DEFINITE PROJECT REPORT
WITH INTEGRATED ENVIRONMENTAL ASSESSMENT

SECTION 206
LAKE BELLE VIEW
AQUATIC ECOSYSTEM RESTORATION PROJECT

APPENDIX G
WATER QUALITY

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1. INTRODUCTION

Water quality improvement is a primary objective of the Lake Belle View Aquatic Ecosystem Restoration Project. This topic is of particular concern to the residents of Belleville, Wisconsin, who ranked water quality and sediment deposition as the two most significant problems of Lake Belle View in a 1995 survey conducted by participants in a University of Wisconsin workshop. The purpose of this appendix is to address the water quality impacts of the restoration alternatives proposed for Lake Belle View. The appendix is comprised of three sections—temperature, sedimentation, and nutrients.

A water temperature assessment was conducted in order to evaluate the potential for successfully extending the cool-water fishery downstream. Temperature modeling was performed in an effort to predict temperature changes that would occur if the Sugar River was separated from Lake Belle View.

Increasing lake depth is another project restoration objective. Sedimentation calculations were performed in order to estimate the lifespan of the proposed dredged areas. The calculations include both sediment and biomass accumulation, and account for periodic overtopping of the overflow spillway due to flooding.

The impact of nutrients, particularly phosphorus, on lake productivity is well documented. Excessive phosphorus concentrations can result in impaired water quality due to algal blooms. The effects of the proposed restoration alternatives on phosphorus concentrations also are discussed.

2. TEMPERATURE

The proposed project at Lake Belle View would result in modified river hydraulics, decreasing the travel time for the majority of flow and making the separated lake portion more lacustrine. An important question is whether this change would impact the water temperatures in the Lake Belle View project area. Numerous studies are available in relevant literature that address temperature in rivers and lakes.[1, 2,3] From these it is clear that the major factor affecting temperature in rivers and lakes similar to the Lake Belle View project area is heat exchange with the atmosphere, i.e., water in lakes receive more heat from the atmosphere and become warmer than water in rivers which receive less heat from the atmosphere. This effect was verified in Lake Belle View during August 2000. Continuous temperature data collected during the month of August 2000 demonstrated an average river inflow temperature of 20°C (68°F) and an average outflow temperature of 22°C (72°F). The proposed Lake Belle View project will affect the heat exchange with the atmosphere in Lake Belle View by changing the amount of exposure from short- and long-wave solar radiation—the river portion will have a decreased amount of exposure and the lake portion will have an increased amount of exposure. Based on references 1, 2, and 3, it is possible to show that the change in exposure and resulting temperature change for the Lake Belle View project will directly depend on the change in travel time and the change in depth resulting from the project.

To evaluate potential changes in the Lake Belle View project area, we chose one hypothetical extreme situation to analyze and made a series of logical assumptions. Calculations based on the existing condition assumed an influent water temperature of 68 degrees Fahrenheit and calculated a water temperature of 79 degrees Fahrenheit immediately downstream of Lake Belle View. Calculations based on the with-project condition assumed an influent water temperature of 68 degrees Fahrenheit and calculated a temperature of 68.5 degrees Fahrenheit in the downstream end of the separated river portion. The lake portion of the proposed Lake Belle View project would approach ambient air temperature. These with-project conditions result in lower temperatures in the river and higher temperatures in the lake (during summer months).

<u>References</u>:

1. *Stream Temperature Dynamics: Measurements and Modeling*, Sinokrat and Stefan, 1993.
2. *A 2-Layer Energy Balance Model for the Prediction of Stream Temperature*, La Marsh, Dubin, Lettenmaier, 1997.
3. *Hydrology and Floodplain Analysis*, Bedient and Huber, 1992.

<u>Calculations</u>:

Part 1. Example Water Temperature Calculation:

Assumptions:
Lake Belle View:
Area: Approximately 93 acres
Depth: Approximately 2 feet
Residence Time: 18 hours
Average Discharge: 118 cfs

Assumptions:
Diverted Sugar River: velocity = 0.5 ft/sec.
Diverted Sugar River residence time = 3 hours
Diverted Sugar River depth = 3 meters
Diverted Sugar River shading = 20%
date = July 15
latitude = 43°
atmospheric transmission coefficient = 0.9
albedo = 6%
air temperature = 30°C
relative humidity = 60%
initial water temperature = 20 C
wind at 0.5 m/s
atmospheric pressure = 1000 mb
assume constant atmospheric conditions

Methodology for Temperature Approximation:

To approximate the temperature in Lake Belle View, a one-dimensional, unsteady heat advection-dispersion equation can be used. This equation assumes that the water body is well mixed and has no significant transverse temperature gradients, i.e., the main variation is in the flow direction (longitudinal direction of the stream).

The finite difference form of the equation is shown below

$$T_i^{t+1} = T_i^t - \Delta t \frac{Q_i}{A_c} \frac{T_{i+1}^t - T_{i-1}^t}{2\Delta x} + \Delta t U \frac{T_{i+1}^t - 2T_i^t + T_{i-1}^t}{\Delta x^2} + \Delta t \frac{S_i^{t+1} + S_i^t}{2\rho c_p * d}$$

where,

T = water temperature
Q = discharge
A = area of flow
x = streamwise distance
t = time
S = source or sink term that equals the net heat transfer with the surrounding environment
U = mean channel velocity
d = mean channel depth
ρ = density of water
c_p = specific heat of water

If the system is in thermal equilibrium with the environment with zero net water/atmospheric heat exchange, the equation simplifies to the following:

Thermal Equilibrium Form: $$T_i^{t+1} - T_i^t = \Delta t \frac{S_i^{i+1} + S_i^i}{2\rho c_p * d}$$

Note: See part 2 for calculation of Source/Sink Term (S)
Calculation of <u>Net source/sink components (S)</u> without shade = 290.23 W/m^2
Calculation of <u>Net source/sink components (S)</u> with shade factor of 0.2 = 212.67 W/m^2
Note: The <u>Net source/sink components (S)</u> term was calculated as an average over 24 hours.

Assume constant atmospheric conditions.

$\frac{S_i^{i+1} + S_i^i}{2}$ = <u>Net source/sink components (S)</u> = 242.83 W/m^2
with shade = 212.67 W/m^2

ρc_p = 1000 kg/m^3* (cp of water = 4190 J/kg deg.C)
1 Joule = 1 kgm^2/sec^2

$T_i^{t+1} - T_i^{t+1}$= (242.83/4190000/d)*Δt without shade

$T_i^{t+1} - T_i^{t+1}$= (165.27/4190000/d)*Δt with shade

for residence time through lake of 18 hours
$T_i^{t+1} - T_i^{t+1}$= 3.76/d

for residence time through diverted Sugar River of 3 hours(with shading = 20%)
$T_i^{t+1} - T_i^{t+1}$= 0.43/d

for residence time through diverted Sugar River of 3 hours(with no shading)

$T_i^{t+1} - T_i^{t+1}$= 0.63/d

For depth of lake = 2 feet = 0.61 meters
$T_i^{t+1} - T_i^{t+1}$= 3.76/0.61 = 6.16 °C

For depth of diverted Sugar River = 3m

$T_i^{t+1} - T_i^{t+1}$= 0.43/3 = 0.14 °C (with shading = 20%)

with no shading in diverted Sugar River

$T_i^{t+1} - T_i^{t+1}$= 0.63/3 = 0.21 °C (with no shading)

Approximation of Lake Belle View and Diverted Sugar River Temperatures

With the approximations used, the temperature increase through the lake was 7.36 °C and the temperature increase through the diverted Sugar River was 0.18 °C with 20% shading and 0.25 °C with no shading. The with-project conditions will lower water temperatures downstream of the dam by up to 13 degrees Fahrenheit in the summer months.

Part 2: Calculation of Source/Sink Term (S)

Calculation of S
S = Source or sink term and expresses heat transfer with the surrounding environment.

$S = S_a + S_b$
S_a = net heat exchange between the water and the air (atmosphere).
S_b = net heat exchange between the streambed and the stream water

Sa = Hs – Hl – He – Hc

Hs = net shortwave (solar) radiation.
Hs = difference between measured incoming (His) and reflected (Hsr) radiation.
= Hsi - Hsr
Hs = (Hsi – Hsr)(1-SF)
Hl = net longwave radiation adsorbed by stream
He = evaporative heat transfer
Hc = convective heat transfer
SF = shade factor

Calculate net radiation adsorbed by stream = Hs + Hl
Refer to Bedient & Huber (1992) pp. 651 – 660
Hs + Hl = (Hs – Hsr)(1-SF) + Hli – Hlr – Hlb
Hsi = incoming shortwave radiation
Hsr = reflected shortwave radiation
Hli = incoming longwave radiation
Hlr = reflected longwave radiation
Hlb = longwave radiation emitted from water surface

Assume date = July 15
Latitude ≈ 43°
Assume atmospheric transmission coefficient of 0.9
Total direct radiation reaching ground = 837 ly/day
Total radiation at top of atmosphere = 963 ly/day
Account for water vapor absorption and ozone absorption
0.91 * 963 = 876 ly/day
Energy scattered out of direct beam = 876 – 837 = 39 ly/day
Half of scattered returns to space: 39/2 = 18 ly/day
Incoming solar radiation (Hsi)= 837 + 18 = 855 ly/day
Average albedo for July = 6%
Reflected shortwave radiation (Hsr) = Qs*albedo = 855*0.06 = 51 ly/day
Assume air temperature = 30°

$$e_s = 2.7489 * 10^8 \exp\left(\frac{-4278.6}{30 + 242.79}\right)$$

= 42.4 mb

assume relative humidity = 60%
vapor pressure ambient:
ea = 42.4 mb * 0.6 = 25.4 mb
emissivity of atmosphere:
εa = 0.51 + 0.066*(25.4)^(-1/2) = 0.843

Longwave atmospheric radiation at 273 + 30 = 303 K
LONG WAVE RADIATION:
Hli = 0.843 * 0.813 * 10^(-10) * 303^(4) = 0.578 ly/min = 832 ly/day
Reflected longwave radiation (Hlr) = (1 – emissivity)* longwave = 0.157 * 832 = 130.6 ly/day

Assume water temperature = 20 C = 293 K
Back radiation (Hlb) = 0.97 * 0.813 * 10^(-10) *293^(4) = 0.581 ly/min = 837 ly /day

Assume SF = shade factor = 0
Net total radiation absorbed by water body = (Hsi – Hsr)*(1-SF) + Hli - Hlr - Hlb
= 855 ly/day -51 ly/day + 832 ly/day - 130.6 ly/day – 837 = 715 ly/day = 299.23 W/m^2
Assume SF = shade factor = 0.2
=(855 – 51)*(1-0.2) + 832 – 130.6 – 837 = 555 ly/day = 221.36 W/m^2

Evaporative Heat Transfer:

$$H_e = \rho * L * (Wftn)_z (e_s - e_a)$$
ea = vapor pressure of air height z.
es = saturated vapor pressure
L = latent heat of vaporization of water.
$Wftn_z$ = wind function using wind velocity at height z.

L = 597.3 – 0.57 (T - 0°) (cal/g)

Assume T = 30°C
L = 597.3 – 0.57(30) = 580.2 cal/g

0.2388 joules = 1 calorie
L = 580.2 *.2388/1000 = 0.138552 J/Kg

He = 1000kg/m^3*0.138552J/Kg*(Wftn)z*(.254kg/m/sec^2)

$$(Wftn)_z = 0.934(\Delta\Theta)^{(1/3)} + 0.852W_2$$

$\Delta\Theta$=the virtual temperature difference
Assume water at 20 C
Assume air at 30 C
Assume wind at 0.5 m/s
Wftn = 0.934*(10)^(1/3) + 0.852*0.5
= 2.44
He = 1000kg/m^3*0.138552J/Kg*2.44*(.254kg/m/sec^2)
He = 85.9 W/m^2sec.

Convective Heat Transfer:

Calculate convective heat transfer with Bowen ratio:
After (Bedient & Huber 1993)
R = Bowen ratio = ratio of heat loss by conduction/convection to heat loss by evaporation

$$R = 0.66 * \left(\frac{Ts - Ta}{es - ea}\right) * \left(\frac{P}{1000}\right) = \gamma \frac{Ts - Ta}{es - ea}$$

=0.66*(20-30)/(42.4 – 25.4)
= -0.39
Heat loss by conduction evaporation = -0.39*He = -0.39 *85.9 W/m^2sec.
= -33.5 W/m^ 2

Streambed Heat Transfer:

The stream bed heat transfer can be approximated
Sb = heff(Tavg – 2 – Tw)
Heff = effective heat transfer coefficient
Tavg = daily average temperature
Tw = water temperature

Assume heff = 0.5
Sb = 0.5(30 – 2- 20)
= 4 W/m^2

Summary of Source/Sink Terms:

S = net heat exchange between water and air and stream bed = Sa + Sb
Sa = net heat exchange between water and air = Hs – Hl – He – Hc
<u>Net total radiation absorbed by water body (Hs – Hl)</u> = 299.23 W/m^2
<u>Net total radiation absorbed by water body with shading factor of 0.2</u>
<u>(Hs – Hl)*(1-0.8)</u> = 221.36 W/m^2

Evaporative Heat Transfer(He) = 85.9 W/m^2sec.
Convective/Conductive Heat Transfer to atmosphere (Hc) = -33.5 W/m^ 2
Sb
Streambed Heat Transfer (Sb) = 4W/m^2

Net source/sink components (S) = 299.23 - 85.59 +33.5 – 4 = 243.83 W/m^2
Net source/sink components (S) with shading = 221.36 - 85.59 +33.5 – 4 = 165.27 W/m^2

3. SEDIMENTATION

Sedimentation calculations were completed to estimate the lifespan of the dredged areas. Environmental benefits derived from dredging occur at depths of 6 feet or deeper. At year 1, it is anticipated that 15.5 acres of lake bottom will be 6 feet or deeper. By year 10, an estimated 11.9 acres will be 6 feet or deeper. At the end of the project life, year 50, it is estimated that 2.4 acres of lake bottom will be 6 feet or deeper, barring any maintenance dredging by the community. These sedimentation rates include both sediment and biomass accumulation and account for periodic overtopping of the overflow spillway due to flooding. The calculations were based on assumptions made on sideslope changes over 50 years applied to a single square-shaped dredged area. This technique resulted in an accumulation rate of 3.0 - 4.0 cm per year (see Exhibit 1), which is similar to the sedimentation rate in some backwater areas of the Mississippi River [Reference: WEST Consultants, *Upper Mississippi River and Illinois Waterway Cumulative Effects Study, Volume 1: Geomorphic Assessment* (Bellevue, WA, submitted to U.S. Army Corps of Engineers, Rock Island District, June 2000)].

The *Cumulative Effects Study* examined sedimentation rates in many backwater locations of the Upper Mississippi River. A typical lower sedimentation rate is approximately 1 cm per year, where higher sedimentation rates are about 3 cm per year. Sedimentation rates for specific locations appear on Table 6.5 of the *Cumulative Effects Study* (see Exhibit 2). While larger sedimentation rates have been observed and measured elsewhere on the Upper Mississippi River, these locations tend to occur closer to the main channel where abrupt velocity changes occur and bedload deposits are significant. For Lake Belle View, suspended load accumulation is more appropriate and is certainly the case where a berm is constructed and the lake is separated from the flow of the Sugar River. The lower range of sedimentation rates (< 1 cm/year) would be expected. This is indeed the case as verified by a special study of Lake Belle View by the University of Wisconsin, which concluded that 0.32 cm per year of sediment accumulates into Lake Belle View [Reference: Potter et al., *Lake Belle View, Research Findings and Alternatives for the Future,* 1995 Water Resources Management Workshop, Dept. of Civil and Environmental Engineering and Institute for Environmental Studies, University of Wisconsin - Madison]. The study also determined the trap efficiency of the lake by three different methods, resulting in a 12-15% trap efficiency. This low trap efficiency percentage implies that Lake Belle View has largely stabilized and filled in with sediment. If the lake were to be dredged without constructing a separation berm, the trap efficiency would be higher.

The HEP analysis uses the 3.0 - 4.0 cm per year rates in its calculation of environmental benefits in order to include the effects of biomass accumulation. After the separation berm is in place, Lake Belle View will have more opportunity to develop and sustain wetland areas. The exclusion of carp and lower sediment inflow will improve water clarity within the lake, leading to an expected increase in vegetative growth. The accumulation rate of 3.0 - 4.0 cm per year is considered a worse case scenario for biomass and sediment accumulation over the life of the project. In this fashion, the HEP analysis is conservative yet uses reasonable assumptions.

On a pure sediment level (ignoring biomass accumulation), sediment accumulation from the Sugar River is predominantly fine-grained suspended sediment. The addition of a separation berm reduces the sedimentation rate in the lake from 0.32 cm per year to less than 0.1 cm per year. The life of the dredged areas is greatly increased by adding the separation berm because it limits the amount of flow passing through the lake. The majority of flow up to a 25-year flood discharge (4,900 cfs) is routed around the lake, and flows above this are allowed into the lake by overtopping a lateral embankment spillway. During floods smaller than the 25-year flood, some flow through the lake increases through the inflow structure and the boat passage structure. The amount of flow will vary according to the design of the structures, which will be designed in the plans and specifications phase of the project. The inflow structure design is very flexible and can incorporate the needs of the sponsors: no flood impacts upstream, boat passage ability, exclusion of carp, allowing a minimum flow of 10 cfs for dissolved oxygen needs of overwintering fish, and limiting the inflow to less than the average annual flow of 115.5 cfs during floods less than the 25-year flood to reduce the amount of sediment inflow to the lake.

Positioning of the dredged areas relative to the inflow structures is very important to the life of the dredged areas. Sediment accumulates at flow separation zones; that is, sediment drops out where the concentration of flow fans out and velocities decrease. If the dredged areas are positioned in flow separation zones, they will quickly fill with sediment. These locations will be determined by studying the circulation patterns within the lake at various flow rates. This analysis and recommendations on best locations of dredged areas will be completed in the plans and specifications phase of the project.

Exhibit 1

Lake Belle View Life of Dredged Areas*
* includes sedimentation and biomass accumulation of dredged areas

15 Acres Dredged to 8 Ft**
** based on single square-shaped dredge area

Year	Assumed Area Filled %	Acres 8 ft	Acres >= 6 ft	Assumed Sideslope Horiz/Vert	Square Dimensions of Area Greater Than or Equal to 6 ft in Depth ft x ft	Total Volume Material in Dredged Areas cubic yards	Rate of Sedimentation and Biomass Accumulation cm per year
0	99.5	0	0	0	0.0	no project condition	
1	67	15	15.45	3	820.3	(138,625) removed	
5	70	13.62	14.19	4	786.1	97038	**2.7**
10	75	11.31	11.90	4.5	719.8	103969	**3.9**
25	85	6.69	7.20	5	559.9	117831	**3.7**
50	95	2.08	2.42	6	324.8	131694	**2.9**

138,625 cy initially removed

Year	8 ft deep sq ft area	8 ft deep dimensions ft x ft	open area calculations: square	open area calculations: ends	open area calculations: corners	total (cy)	additional material gained: cy	additional material gained: year	mass accum rate Ac-ft/year	midslope acreage
1	653400	808.3								
5	593086	770.1	120813.8	6902.6	197.2	127914	10,711	5	1.3279	14.40
10	492563	701.8	100336.9	7076.8	249.6	107663	30,962	10	1.9191	12.12
25	291517	539.9	59383.1	6049.1	308.1	65740	72,885	25	1.8071	7.39
50	90471	300.8	18429.2	4043.9	443.7	22917	115,708	50	1.4344	2.56

0.01	0.01
1	3
5	4
10	4.5
25	5
50	6

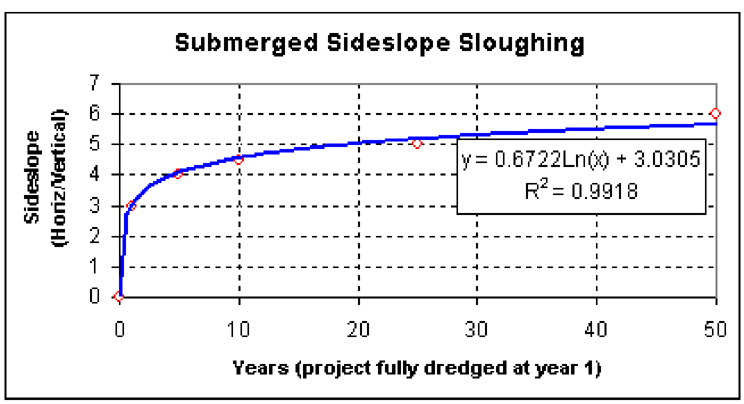

Exhibit 2

Table 6.5: Summary of UMR sedimentation rate estimates (see also Figure 6-3).

Source Reference	Location	Estimated Sedimentation Rate (cm/year)	Applicable Time Period	Comments
Current Study	Lower Pool 11	1.56	1938 - 1951	Average of 13 cross sections (RM 584 - 597) for backwater areas
		0.34	1951 - 1995	
	RM 403 to 580 Pools 12 - 19	0.05 (0.04)*	Primarily ~mid-1940s to 1995	Average for backwater areas derived from sediment budget, assuming dredged material left in *(dredged material taken out).
	RM 364 to 403 Pools 19 - 20	0.23 (0.22)*	Primarily ~1950 to 1995	
	RM 218 to 364 Pools 20 - 26	0.31 (0.20)*	Primarily ~mid-1960s to 1995	
Rogala and James (1997)	Pool 8	0.46	1989 - 1996	Mean rate for 25 backwater transects
Rogala and Boma (1996)	Pools 4, 8, 13	0.25	1989 - 1996	Average based on 42 backwater transects, excluding dredge cuts
Knox and Faulkner(1994) (upstream from the confluence with MR along Buffalo River)	Pool 4: Lower Buffalo River (Silt Range 163)	2.0	1935 - 1954	Cesium-137 dating, Based on two core holes (about 1000 m upstream)
		0.9	1954 - 1992	
	Pool 4: Lower Buffalo River (Silt Range 158)	3.3	1935 - 1945	Cesium-137 dating, Based on entire transect (about 200 m upstream)
		1.4	1945 - 1954	
McHenry et al. (1984)	Pools 4, 5, 5A, 6, 7, 8, 9, 10	3.4	1954 - 1964	Cesium-137 dating, Average based on 47 profiles.
	Pools 4, 5, 5A, 6, 7, 8, 9, 10	1.8	1965 - 1975	
Nakato (1981a)	Pools 11, 12, 14, 16, 17, 20, 21, 22	1.62	Primarily 1930s - 1950s	Average rate based on 19 cross sections for selected backwater areas

WEST Consultants, *Upper Mississippi River and Illinois Waterway Cumulative Effects Study, Volume 1: Geomorphic Assessment* (Bellevue, WA, submitted to U.S. Army Corps of Engineers, Rock Island District, June 2000)

4. NUTRIENTS

Belleville residents ranked water quality as the most significant problem of Lake Belle View in a 1995 survey conducted by participants in a University of Wisconsin workshop (Water Resources Management Workshop 1995). Water quality is influenced in part by the cycles of two key nutrients—phosphorus and nitrogen. These nutrients are critical for aquatic plant growth. Phosphorus is often the limiting nutrient because it is usually present in low concentrations. Water quality problems arise when increases in the phosphorus concentration result in excessive lake productivity. Elevated phosphorus concentrations often result in algal blooms and/or excessive aquatic macrophyte growth. In order to determine the effects of the proposed lake restoration project on water quality, it is essential that the nutrient phosphorus be addressed.

According to McCutcheon et al. (1993), in order to prevent eutrophication, the total phosphorus concentration should not exceed 0.05 mg/L in streams and 0.025 mg/L in lakes. The limited data available for the Sugar River and Lake Belle View suggest that total phosphorus concentrations in the watershed exceed these threshold values by a considerable margin. This is not unexpected, considering the predominantly agricultural nature of the watershed. The Water Resources Management Workshop (1995) reported total phosphorus concentrations of 0.195 to 0.636 mg/L in the Sugar River (upstream of Lake Belle View) and 0.138 to 1.04 mg/L in Lake Belle View. These concentration ranges were based on 3 (river) and 4 (lake) samples collected during June and July of 1995. Fourteen samples were collected from the Sugar River upstream of Lake Belle View by the Wisconsin Department of Natural Resources (WDNR) and the Madison Metropolitan Sewerage District from 1992 through 1995: phosphorus concentrations ranged from 0.10 to 0.79 mg/L (Marshall and Stewart 1993; Madison Metropolitan Sewerage District 1995). These concentrations also exceed the eutrophication threshold values. Most likely, the primary source of phosphorus from the watershed is runoff from agricultural land. Other sources include streambank erosion, animal waste from dairy farms, fertilizer runoff from urban areas and domestic wastewater. Phosphorus readily sorbs to sediment particles and is transported mainly in the particulate form. According to Horne and Goldman (1994), 90% to 95% of phosphorus exists in the particulate form. Thus, a major pathway of phosphorus entering Lake Belle View is via attachment to sediment particles present in surface runoff or from particles that have been eroded from streambanks within the watershed.

In addition to the external loading of phosphorus to the lake, internal loading can also be a major contributor to the high concentrations observed. Internal loading can result from release of phosphorus from the sediment, plant and animal decay, and animal excretion. The phosphorus release rate from the sediments of Lake Belle View has not been determined; however, several studies have demonstrated that from 25% to 50% of a lake's total nutrient loading is from release of phosphorus from the sediments (Peterson 1981). Therefore, it is critical to take into account internal phosphorus loading when considering restoration alternatives for Lake Belle View. It is also important to note that release of phosphorus from the sediments increases significantly under anoxic conditions, and when the pH is greater than 9 (Barko and James 1998).

Alternatives for restoring Lake Belle View have been under consideration for several years. R. A. Smith and Associates submitted a proposal in 1989 to dredge Lake Belle View and construct a diversion dam and ditch that would divert all flow around the lake during spring runoff and storm events with less than a 2-year frequency. Lillie (1990) reviewed this proposal and predicted that the restored lake would be eutrophic and the water quality would be poor. WDNR staff also indicated that dredging would not be a long-term solution to the lake's water quality problems because the water quality of the lake would be only as good as that of the Sugar River (WDNR 1993). A variety of erosion control and streambank improvement projects have been implemented in the Sugar River watershed within the past 20 years. Marshall and Stewart (1993) state that these initiatives have resulted in better water quality; however, previously eroded sediment deposits remain in the river basin, tributaries, hillsides and valley bottoms and these will continue to be a source of sediment to the lake for many years. Phosphorus is closely associated with sediments that have been eroded from agricultural land; thus, from a nutrient loading standpoint, it is critical that any plan for restoring Lake Belle View include an alternative that separates the river from the lake.

MSA Professional Services, Inc. (1999) prepared a report for the Lake Belle View Lake Restoration Committee that discussed the development of planning tools for the evaluation of restoration alternatives. The water quality portion of the report addressed the implications of separating the lake from the Sugar River (both east and west Sugar River diversions were evaluated). In particular, the evaluation attempted to determine the impact on water quality based on an examination of nutrient (phosphorus) loading to the lake and predicting the lake's response. Four empirical models were used to predict phosphorus concentrations in the lake following restoration. A water budget and phosphorus budget were developed in order to apply the phosphorus models. The models indirectly accounted for some internal release of phosphorus from the sediment. They did not, however, account for a decrease in internal phosphorus loading that would occur if phosphorus-enriched sediments were removed from the lake. The phosphorus concentrations predicted by the models were compared to a trophic state index to determine the trophic status of the restored lake. The model results also were used to qualitatively evaluate the water quality of the restored lake by comparison to the water quality index of Lillie and Mason (1983).

The results of the modeling efforts in the MSA report predict that Lake Belle View, under either diversion alternative, would remain eutrophic with an average phosphorus concentration in the general range of 0.040 to 0.090 mg/L. The phosphorus concentration would be lower, compared to a lake not separated from the river, but the water quality would be in the "fair" to "poor" range according to the water quality index of Lillie and Mason (1983). Water quality would be adversely impacted in particular by large storm events in which Sugar River water entered the lake. If a large volume of the lake was replaced with Sugar River water, the phosphorus concentration could remain elevated for 2 to 3 months, thus resulting in impaired water quality. The report also addressed phosphorus inputs to the lake from groundwater and direct surface runoff and concluded that an eastern diversion would result in lower yearly average phosphorus inputs to the lake relative to a western diversion.

The findings in the MSA report are a valuable resource for evaluating the restoration alternatives currently under consideration. The report identifies the Sugar River as being a major source of phosphorus to Lake Belle View. Phosphorus is closely associated with suspended sediment particles, and likely the most significant input of phosphorus to Lake Belle View occurs during storm events. Thus, for any restoration alternative to be successful from a phosphorus reduction standpoint, it is critical that the Sugar River inflow be diverted from the lake. In the MSA report, the elevation of the berm proposed for separating the Sugar River from Lake Belle View results in an overtopping frequency of approximately once every 5 years with a western diversion and annually with an eastern diversion. The elevation of the berm under consideration in the current proposal results in a 25-year level of protection for either an eastern or western diversion. This level of protection significantly reduces the potential for Sugar River water and its accompanying phosphorus load to enter the lake.

Although internal phosphorus loading was not addressed quantitatively in the MSA report, it is likely that release of phosphorus from the sediments is a significant source of phosphorus to the lake. According to Ryding (1981), lake recovery to a less eutrophic state can be delayed for many years if internal phosphorus loading is not taken into account. Dredging would be one method to reduce the internal phosphorus load to Lake Belle View. Removal of phosphorus-enriched sediment from the lakebed would reduce the amount of phosphorus available for transport to the overlying water column.

Phosphorus inactivation would be another method for reducing the internal phosphorus load. Phosphorus inactivation is a method of controlling sediment phosphorus release by binding inorganic sediment phosphorus through the addition of chemicals, typically aluminum sulfate (alum). Lakes that are good candidates for this treatment are those that have had external sources of phosphorus diverted and have a high internal phosphorus load (U.S. EPA 1990). Phosphorus inactivation has been used as a lake restoration tool in both shallow and deep lakes for more than 30 years. Welch and Cooke (1995) found that alum treatments were more effective and longer lasting in deep lakes that stratified. In one lake, control of sediment phosphorus release was evident for at least 19 years following treatment. Of the nine shallow lake treatments that were studied, six were effective in controlling sediment phosphorus release. The average length of effectiveness was 8 years. In the shallow lakes where the treatment failed or longevity was short, submersed macrophytes were abundant throughout the lake. It was theorized that the thick stands of macrophytes may have prevented a uniform coverage of alum on the lake bottom. Senescence of certain species of macrophytes in the late summer and plant-induced high pH values were also thought to have contributed to increases in water column phosphorus concentrations.

Alum is not the only form of chemical treatment used for phosphorus inactivation in lakes, although it is by far the most common. Quaak et al. (1993) indicated that iron can be used for phosphorus inactivation in shallow lakes subject to frequent sediment resuspension. Sediment oxidation with calcium nitrate is another method used for phosphorus inactivation. This treatment method, described by Ripl (1976), utilizes oxidation of organic matter to enhance the binding of phosphorus with ferric hydroxide complexes. More recently, a lanthanum modified clay called Phoslock was tested in 2000 and 2001 by the Commonwealth Scientific and Industrial Research Organization in two impounded rivers in Australia. The Phoslock reduced phosphorus in the water column to undetectable levels, and following heavy rains, it was still active in reducing phosphorus release from the sediments. Use of these additional phosphorus inactivation methods is not widespread and further studies are needed in order to determine if they could be used successfully in Lake Belle View.

A current trend for improving eutrophication problems in shallow lakes is to combine the efforts of nutrient management with biomanipulation. Biomanipulation, first described by Shapiro et al. (1975), is a set of procedures for restructuring the biotic components of a lake for the purpose of improving water quality. The objective of biomanipulation is to control algal blooms by increasing zooplankton populations to promote grazing on algae (Gophen 1990). Biomanipulation typically works well in small shallow lakes because organisms are not spatially separated by depth, and nutrient levels are more stable since losses to the hypolimnion are unlikely (Hanson and Butler 1994). One method to increase zooplankton populations is to decrease the number of planktivorous fish. This could be accomplished at Lake Belle View by performing a fish kill to remove the undesirable species, followed by stocking of piscivorous species. The intent of the stocking would be for piscivorous fish to keep planktivore populations in check; thus, allowing for an increase in zooplankton biomass. Creating refuges for zooplankton to avoid predation enhances the effectiveness of biomanipulation. If macrophytes are lacking, bundles of brush may be added to a lake to provide a refuge for zooplankton (Shapiro 1990). According to Kitchell (1992), controlling nutrient levels along with food web manipulation has the potential to create long-lasting restoration results because neither food web interactions nor nutrients are the sole regulators of phytoplankton populations.

Another form of biomanipulation that could improve water quality is to remove benthivorous fish such as the common carp (U.S. EPA 1990). Bottom-feeding fish have been shown to release significant amounts of nutrients to the water column as they feed and digest food. Common carp are notorious for stirring up and resuspending bottom sediments as they feed.

Bottom sediments can also be resuspended by wind-induced waves; thus, reintroducing phosphorus to the water column. This can be particularly problematic in shallow lakes devoid of vegetation. Performing a periodic lake drawdown would allow for sediment consolidation and promote emergent vegetation growth. These two factors, along with the proposed creation of wetlands, would help reduce sediment resuspension.

In summary, in order to improve the water quality of Lake Belle View, it appears that a multi-faceted approach is required for reducing the phosphorus load to the lake. Utilizing a restoration plan that calls for reductions in the external and internal phosphorus loads to the lake, biomanipulation (including rough fish removal), periodic drawdown, and wetland creation, would likely offer the best opportunity for improving water quality within the lake.

In order to reduce the external phosphorus load to the lake, it is essential that the lake be separated from the river. The MSA report found that an eastern diversion would result in lower yearly average phosphorus inputs (from groundwater and direct surface runoff) to the lake relative to a western diversion. Increasing the duration of separation between the lake and river would increase the duration of improved water quality within the lake. This is accomplished by raising the elevation of the proposed berm that will separate the river from the lake. Several factors were considered in determining the elevation of the proposed berm, among which were: frequency of overtopping; effect on flood heights; construction concerns; cost; and impact on the viewshed. The recommended plan calls for an elevation that would result in a 4% overtopping frequency (once every 25 years). This level of protection would result in a significant reduction in the external phosphorus load to the lake, yet not adversely impact the remaining factors considered in determining the elevation of the berm.

Any proposed inflow structure that is incorporated in the berm should be designed to allow for the least amount of sediment transport from the river to the lake as possible. Typically, during the winter this would not be a problem since the sediment load of the Sugar River would be minimal. Also, during the winter, it would be beneficial to have some river water (approximately 5-10 cfs) entering the lake in order to prevent dissolved oxygen concentrations from reaching levels that could cause fish kills and/or increase the rate of phosphorus release from the sediments. This volume of inflow would allow for a reasonable compromise between having sufficient dissolved oxygen to support aquatic life and keeping velocities low enough to not adversely impact over wintering fish. A small inflow of river water to the lake during the winter might also help "flush" phosphorus from the lake, which might have accumulated in the water column following senescence of macrophytes in the fall. Inflow to the lake during other times of the year when the sediment load of the Sugar River is relatively low could also be beneficial.

Dredging 15 acres of the lake to a depth of 8 feet will significantly reduce the internal phosphorus load by removing the surficial sediments, where the highest phosphorus concentrations are found. This will also help with the prevention of fish kills by increasing the volume of oxygen available in the lake prior to ice formation.

Biomanipulation should be considered concurrently with nutrient reduction as a management tool for improving water quality in Lake Belle View. A fish kill to remove the current fish assemblage, followed by stocking to achieve a fish composition of 30% to 40% piscivores, is desirable to keep planktivorous fish populations in check. This, in turn, would allow for an increase in zooplankton populations and a decrease in the frequency of algae blooms. Water quality would also be improved by the removal of benthivorous fish, which would result in a decrease in lake turbidity and suspended solids levels.

A periodic drawdown should be called for in the lake management plan. This would allow for sediment consolidation and help control resuspension of sediments by wind-induced waves. The proposed creation of wetlands within the lake would also help reduce sediment resuspension.

Implementation of the above multi-faceted restoration approach will undoubtedly result in an improvement to the water quality of Lake Belle View. The degree and duration of the improvement is difficult to predict. The trophic status of the lake should improve; however, it will most likely still fall within the eutrophic range. Long-term monitoring will be necessary in order to determine the success of the restoration measures. Should the lake's phosphorus concentrations return to pre-restoration levels and/or algal blooms increase in frequency, then phosphorus inactivation should be considered as a management tool.

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