to the stream based on high levels of ammonia and hydrogen sulfide and low dissolved oxygen. Bioassay tests indicated hypolimnetic water toxicity to *Ceriodaphnia dubia* but fathead minnows were unaffected.
5. The two test releases showed that the existing valve could be manually set to accurately control the low flow rates needed for a bottom discharge, but the submerged dam makes the existing structure ineffective at removing high phosphorus concentrations from the lake. Some aeration occurred at the discharge valve and pipe. Downstream dissolved oxygen remained high in Big Creek during both tests. Elevated ammonia concentrations were found in Big Creek and to a lesser extent in the Baraboo River.
6. Whether or not structural changes are made to avoid effects of the submerged dam, a Chapter 30 and/or WPDES permit will be required for any proposed hypolimnetic discharge in an effort to protect downstream fisheries, the public interest and water quality standards. As part of the permitting process, effluent calculations will limit hypolimnetic discharge rates based on a number of factors including stream

classification, stream dilution and effluent quality. Maximum hypolimnetic discharge rates to Big Creek and directly to the Baraboo River are .123 and 3.1 cfs respectively.

7. Strong hydrogen sulfide (rotten egg) odors would be produced during a hypolimnetic withdrawal and create nuisance conditions during heavy park use periods.
8. Results of the Lake Planning Grant-Baraboo River Restoration and Research Study have largely confirmed the predictions and support recommendations of the 1997 Lake Redstone Water Quality Model Study that suggests controlling internal loading is less important than controlling significant external phosphorus sources.
9. From a statewide perspective on water quality management, a thorough analysis of lake response and downstream impacts is recommended for all proposed hypolimnetic withdrawal projects, whether the goal is internal phosphorus loading reduction or sustaining a desired downstream temperature regime.

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Appendix 1: Water Quality-Based Effluent Limitations for proposed Lake Redstone hypolimnetic discharge. Prepared by Nasrin Mohajerani.

Table-1 Recommended Effluent Limitations For Baraboo

Substances	Daily	Weekly Avg.	Monthly Avg.
BOD5 *		20 mg/L	
TSS*		40 mg/L	
Dissolved Oxygen	7.0 mg/L – Min		
pH (s.u.)	6.0 min. - 9.0 max.		
Ammonia:			
May – Oct	6.55 mg/L		
Nov. – Apr.	limit not needed		

* - limitations are based on best professional judgment.

Table- 2 Recommended Effluent Limitations For Big Creek

Substances	Daily	Weekly Avg.	Monthly Avg.
BOD5 *		20 mg/L	
TSS*		40 mg/L	
Dissolved Oxygen	7.0 mg/L – Min		
pH (s.u.)	6.0 min. - 9.0 max.		
Ammonia :			
May – Oct	5.9 mg/L		
Nov. – Apr.	limit not needed		

* - limitations are based on best professional judgment.

General Procedures for Establishing Effluent Limitations

BOD_5:

In establishing BOD_5 limitations based on water quality standards the following formula was used.

$$BOD_5 = \{(2.4)(DO)(Qe + Q7,10)(0.967)^{(T-24)}\} / Qe$$

where:

DO = The decrease in DO (mg/L) (2 mg/L in warm water)
Qe = The effluent design flow (mgd) (converted to cfs)
Q7,10 = The receiving water Q7,10 (cfs)
T = The receiving water temperature (C)

Weekly average limitations are calculated based on 26 pounds of BOD discharged per cfs of flow (after mixing) in order to produce an edge-of mixing-zone decrease of 2 mg/L

DO at a temperature of 24° C (75° F). Corrections to the formula are necessary at different temperatures and/or to account for different DO decreases. A decrease from an assumed background concentration of 7 mg/L DO to the 5 mg/L warm water standard equals the 2 mg/L decrease mentioned earlier.

TSS:
The suspended solids limitations are primarily given to maintain or improve water clarity, and are not water-quality based. Normally suspended solids limitations are thus established the same as the BOD_5 limitations in accordance with s. NR 102.04 to prevent objectionable deposits on shores or beds of receiving waters. Although the Department normally recommends that the TSS limits be set equal to the recommended BOD_5 limits for discharges with water quality-based limits however, if the BOD_5 limits are less than 10 mg/L it is recommended that TSS limit not to be set lower than 10 mg/L monthly average for the entire year.

pH:
The pH requirement is required under s. NR 102.04(4)(c) where the effluent pH cannot change the ambient pH range by 0.5 units or be outside the range of 6.0 - 9.0 s.u. Therefore, a daily pH range of 6.0 - 9.0 s.u. is recommended.

Ammonia Nitrogen:
The existing procedure for calculating effluent limitations for ammonia is based on the application of an in-stream un-ionized ammonia nitrogen (NH3-N) criterion of 0.04 mg/L after mixing in the receiving water taking into account background pH levels and background river temperatures, each of which influence the criterion. The general calculation procedure and information is summarized below:

In establishing ammonia nitrogen limitations where daily variables are used, the daily percent of un-ionized ammonia has to be determined.

To determine the percent of total ammonia the following equations are used:

$\%\ NH3\text{-}N = 1 / (1 + 10^{(pka-pH)})$
Where:
pka = 0.09018 + 2729.92 / T

T = Temperature © + 273.2
Receiving water temperature:

%NH3-N = Percent of the total NH3-N in the un-ionized form
The total NH3-N concentration is then equal to the appropriate un-ionized NH3-N criterion divided by the %NH3-N.

In establishing ammonia effluent limitations the daily percent of unionized ammonia is calculated and a background pH is determined. The receiving water temperature is also used. Establishing these appropriate background concentrations is a critical step. Once

the total allowable ammonia is determined, then a mass balance is used to determine the appropriate effluent limitation.
With this determined and the receiving water temperature measured, the formulas used to determine the fraction of the total NH3-N are applied resulting in total allowable NH3-N values for use in the equations.

To determine the chronic effluent limitation on any given day, a mass balance of the receiving water input parameters and effluent parameters is calculated. The mass balance calculation includes input parameters such as allowable dilution, background concentrations, and total allowable ammonia to determine the final effluent limitation. The mass balance equation is as follows:

$$NH3 - N_{(effluent)} = Q_{(mix)} * NH3\text{-}N_{(total\ allowable\ ammonia)} - Q_{(receiving\ water)} * NH3\text{-}N_{(receiving\ water)} \,/\, Q_{(effluent)}$$

where:
$NH3\text{-}N_{(effluent)}$ = Final limitation
$NH3\text{-}N_{(receiving\ water)}$ = Background concentration

$NH3\text{-}N_{(total\ allowable\ ammonia)}$ = Total allowable NH3-N
$Q_{(mix)} = Q_{(receiving\ water)} + Q_{(effluent)}$

$Q_{(receiving\ water)}$) = Allowable dilution
$Q_{(effluent)}$) = Effluent flow

Dissolved Oxygen:
Dissolved oxygen (DO) limits are typically given when BOD_5 is water quality-limited. Dissolved oxygen limits are set as 1 mg/L above the instream criterion to prevent concerns over acute impacts on DO near the outfall when low DO is discharged along with some BOD_5. Where the effluent dissolved oxygen is zero, which is the case in here, DO limits are typically set at or near the criterion but may adjust based on the BOD_5 limit.

Phosphorus: Chapter NR 217 of the Wisconsin Administrative Code addresses point source discharges of phosphorus to surface waters. The code limits dischargers that are not subject to ch. NR 210 (meaning dischargers other than municipalities) of more than 60 pounds of phosphorus per month to 1.0 mg/L total phosphorus.

Temperature:
Section NR 102.04(4) (b) requires that the instream temperature shall not exceed 89° F for warm water fish and also that the instream temperature not to be raised by more than 5° F above the existing natural temperature for a stream. The Department is currently in the process of revising its policies and procedures for establishing thermal limitations. The permittee should be advised that review of the thermal limitations would be considered during the next permit term.

Discharge to the Baraboo River
The proposed discharge site is to Baraboo River, which is classified as warm water sport fish community. The receiving water flows used in establishing effluent limitations were

obtained from U.S. Geological Survey based on flow information obtained at Lavalle Sauk County.

BOD$_5$ Limit Calculation:

Following table summarizes the effluent and receiving water data used in calculating water quality-based effluent limitations.

BOD LIMIT CALCULATIONS (26 LB RULE) **Lake Redstone**

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RECIVING WATER:	Baraboo River	
PROPOSED DESIGN FLOW (MGD)	2	2
RIVER FLOW 7Q10 (cfs)	42	42
RIVER TEMPERATURE	25	3
EFFLUENT DO (mg/L)	7	7
BACKGROUND DO (mg/L)	7	7
MIX DO (mg/L)	7	7
DO CRITERION (mg/L)	5	5
BOD5 Concentration Limits (mg/L)	67.5	141.3
Mass (lbs/d)	1126.1014	2356.1072

Mass = (Design flow)(BOD5)(8.34)
BOD5 (mg/L) = 2.4(DObg-DOcr)[a](0.967^(T-24)
where: a = (Q7,10(0.645) + Qd)f/Qdf
Mass = (Design flow MGD)*(BOD5 mg/L)*(8.34)
Mass limits based on proposed design flow

Recommendation: Because there are a lot of available dilution, effluent limitations for BOD5 based on water quality standards are much greater than Best Professional Judgment limit of 20 mg/L weekly average, therefore, 20 mg/L BOD_5 limit is recommended.

Ammonia Limit Calculation:

Following table summarizes the effluent and receiving water data used in calculating water quality-based effluent limitations.

AMMONIA LIMIT CALCULATIONS		**Lake Redstone**	Baraboo	River
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Input Parameters:		Output Parameters:		
EFFLUENT FLOW (mgd) =	2.000 3.1		**SUMMER**	**WINTER**
MAX. EFFL. pH =	9.00		------	------
		BACKGRD. pH =	8.21	7.97
RIVER 7Q10 (cfs) =	**42.00**			
BACKGROUND NH3-N:		PKa =	9.28	9.97
Summer	0.06			
Winter	0.12	MIX NH3-N =	0.51	4.08
BACKGROUND pH:				
Summer	8.21	NH3-N LIMIT:		
Winter	7.97			
RIVER TEMPERATURE (C):		Mg/L	**6.55**	**57.76**
Summer	24.00			
Winter	3.00	Lb/d	**109.18**	**963.47**
UN-IONIZED NH3-N CRITERION (mg/L) =	0.04			

Recommendation: Based on the above-calculated effluent limitations for ammonia a weekly average limitation of 6.6 mg/L (rounded) 110 lbs/day for summer is recommended.

Discharge to Big Creek

The proposed discharge site to Big Creek is located at SE ¼ of SW ¼ of Section 24, T13N _ R3E. Big Creek is classified as warm water sport fish community.

BOD_5 Limit Calculation:

Following table summarizes the effluent and receiving water data used in calculating water quality-based effluent limitations.

BOD LIMIT CALCULATIONS (26 LB RULE) **Lake Redstone**

'--

RECIVING WATER: **Big Creek**

	Summer	**Winter**
PROPOSED DESIGN FLOW (MGD)	0.08	0.08
RIVER FLOW 7Q10 (cfs)	1.5	1.5
RIVER TEMPERATURE	25	3
EFFLUENT DO (mg/L)	7	7
BACKGROUND DO (mg/L)	7	7
MIX DO (mg/L)	7	7
DO CRITERION (mg/L)	5	5
BOD5 Concentration Limits (mg/L)	**60.8**	**127.2**
Mass (lbs/d)	40.54	84.84

Mass = (Design flow)(BOD5)(8.34)
BOD5 (mg/L) = 2.4(DObg-DOcr)[a](0.967^(T-24) =
where: a = (Q7,10(0.645)+Qd)f/Qdf
Mass = (Design flow MGD)*(BOD5 mg/L)*(8.34)
Mass limits based on proposed design flow

Recommendation: Because effluent limitations for BOD5 based on water quality standards are much greater than Best Professional judgment limit of 20 mg/L weekly average, therefore, 20 mg/L BOD$_5$ limit is recommended.

Ammonia Limit Calculation:
Following table summarizes the effluent and receiving water data used in calculating water quality-based effluent limitations.

AMMONIA LIMIT CALCULATIONS		Lake Redstone		
-------------------------------- ----------- -------				
Input Parameters:		Output Parameters:		
EFFLUENT FLOW (mgd) =	**0.080** 0.1		SUMMER	WINTER
MAX. EFFL. pH =	9.00		------	------
		BACKGRD. pH =	8.21	7.97
RIVER 7Q10 (cfs) =	**1.50**			
BACKGROUND NH3-N:		PKa =	9.28	9.97
summer	0.06			
winter	0.12	MIX NH3-N =	0.51	4.08
BACKGROUND pH:				
summer	8.21	NH3-N LIMIT:		
winter	7.97			
RIVER TEMPERATURE (C):		Mg/L	**5.90**	**52.01**
summer	24.00			
winter	3.00	lb/d	**3.94**	**34.70**
UN-IONIZED NH3-N CRITERION (mg/L) =	0.04			

Recommendation: Based on the above-calculated effluent limitations for ammonia a weekly average limitation of 5.9 mg/L (4 lbs/day) for summer is recommended.

Phosphorus: Chapter NR 217 of the Wisconsin Administrative Code addresses point source discharges of phosphorus to surface waters. The code limits dischargers that are not subject to ch. NR 210 (meaning dischargers other than municipalities) of more than 60 pounds of phosphorus per month to 1.0 mg/L total phosphorus.

The effluent data collected from the Lake Redstone by the Department (DNR) has been evaluated.

Bottom discharge water chemistry data:

10 meters	BOD(mg/L)	pH(s.u.)	NH3(mg/L)	TP(mg/L	Temp.©	D.O.(mg/L)
08/24/2000	31	7.5	4.07	0.937	11	0
09/12/2000			4.43	1.2	12.5	0
09/27/2000	30.8	7.38	5.74	1.5	12	0

The data collected has demonstrated that monthly phosphorus loading is greater than the 60-lbs/month threshold in accordance with ch. NR 217 of the Wis. Adm. Code for discharge of 2 mgd to Baraboo River.

Recommendation: Since this is not a continuous discharge, calculated annual monthly average loading is lower than 60 lbs/month threshold Phosphorus [(1.2 mg/L x 2 mgd x 8.34 x 30day/mon) / 12 month/yr = 50 mg/L]. Flow monitoring is required.

Also, water quality-based phosphorus standards are currently under development, which may result in a phosphorus effluent limitation lower than 1 mg/L. Therefore, management planing should consider potential changes to meet a phosphorus effluent limitation at or below 1 mg/L.