East Balsam Lake Water Quality Study

Feasibility of Engineered Solutions for Summer Algae Blooms

Prepared for:

Balsam Lake Protection and Rehabilitation District
Balsam Lake, WI

March 2014

East Balsam Lake Water Quality Study

Feasibility of Engineered Solutions for Summer Algae Blooms

AYRES ASSOCIATES
3433 Oakwood Hills Parkway
Eau Claire, WI 54701-7698
715.834.3161 • Fax: 715.831.7500
www.AyresAssociates.com

Ayres Associates Project No. 26-0783.00
File: v:\es\secr-es\26-0783.00\140403r.docx

Contents

Page No.

List of Figures

Page No.

List of Tables

Page No.

1. INTRODUCTION

This report analyzes the potential of three engineered solutions to increase the water quality of the eastern portion of Balsam Lake, East Balsam Lake, in Polk County, Wisconsin. Additional non-engineered solutions were identified throughout the process but need further evaluation. Figures 1-1 and 1-2 are location maps of East Balsam Lake. Figure 1-2 also notes the Basin delineations of Balsam Lake performed by BARR Engineering 2011.

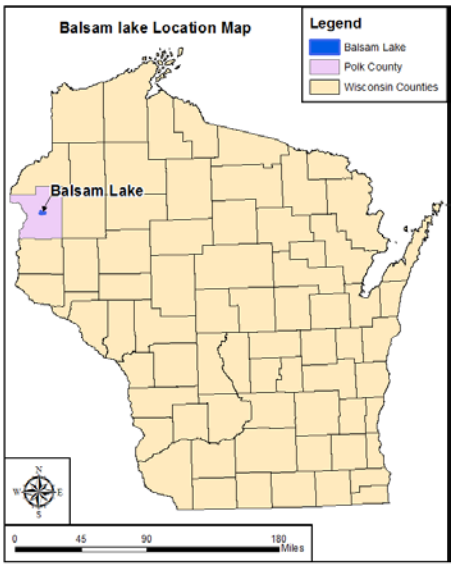

Figure 1-1: Balsam Lake Location Map

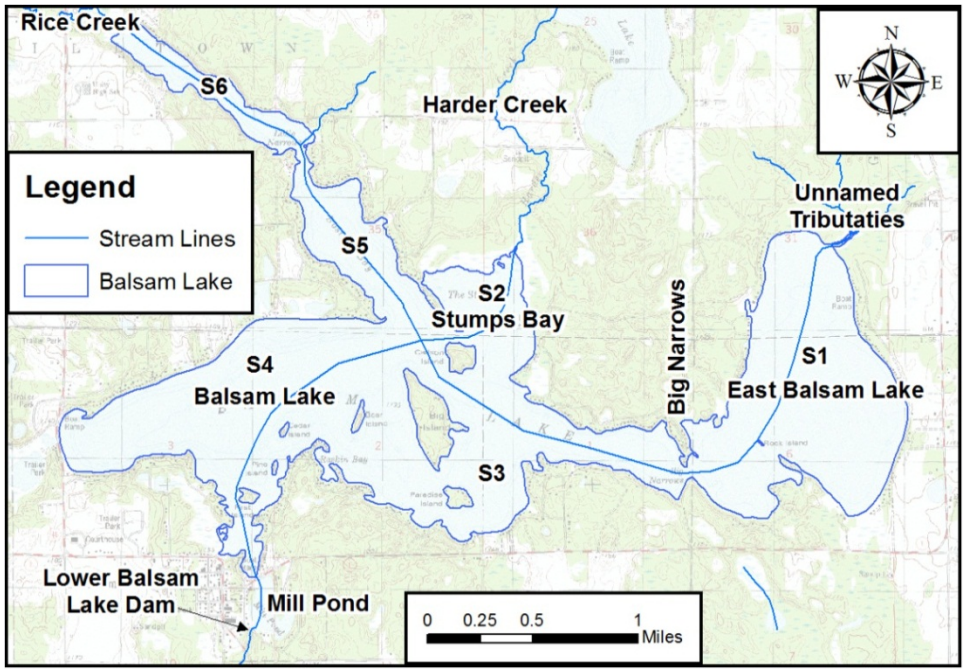

Figure 1-2: Balsam Lake Location Map and BARR Lake Basin Notation (USGS Seamless Quad Background)

East Balsam Lake is separated from the remainder of Balsam Lake due to a natural topographic feature known as the Big Narrows. The majority inflows do not directly enter East Balsam Lake; they enter the remainder of the Balsam Lake complex. Harder Creek flows into S2 and Rice Creek flows into S6. The lake's outlet is through Mill Pond at the south end of S4; Mill Pond's flow is controlled by the Lower Balsam Lake Dam.

Algae blooms are a consistent complaint from the local populous of East Balsam Lake residents. The lake has been recommended for listing as an impaired water body by the Wisconsin Department of Natural Resources, DNR (DNR, 2014). East Balsam Lake is impacted by internal and external phosphorus loading in the summer season where anoxic conditions consistently occur. The low oxygen concentration induces sediment phosphorus loading or internal phosphorus loading. This internal phosphorus loading makes up a major portion of the total phosphorus loading of East Balsam Lake and is a major contributor to algae blooms during the summer months which generally start in late June.

Five engineered solutions were analyzed to increase water quality by decreasing the phosphorus load and/or decreasing the retention time of East Balsam Lake. The engineered solutions analyzed were dredging, flushing by weir, flushing by pump, aeration, and alum capping. Viability and recommendations for each type of treatment are provided. This report is conducted under contract with the Balsam Lake Protection and Rehabilitation District.

Elevations referenced are to both NGVD 1929 and NAVD 1988 as noted per measurement.

2. HISTORICAL STUDIES OF BALSAM LAKE

The following reports are historical studies of Balsam Lake and are referenced within this report for technical content.

2.1 East Balsam Lake Water Quality Monitoring, BARR 2010

From 2009-2010, BARR Engineering (BARR) performed a water quality assessment of Balsam Lake published in 2011. This report was performed under contract with the Balsam Lake Protection and Rehabilitation District. The report examined the phosphorus loading and other common water quality measurements of Balsam Lake. The lake was split into six distinct zones for measurement and modeling.

2.2 Water and Phosphorus Budgets and Trophic State, Balsam Lake, Northwestern Wisconsin, 1987-1989, Water Resources Investigation Report 91-4125

A water budget and phosphorus loading study for Balsam Lake was conducted from 1987-1989. The water budget inflows/outflows accounted for in the report included precipitation, surface water inflow, groundwater discharge to the lake, evaporation from the lake, surface water outflow, and groundwater recharge. Precipitation was found to be the dominant water budget component followed by, in decreasing order, inflows from Rice Creek, ground water discharge, Harder Creek, and runoff from the watershed adjacent to the lake. The water budget study was performed during drier than normal years with rainfalls of 6.09 inches and 8.71 inches below normal for the first and second years respectively. Groundwater recharge was found to account for 2% of outflows where outflow through the Lower Balsam Lake Dam to Balsam Branch accounted for 98% of outflows. Over the entire year for the entire Balsam Lake complex,

evaporation was determined to be insignificant. Outflows to Balsam Branch were determined to remove only 30% of the phosphorus which was carried by the inflows.

3. EAST BALSAM LAKE HYDROLOGY AND HYDRAULICS

The hydrology and hydraulics of East Balsam Lake must be understood to analyze the water quality issues and evaluate solutions to those issues.

3.1 Precipitation

The BARR report concentrated on a single water year for water quality data. Historical average hydrology is necessary for a long term solution. Precipitation is the main driver for flows into Balsam Lake including East Balsam Lake (Rose, 1993). The historical average precipitation was analyzed for East Balsam Lake using inverse distance weighting for four surrounding historical precipitation gages. The four gages have a common recording period of 43 years, 1971 to 2013. The gages are all similar in elevation and are all located within 20 miles of East Balsam Lake. Three of the gages were used in Rose, 1993 to determine historical average precipitation for Balsam Lake. The Cumberland gage was added as a surrounding gage to the east. The gages analyzed are noted in Table 3-1.

Table 3-1: NCDC Data Center Precipitation Gages Analyzed For East Balsam Lake

Gage ID	Gage Name	Latitude	Longitude	Elevation (NAVD 88)	Distance to East Balsam Lake (miles)
GHCND:USC00470175	Amery	45.301	-92.363	1070 ft	7.8
GHCND:USC00471923	Cumberland	45.533	-92.022	1240 ft	18.8
GHCND:USC00474894	Luck	45.573	-92.485	1220 ft	8.4
GHCND:USC00477464	St. Croix Falls	45.411	-92.646	770 ft	12.9

Figure 3-1 presents annual data averaging from 1971 through 2013 for the precipitation gages noted in Table 3-1. The data is weighted by inverse distance weighting to determine annual precipitation averages for East Balsam Lake. As can be seen from Figure 3-1, 2010 was a significantly wetter year than the annual averages. Therefore, flows from the BARR report will be adjusted by 0.82 for comparison. Lake water levels are controlled by the Lower Balsam Lake Dam under agreement with the DNR. This indicates that the volumes and thus retention times will vary by this discrepancy with historical average rainfall. Retention times will be adjusted by a factor of 1.22.

The average amount of rainfall per month based on the USGS gage data for the Balsam Lake area is:

- June = 4.35 inches
- July = 3.90 inches
- August = 4.31 inches
- September = 3.60 inches

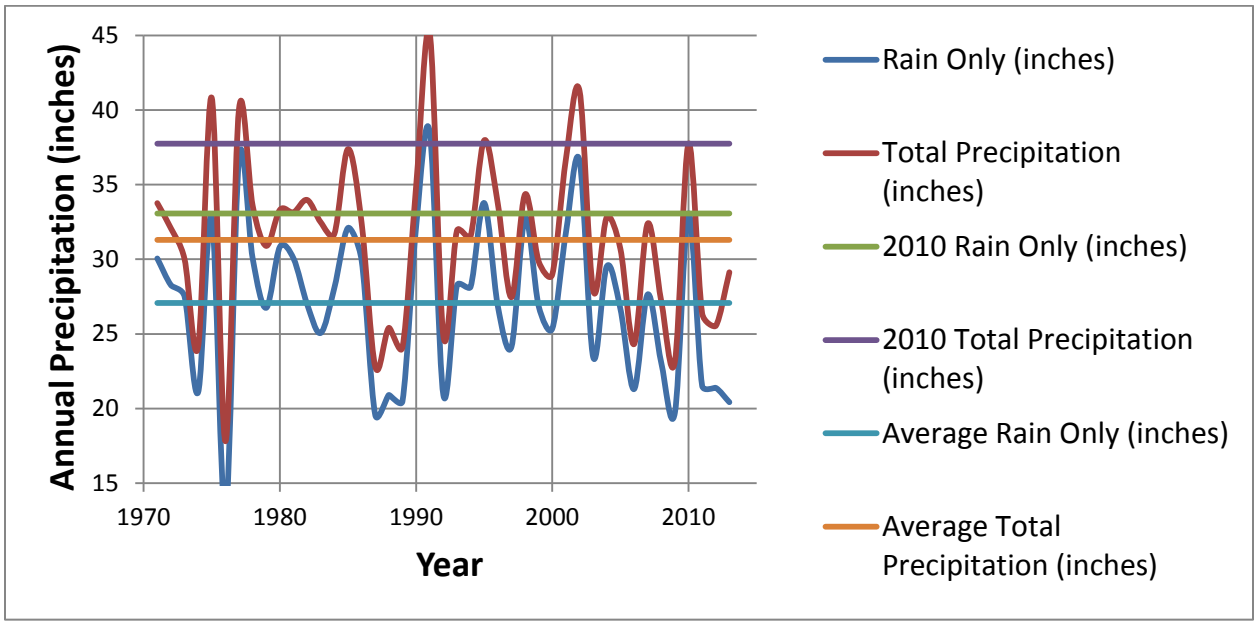

Figure 3-1: East Balsam Lake Annual Precipitation Averages

3.2 Watershed

The East Balsam Lake watershed is 3070 acres using the Big Narrows as a separation point. Figure 3-2 shows the watershed delineation for East Balsam Lake per the Purdue Long Term Hydrologic Impacts website.

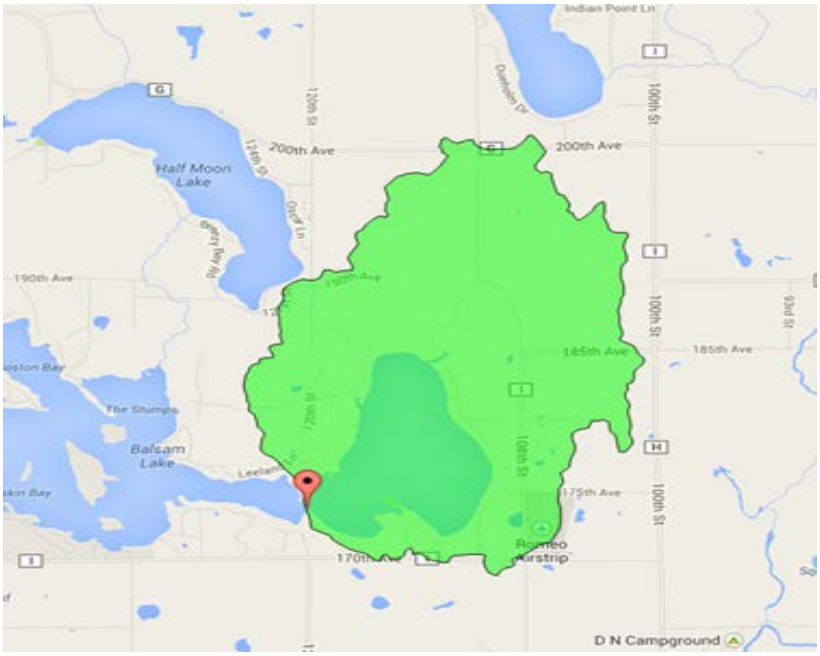

Figure 3-2: East Balsam Lake Watershed (Purdue, 2014)

The East Balsam Lake watershed has significant amounts of non-contributing area as shown in Figure 3-3. Figure 3-3 is a comparison of the watershed delineation for Balsam Lake performed by Rose for the 1993 report verses the Purdue Long Term Hydrologic Impacts digital elevation model watershed delineation. Both images were geo-referenced to obtain the overlay. As can be seen, the areas are only approximately equal. As is shown in Figure 3-3, the light green areas are considered by the USGS as non-contributing. The combined contributing boundary for the Purdue delineated watershed was found to be 2215 acres.

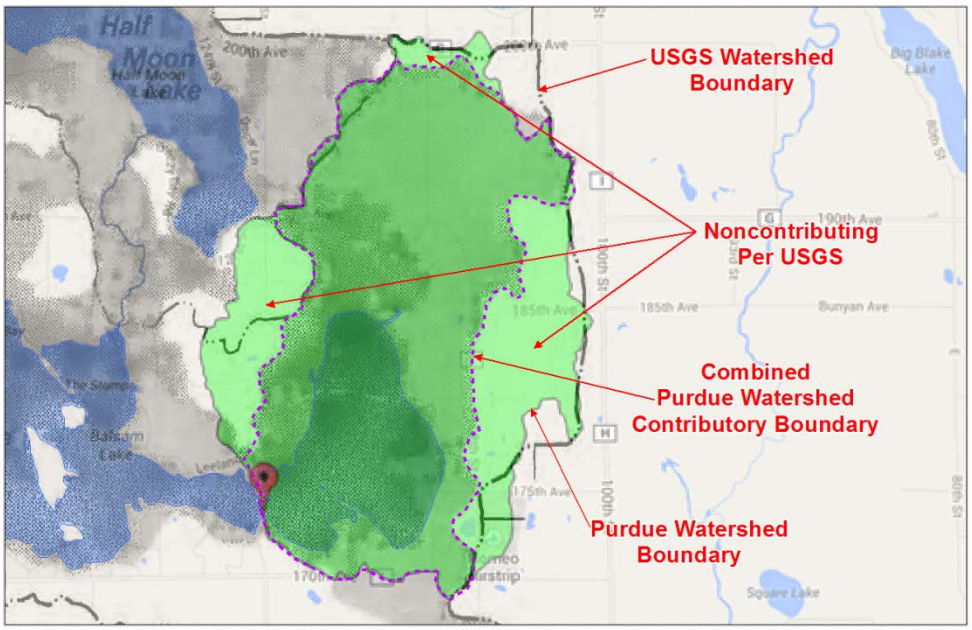

Figure 3-3: Watershed Delineation Comparison USGS vs Purdue Long Term Hydrologic Impacts

3.3 Lake Depth and Volume

East Balsam Lake is shallow averaging 9.5 feet deep (BARR, 2011, page 32). Figure 3-4 shows the depth storage curve for East Balsam Lake as derived from BARR 2011. Figure 3-5 shows the bathymetry map of Balsam Lake developed by the DNR in 1964. No water surface reference elevation was determined from the report and it is assumed that the reference elevation is determined from the USGS quadrangle map as 1133 feet elevation NGVD 1929.

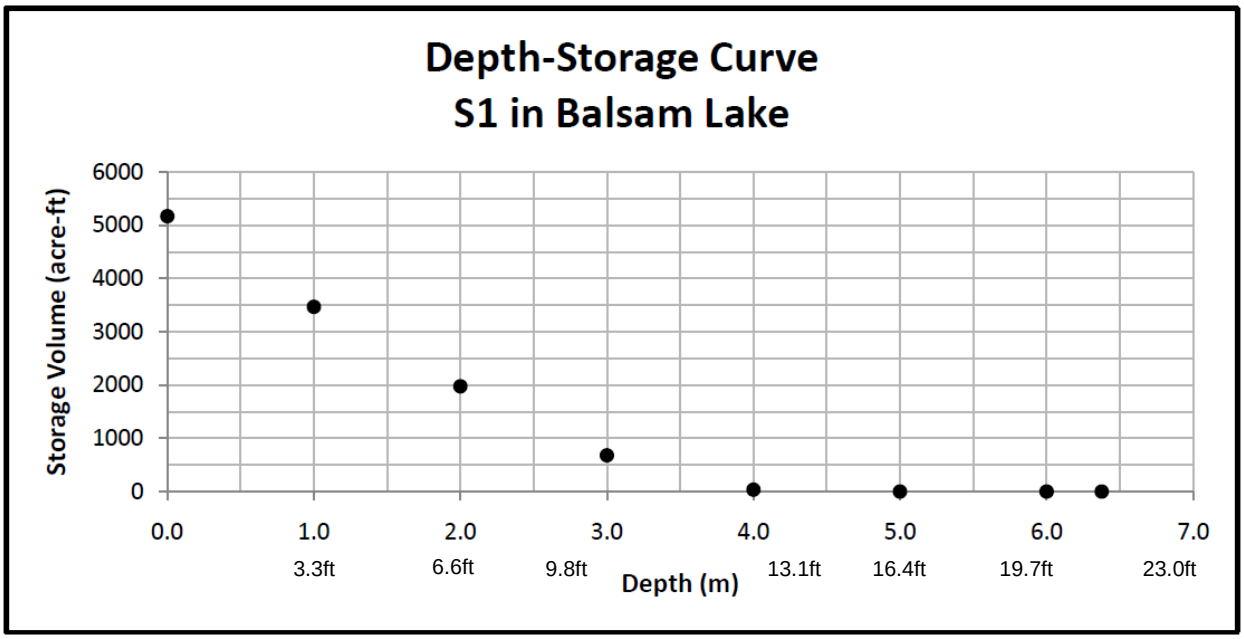

Figure 3-4: East Balsam Lake Depth Storage Curve (BARR, 2011, Appendix R-2)

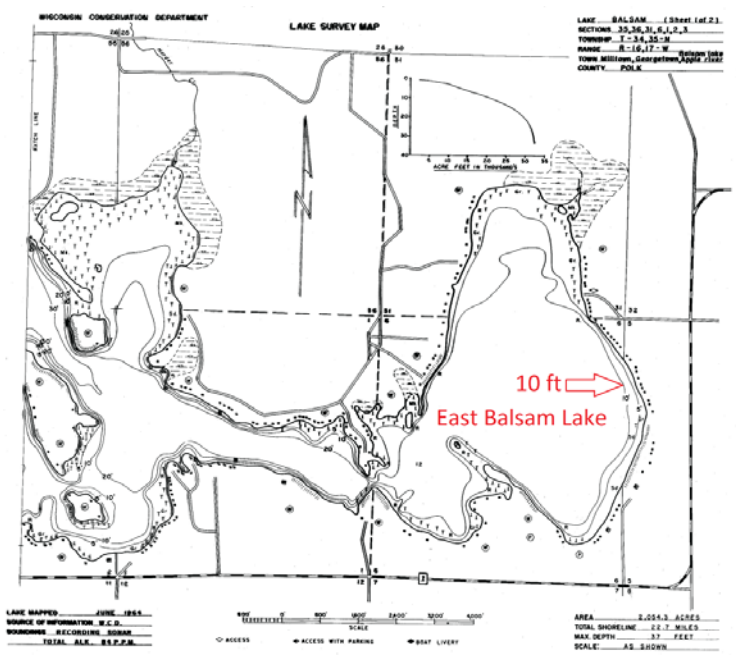

Figure 3-5: East Balsam Lake Bathymetry Map (DNR, 1964 annotated)

3.4 East Balsam Lake Summer Season Water Budget

Average precipitation rates were determined for East Balsam Lake to estimate a flow rate into the lake from precipitation. Evaporation was determined as the average of the USGS 1988, USGS 1989, and BARR 2010 reported values. These values were reported during non-average years where 1988 and 1989 had below average precipitation and 2010 had above average precipitation. The average should generate an approximate average evaporation rate during the

summer. Precipitation rates for Balsam Lake were derived from inverse distance weighting to the four gages noted in Table 3-2 for the summer months of 1971 through 2013. Lake areas were derived from the National Hydro Dataset 24k resolution Balsam Lake area shape file.

Table 3-2: Balsam Lake Evaporation

Month	USGS 1988 (in./month)	USGS 1989 (in./month)	BARR 2010 (in./month)	Average (in./month)
June	6.76	4.48	2.00	4.41
July	6.73	5.11	2.90	4.91
August	5.13	4.16	2.40	3.90
September	2.96	3.35	2.30	2.87

Table 3-3: Summer Lake Average Flows Due To Net Precipitation

Month	Precipitation (in./month)	Evaporation Summer 2010 (BARR, 2011) (in./month)	Net Precipitation (in./month)	Balsam Lake Complex Flow Rate for 1900 acres (cfs)	East Balsam Lake Flow Rate for 550 acres (cfs)
June	4.35	4.41	-0.06	< 0	< 0
July	3.90	4.91	-1.01	< 0	< 0
August	4.31	3.90	0.41	1.1	0.3
September	3.60	2.87	0.73	1.9	0.6

The Lower Rice, Harder, and Otter Creek average summer flow rates were determined through analysis of available data. Rice and Harder Creek inflows were determined as averages of the USGS 1988, USGS 1989, and BARR 2010 data. Similar to evaporation these data are assumed to average out due to the below and above average years which were reported on. The Otter Creek inflow is stated in BARR 2011 data but was adjusted by 0.82 to account for the above average flows. It should be understood that flow rates are not linearly related to precipitation and the average flow in Otter Creek is probably overstated but due to the low value the overstatement is insignificant. Figure 3-6 demonstrates reported values for Rice and Harder Creeks by USGS in 1988 and 1989.

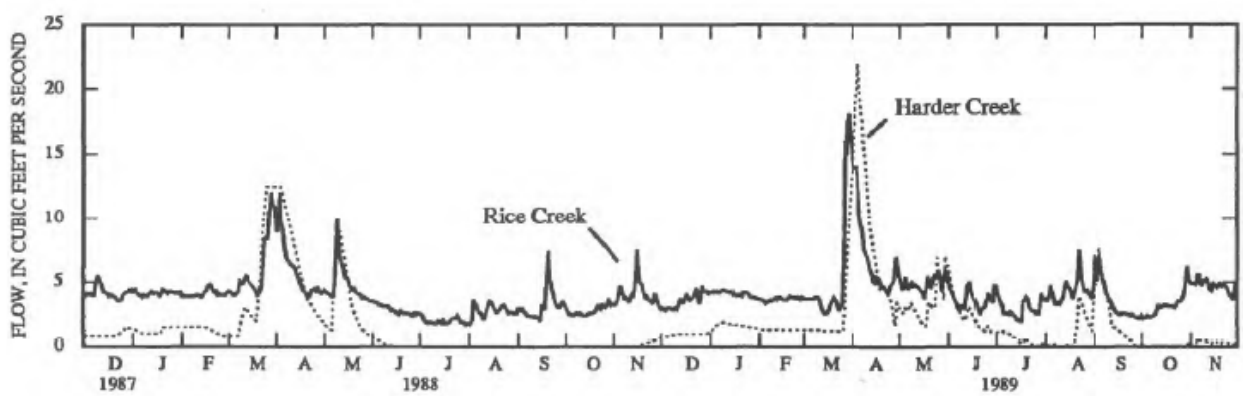

Figure 3-6: Rice and Harder Creek Flow Rates 1988 – 1989 (Rose, 1993, Figure 6b)

The average summer inflows for the three contributing creeks are:

- Lower Rice Creek and Otter Creek= 4.3 cfs
- Harder Creek = 2.6 cfs

The Balsam Lake water surface elevation is controlled by the Lower Balsam Lake Dam. Currently once the lake is at its maximum water surface elevation limit, additional flow is passed through the dam into the Balsam Branch.

4. EAST BALSAM LAKE WATER QUALITY ISSUES

East Balsam Lake has multiple water quality issues including anoxic conditions near the bottom of the lake (at certain times of year), high residence times, and net increases in phosphorus loads.

4.1 East Balsam Lake Retention Time

Table 4-1 demonstrates how East Balsam Lake has a relatively high retention time of 2.0 years compared with the other portions of the Balsam Lake complex. The other portions of the Balsam Lake complex have less severe water quality issues; therefore, improving the retention time of East Balsam Lake will have a positive impact on the water quality. It is understood that algae blooms will form in East Balsam Lake if the lake sits for 7 to 10 days. It is assumed that a retention time of 6 days or less would be required to prevent algae blooms and is presented as a unitary comparison value only.

Table 4-1: Balsam Lake Water Bodies and Retention Times (per BARR 2011, Section 6.2 and Appendix R)

Lake Body	BARR 2010 Designation	Volume (acre*ft)	Retention Time in 2010 (yrs)	Retention Time average (yrs)
East Balsam Lake	S1	5100	1.6	2.0
Stumps Bay	S2	600	0.24	0.29
Balsam Lake (1)	S3	6100	0.55	0.67
Balsam Lake (2)	S4	12700	0.70	0.85
Boston Bay	S5	2600	0.54	0.66
Little Narrows	S6	1200	0.25	0.31

4.2 East Balsam Lake Dissolved Oxygen Concentrations

Anoxic conditions were monitored by BARR in 2010 in East Balsam Lake. “When oxygen concentrations are less than 2mg/L (anoxic conditions), sediments pump phosphorus into the lake.” (BARR, 2011, page 35). Anoxic conditions were determined to be the cause of the internal sediment phosphorus loading.

Figure 4-1 is a graph of time and depth vs dissolved oxygen for East Balsam Lake. It can be seen from Figure 4-1 that dissolved oxygen rates dip below 2 mg/L at depths greater than 3.5 m during the period of late June to late August. It is assumed that the low dissolved oxygen concentrations occur every year during the summer months. For analysis purposes and to be

conservative it is assumed that this period occurs from June 15th to September 15th totaling 92 days.

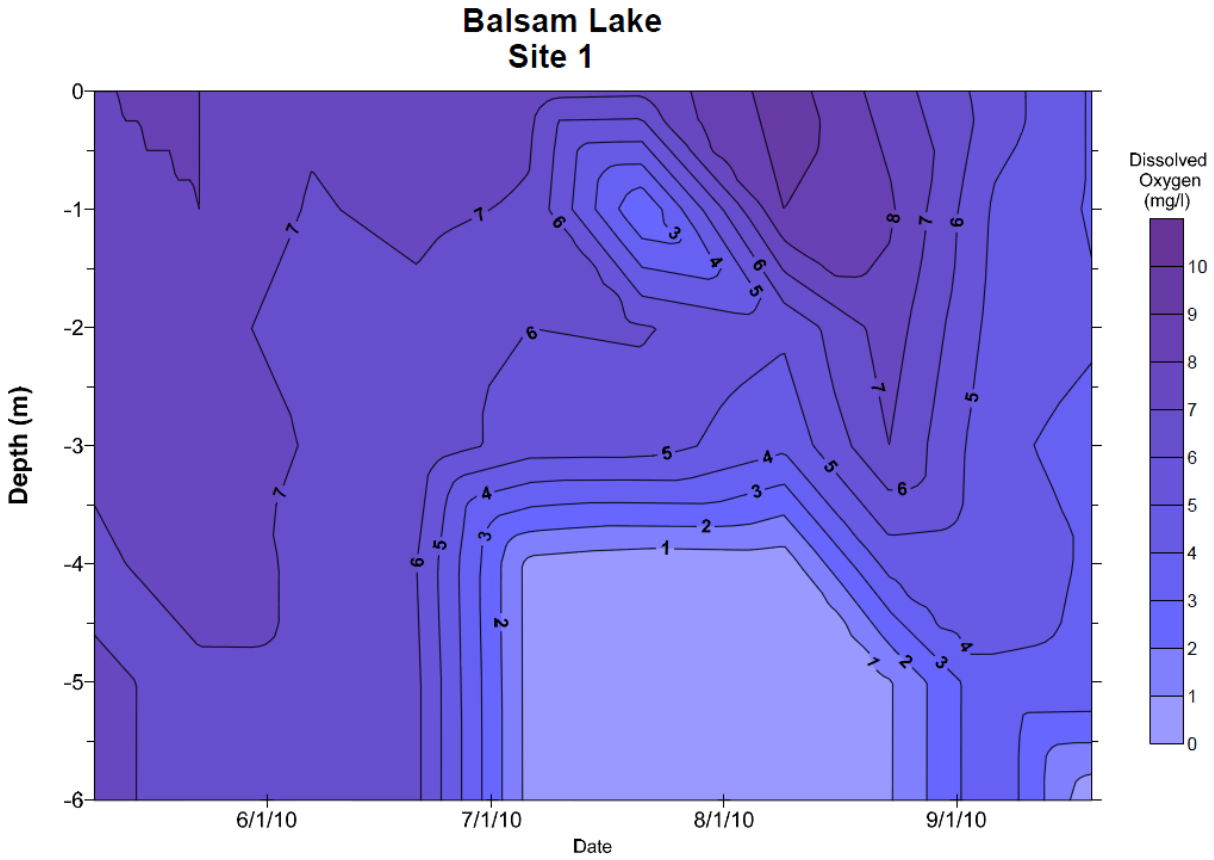

Figure 4-1: East Balsam Lake Dissolved Oxygen Isopluvial Graph
(BARR, 2011, Appendix F-2)

4.3 East Balsam Lake Phosphorus Loading

Phosphorus loading to East Balsam Lake consists primarily of runoff from upstream and internal soil loading. “In 2010 East Balsam Lake conveyed nearly 40% of its annual phosphorus load to S3 (Balsam Lake (1)).” (BARR, 2011, page 35). The East Balsam Lake watershed area consists primarily of the following: (BARR 2011, page 12)

- 17.50% Lake
- 23.76% Cropland
- 6.64% Forage/Pasture
- 31.83% Forest
- 4.26% Lake Residential
- 2.63% Rural Residential
- 10.23% Wetland

Phosphorus export rates were determined to be well within Wisconsin regulatory limitations for Otter Creek, Harder Creek, and Lower Rice Creek. The low export rates are reflective of a well-

managed watershed (BARR, 2011). Although no specific mention is made of the unnamed tributaries to East Balsam Lake it is reasonable to assume that similar export rates are produced to these seasonal streams. Figure 4-2 presents total phosphorus concentrations vs time for East Balsam Lake in 2010. As can be seen, there is a spike in the bottom water layer in phosphorus concentrations during the summer period which coincides with anoxic conditions, indicating the validity of the soil loading theory. The time period is also consistent with Figure 4-1 and Figure 4-4. Figure 4-3 is a breakdown of the phosphorus loading sources as determined by BARR 2011 where S1 refers to watershed runoff.

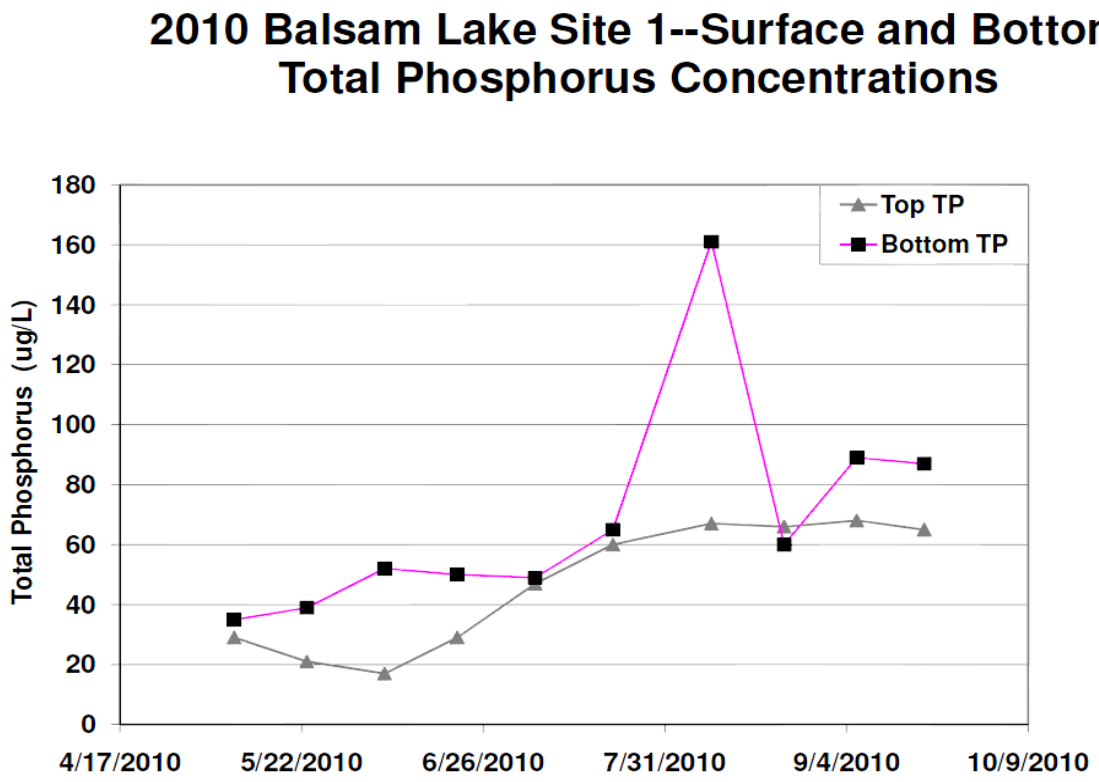

Figure 4-2: East Balsam Lake Total Phosphorus vs Time 2010 (BARR, 2011, Page 52)

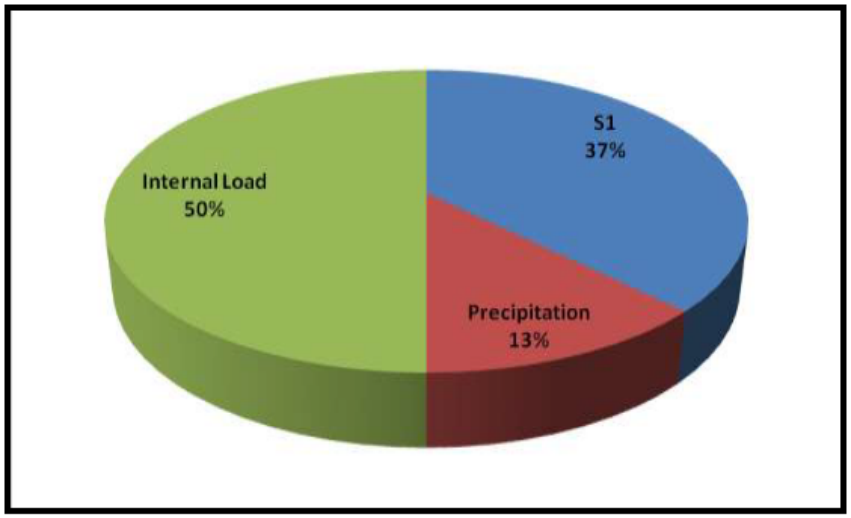

Figure 4-3: East Balsam Lake Phosphorus Budget (BARR, 2011)

4.4 Water Clarity, Secchi Depths

Water clarity is measured by Secchi depths; Secchi depths are available for Balsam Lake from historical records from volunteer measurements (BARR, 2011). Figure 4-4 presents Secchi depths vs time for East Balsam Lake during summer, 2010. It can be seen from Figure 4-4 that water clarity follows a similar time table to low dissolved oxygen levels of approximately June 15th to September 15th. Note that the other areas of Balsam Lake are all eutrophic in late summer per BARR, 2011, Figure 5-9.

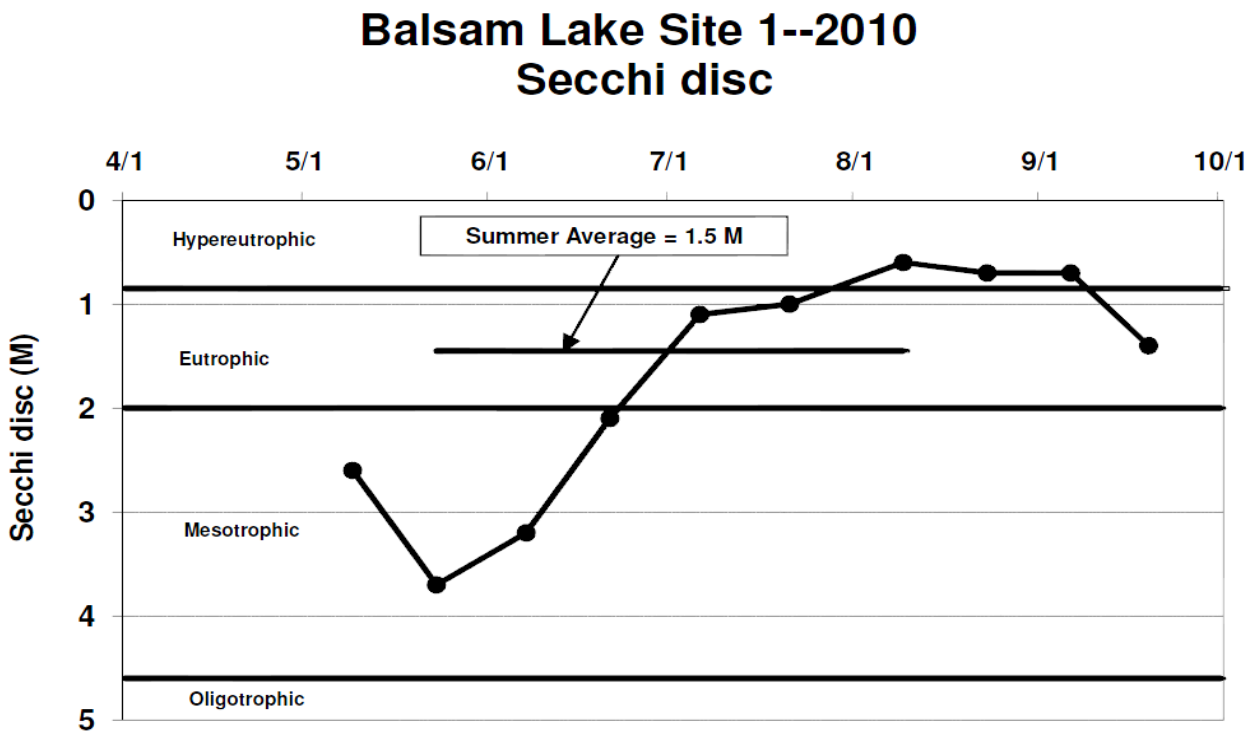

Figure 4-4: East Balsam Lake Secchi Depths vs Time, 2010 (BARR, 2011, Appendix F-8)

5. ENGINEERED SOLUTIONS TO WATER QUALITY ISSUES IN EAST BALSAM LAKE

Five engineered solutions to water quality issues in East Balsam Lake were examined for feasibility. Feasibility includes available water resources, potential cost, and ability to be permitted. The potential solutions include dredging, flushing by pumping, flushing by weir, aeration, and alum capping.

5.1 Dredging

Dredging is the removal of the top sediment layer by mechanical or hydraulic means. It is assumed that the internal phosphorus loading is generated by only the top 1 or 2 feet of sediment in the lake bottom. Dredging would remove the phosphorus laden layer and the potential for internal phosphorus loading. The soil has not been analyzed to determine the exact depth of soil needed to be removed for this process to be effective

Dredging is a heavy environmental impact solution. Removal of the bottom soil layer includes the life sustaining soil of the lake. It would take years or even decades for the lake to reestablish the existing ecosystem of aquatic plants and animal life.

East Balsam Lake is approximately 550 acres in area. Assuming 1-2 feet of soil removal is sufficient, the estimated quantity of soil removal required to successfully remove the phosphorus is from 890,000 cubic yards to 1,800,000 cubic yards of sediment. Costs to remove sediment include the mechanical removal, hauling, and disposal. Due to the quantity of sediment removal only engineering experience was used to estimate the cost and a fill site was not found. The estimated cost for dredging, hauling, and disposal is $20 per cubic yard. At $20 per cubic yard of soil removed the estimated cost of removing soil by dredging ranges from $18 Million to $36 Million. Lake bed soil should be sampled for phosphorus content by depth before any dredging project is considered to obtain a more accurate estimate of necessary soil removal.

5.2 Flushing by Weir

Flushing is a recognized technique to improve water quality. The State of Washington used flushing to improve the water quality of Moses and Green Lakes using diverted water from nearby cleaner sources (EPA, 1981). This effort relied upon the higher water quality of the Columbia River to “flush” out the lake. The lake would reach the steady state quality of a flow ratio mix of the natural inflow and diverted river inflow concentrations.

A similar potential for flushing exists for East Balsam Lake using Harder Creek, Otter Creek, an d Lower Rice Creek water diverted from its natural alignment to move south under Highway I. Rice and Harder Creeks both have higher water quality for phosphorus content than East Balsam Lake. Currently they flush the remainder of the lake complex. Figure 5-1 is a schematic showing the inflows into the Balsam Lake complex and a drawing of the flushing by weir technique for East Balsam Lake.

Balsam Lake is the reservoir created by the Lower Balsam Lake Dam; flow from the lake is controlled by the dam. Potentially, the exit weir can be redesigned to force flow through East Balsam Lake and exit south to an existing designated wetland. A culvert would need to be constructed under existing Highway I to pass the redirected flow.

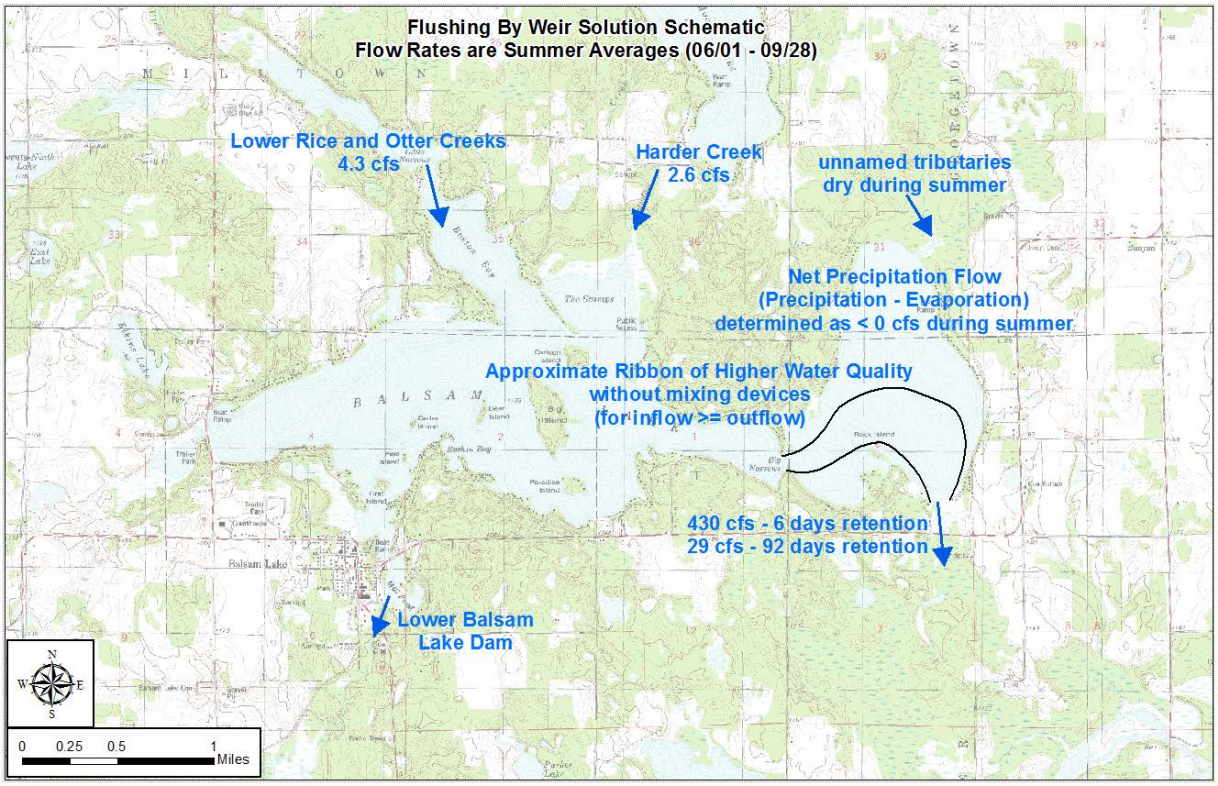

Figure 5-1: Flushing by Weir Schematic and Flow Budget (USGS Seamless Quad Background)

As can be seen from Table 3-3 net precipitation flow during the summer is not a reliable source of significant amounts of flushing flows.

Due to entrance of flow into East Balsam Lake from “Big Narrows” a ribbon of higher water quality would be generated without improving quality for all of East Balsam Lake. Figure 5-1 demonstrates the potential for a flow ribbon also known as short circuiting. Short-circuiting is described as “the last water that entered the tank is the first water drawn from the tank” and “the oldest water cannot be drawn from the tank due to the location of the outlet pipe” (Duer, 2010). Figure 5-2 demonstrates the principle of tank short circuiting where the darkest water on the edges of the tank are the worst quality and the quality improves towards the outlet. Proper mixing is generally used to prevent short circuiting but properly mixing East Balsam Lake is impractical.

Figure 5-2: Water Tank Short Circuiting (Duer, 2010, Figure 3)

It is understood that algae blooms will occur in East Balsam Lake with a retention time of greater than 6 days. The volume of East Balsam Lake at an average lake surface elevation is 5100 acre-feet. The flow required to flush, replace all the water, East Balsam Lake in 6 days is 430 cfs. This flow is greater than the average inflow of all combined inflowing creeks and would require drying out the natural outflow in addition to requiring the artificial input of 423 cfs.

To create a retention time similar to the other portions of Balsam Lake, a 92 day retention time, a flow of 29 cfs would be needed. This would still be greater than the average inflow of all combined inflowing creeks. This would require drying out of the natural outflow in addition to requiring artificial inputs. It is unknown if using a flow of 29 cfs would increase water quality, it does not follow the understood retention time recommendation. Because it does not meet the recommended retention time, other issues such as the shallow waters and internal phosphorus loading would likely still cause algae blooms.

If all 6.9 cfs or a portion of the flow entering the Balsam lake complex were rerouted through East Balsam Lake, it would reduce the retention time, but not enough to prevent algae blooms. This rerouting of flow would require drying out of the natural outflow. This is the same flow that flushes the other portions of Balsam Lake but there are many other aspects that could cause algae blooms if the recommended retention time is not met. The rerouted flow may have a negative effect on the other portions of the Balsam Lake Complex.

Additional amounts of flow may not be allowable into the wetlands mapped south of East Balsam Lake and could potentially be considered a dangerous flooding impact. Rerouting the entire combined flow of Lower Rice Creek, Otter Creek, and Harder Creek would not be easily permitted. This reroute of the flow would bypass approximately 17.8 miles of natural flow while still emptying into the same Apple River. Figure 5-3 demonstrates the bypass configuration in terms of the Apple River Watershed.

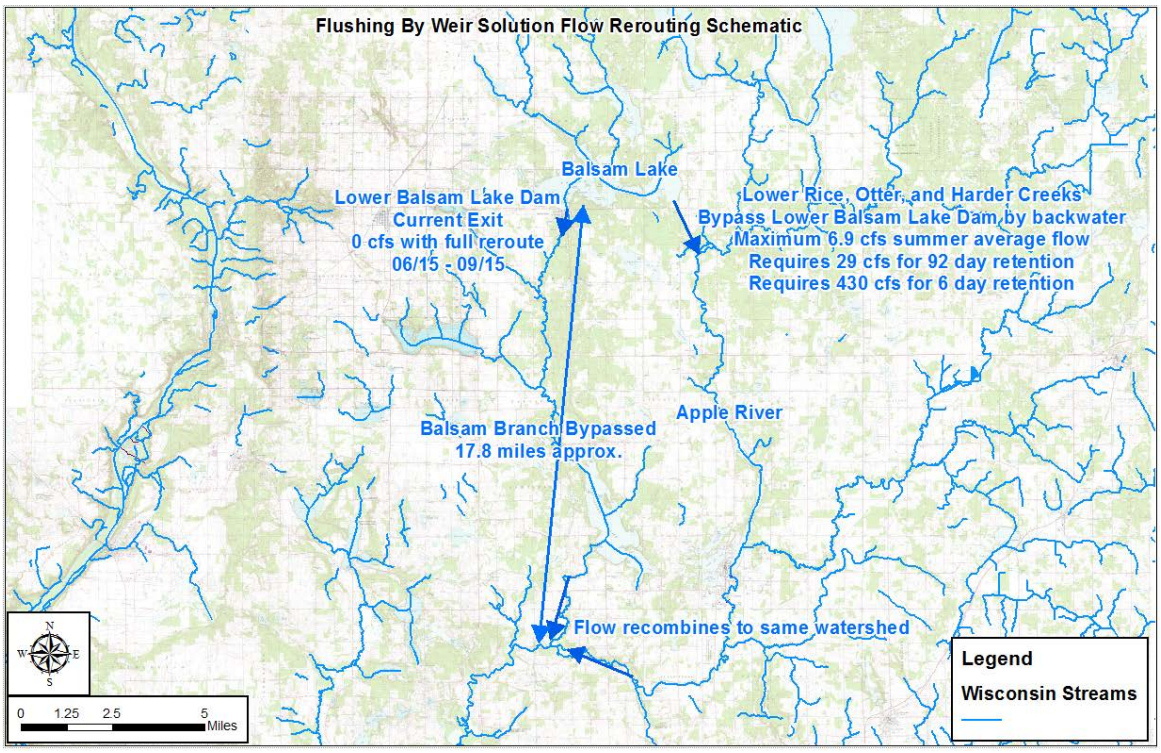

Figure 5-3: Flushing by Weir Control Reroute Schematic (USGS Seamless Quad Background)

Due to the lack of required inflows to flush the East Balsam Lake complex the lake would actually be drained, without additional inflows, rather than flushed. In addition, rerouting of the entire inflows of Harder, Otter, and Rice Creeks would not be easily permitted as bypassing approximately 17.8 miles of Balsam Branch. If a retention time of 6 days is not met, algae blooms may still occur due to a combination of other factors. Flushing by weir is not a recommended alternative.5.3 Flushing by Pump and Pipe

5.3 Flushing By Pump And Pipe

Flushing by pump and pipe would force higher quality flow from “The Stumps” to the northern edges of East Balsam Lake where the flow would be able to interact with a larger portion of the lake before exiting through “Big Narrows” into Balsam Lake. Note that multiple outlets and baffles would be required to force all of the lake to mix with the inflow. Figure 5-4 demonstrates a schematic and preferred pipe alignment for this potential solution.

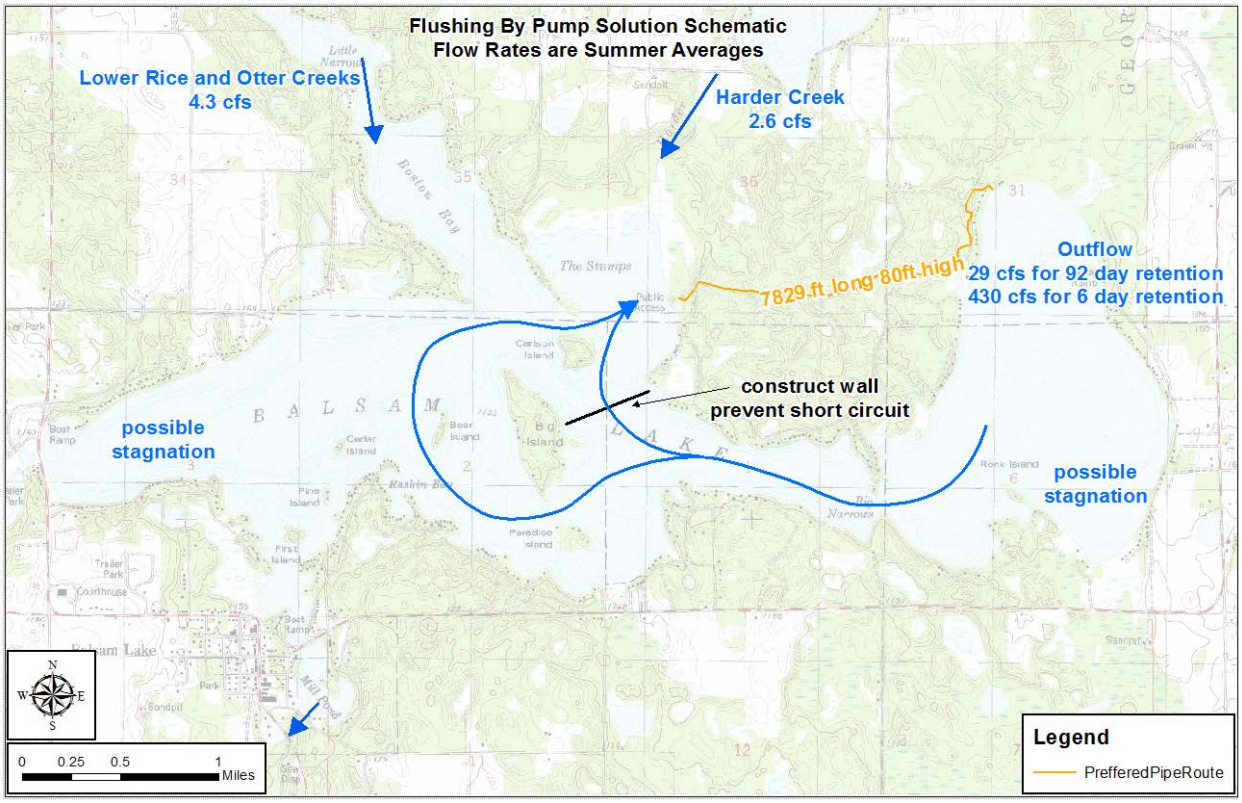

Figure 5-4: Flushing by Pipe and Pump Schematic
(USGS Seamless Quad Background)

Flushing requires removal of the entire lake within 6 days. This is the same flow rate noted in the flushing by weir option with a different method of water movement. Unlike the flushing by weir option, flushing by pumping does not require artificial water resource input to maintain lake levels as the water is recycled through the Balsam Lake complex. In addition, flushing by pipe would not require a rerouting of natural flows to Balsam Branch. Figure 5-4 shows that not as much water will inflow to the Balsam Lake complex as is being pumped. This will cause a recycle effect where the lakes will mix in an approximate steady state mixture rather than a flushing effect from the incoming sources. A baffle/wall would likely need to be constructed between Big Island and the peninsula to prevent short circuiting of flow between only East Balsam Lake and Stumps Bay.

Construction of inlets and outlets that can handle 430 cfs will cause significant suction and jetting velocities at the entrance and exit. Velocities for 430 cfs flow within a 5.5 ft. diameter pipe are approximately 18 fps. Construction of the pump and pipe system would require cordoning off areas of Stumps Bay and northern East Balsam Lake from human and boat access.

The high velocities surrounding the inlet and outlet may overpower fish near the suction flows and cause erosion in the lake bottom near the inlet and outlet. In addition to addressing human safety concerns, construction of the pump and pipe system would require addressing lake-bottom erosion and fish protection issues.

Construction of a pump and pipe system that can handle 430 cfs is a significant multi-million dollar infrastructure investment in addition to ongoing maintenance and power consumption costs. A 430 cfs pump is comparable to pumps that are used for power stations, water supplies,

flood control, and desalination plants (Flygt, 2014). Pumps this large would be impractical for this application. Figure 5-5 shows a 430 cfs pump, a Flygt A-C Series Column Pump.

Figure 5-5: 430 cfs Pump, Flygt A-C Series Column Pump (Flygt 2014)

The preferred pipe alignment would be approximately 8100 feet long including additions into the lake for entrance and exit beyond the shoreline.

Figure 5-6 shows the expected annual pumping costs for the understood flow rates vs internal steel pipe diameter. Power costs are based on $0.112/kW*hr assumption which is the local average power cost. The preferred pipe diameter would minimize total installment + power consumption costs. It is assumed that pumping would occur continuously throughout the 92 day period to prevent stagnation.

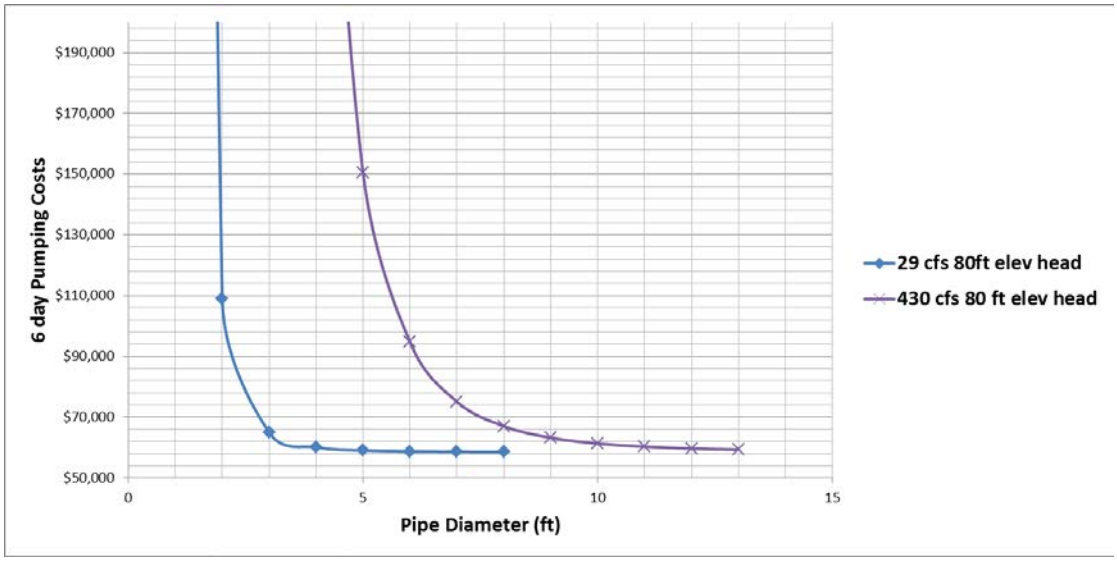

Figure 5-6: Annual Pumping Costs for Given Design Flow Rates vs Pipe Internal Diameter

Figure 5-7 demonstrates how the total 20 year cost will vary depending upon internal pipe diameter. The total cost changes per diameter by pumping power required and unit pipe installation costs. Unit installation costs are derived from www.get-a-quote.net for 2009 Wisconsin Heavy Construction Costs for welded steel pipe. Welded steel pipe is chosen based on its longevity and low seepage histories. Due to the amount of flows considered only maximum wall thicknesses were chosen for the unit cost trend analysis. Per Figure 5-6, an internal diameter pipe of 5.5ft would optimize the total 20 year cost. Due to the continuous flushing no annual pumping costs would meet the understood $100,000 annual maximum. This 20 year cost analysis does not include the construction of a pumping house, installation of the pumps, and improvement of the local electrical grid to handle the increased load. These additional costs can easily range from $2-10 Million beyond stated costs in Figure 5-7.

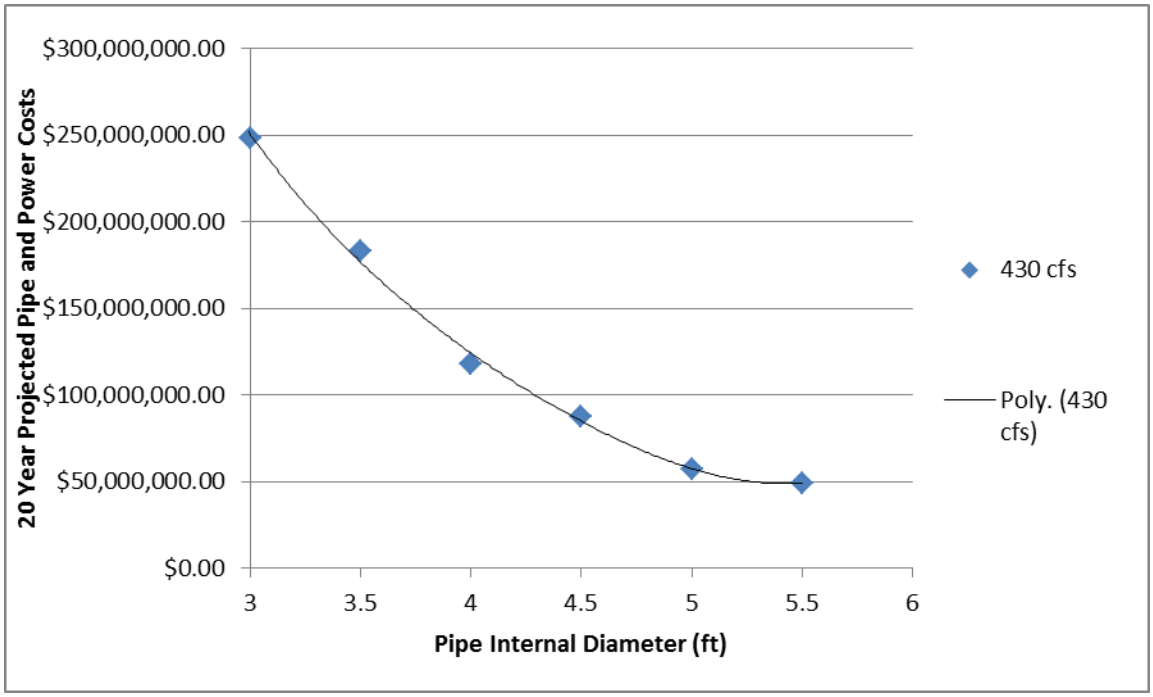

Figure 5-7: 20 Year Cost Investment (Pipe and Power Only) vs Pipe Diameter

Flushing by pump and pipe would not have sufficient inflow to the Balsam Lake complex to replace the phosphorus loaded water with fresh water within East Balsam Lake. As shown in Figure 5-4, flushing would more likely approach a steady state mixture of the entire Balsam Lake complex. This would improve the water quality of East Balsam Lake but could have negative water quality effects on the rest of Balsam Lake. As shown in Figures 5-8 to 5-10, all portions of the Balsam Lake complex are in or near a Eutrophic state during late summer. It could be detrimental to the rest of the lake to force heavy mixing of East Balsam Lake with the rest of the complex.

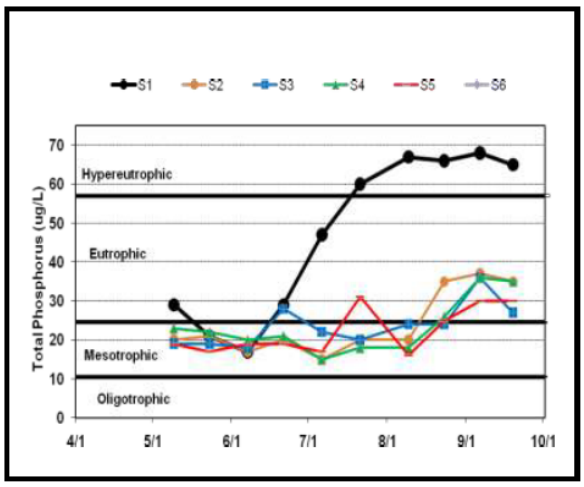

Figure 5-8: 2010 Phosphorus Concentrations for All Balsam Lake Areas (BARR, 2011, Figure 5)

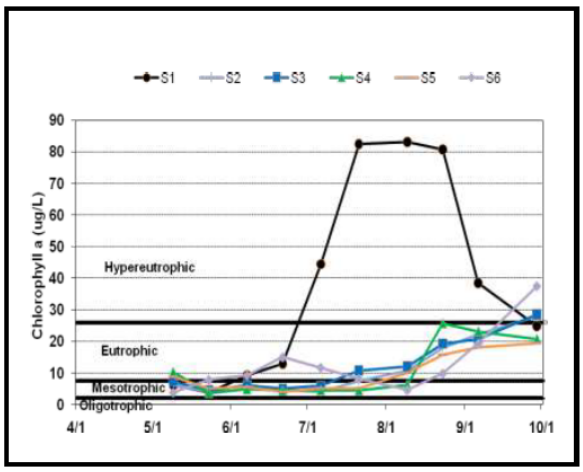

Figure 5-9: Balsam Lake Chlorophyll A Concentrations All Areas (BARR, 2011)

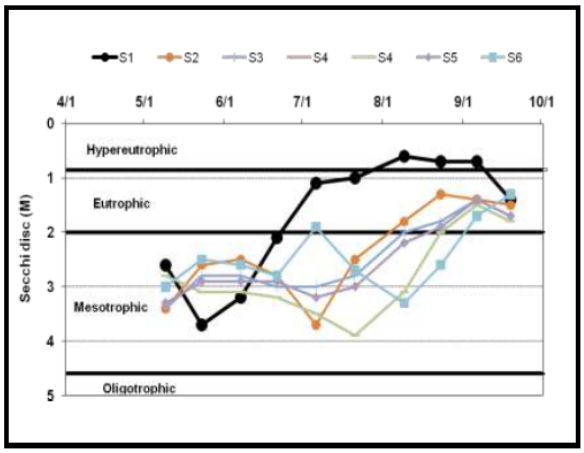

Figure 5-10: Balsam Lake Secchi Disc Depths All Areas (BARR, 2011)

Note that the measurements taken in Figures 5-8 to 5-10 were performed during an above average precipitation year and should generally reflect higher water quality than normally exists within the lakes.

Pumping 29 cfs, to obtain a retention time similar to the rest of the Balsam Lake complex, may be a feasible amount of water to pump. It would decrease the retention time but East Balsam Lake would not be completely flushed within 6 days. It is unknown if this would have an effect on the water quality because the retention time would not meet the required time. Other contributing factors such as shallower water depths of East Balsam Lake and internal loading may still cause algae blooms if the required retention time is not met.

Due to the lack of sufficient and reliable higher quality inflows, the high investment costs, the ability to negatively impact the rest of the lake, negative environmental impacts on the lake from high flows and velocities, blocking off portions of the lake from recreational activities, and dangerous conditions for residents and visitors due to high flows and velocities; flushing by pump and pipe is not a recommended alternative.

5.4 Aeration

Aeration uses pumps and perforated hoses/pipes to force air into the bottom layers of the lake. This would increase the oxygen concentrations in the anoxic layers of the lake during the summer months. Controlling the oxygen content in the soil layers may prevent the internal loading of the lake phosphorus from the sediment layers.

Aeration is a feasible option to reduce blue-green algae growth (Washington Department of Ecology). Blue-green algae are also known as cyanobacteria and are toxic. This type of algae is discouraged in growth by the use of aeration, due to the increased oxygen and de-stratification of the lake. Local lake residents have noted the existence of some blue-green algae, but it is not known if it is the predominant algae during the late summer months.

Another aeration method is forced mixing through mechanical lift devices. Several companies produce these devices commonly used for potable water tanks and reservoirs. Medora Corporation of North Dakota makes a product called the SolarBee; its website claims the SolarBee is 90-95% effective in controlling blue-green algae blooms (Medora Corporation).

Depending on the type of algae present in East Balsam Lake aeration or forced mixing may be a viable alternative. Further research into whether aeration or forced mixing would be affective in this application should be done by a limnologist more familiar with the biological process or the lake.

5.5 Alum Capping

Alum capping is the placement of alum into a lake. The Alum flocculates with the phosphorus in the water and drops to the lake floor forming an Alum layer. This layer traps the phosphorus within the soil from being released during times when minimal dissolved oxygen is present. Alum treatment would not have the same environmental impact as dredging. The addition of Alum to a lake is environmentally degrading only when the concentration causes a pH to drop below acceptable levels. Historical studies have shown that the addition of Alum does not interfere with the lake bottom ecosystem (BARR, 2009). However Alum treatment in shallow lakes is much less effective and has a shorter life span than Alum treatment in deep lakes.

A national study of Alum treatment in lakes found that treatment is much less effective in shallow lakes with significant external phosphorus loading (DNR, 2003). From Figure 3-5 it can be seen that Balsam Lake is a shallow lake with maximum depths near 10ft. From Figure 5-11, it can be seen that East Balsam Lake receives 50% of phosphorus loading from external sources (BARR, 2011).

Further investigation into the feasibility of Alum capping in this situation should be done by a limnologist more familiar with the alum treatment process.

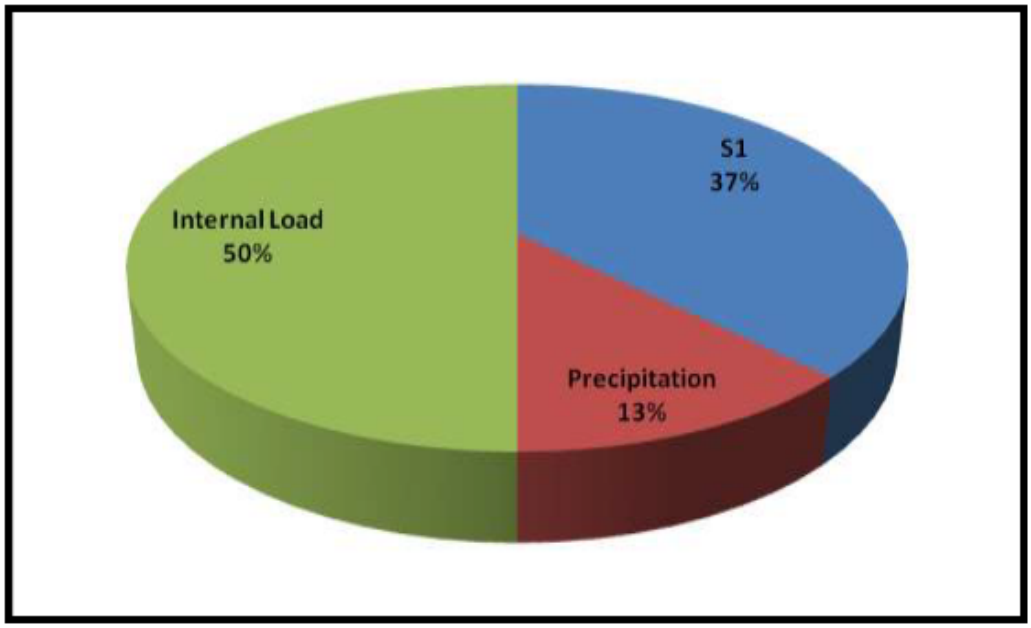

Figure 5-11: East Balsam Lake Phosphorus Budget (BARR, 2011)

6. RECOMMENDATIONS

It is recommended that none of the potential solutions be implemented as engineered solutions to East Balsam Lake water quality issues. Aeration and Alum capping could be investigated further by a limnologist. Table 6-1 summarizes each analyzed solution, a cost estimate, and the governing disadvantages as a solution.

Table 6-1: Summary of Engineered Solutions to East Balsam Lake Water Quality Issues

Engineered Method	20 Year Cost Estimate Present Value (2016 cost)	Governing Solution Disadvantages
Dredging	$18 to 36 Million	Environmentally destructive, cost prohibitive
Flushing By Pump	$50 Million	Not feasible with 6 day flush requirement, cost prohibitive with 6 day flush requirement
Flushing By Weir	Not Feasible	Not feasible with 6 day flush requirement
Aeration	Consult a limnologist	Consult a limnologist
Alum Capping	Consult a limnologist	Consult a limnologist

Twenty year cost estimates for 2016 are based on average annual inflation of 3%. The cost estimates are projected to 2016 understanding that 2016 is the earliest project start date.

7. CONCLUSIONS

East Balsam Lake has water quality issues annually over the summer months. Previous analyses have provided data that define the water quality issues and allow alternatives to improve water quality to be investigated.

The contributory watershed to East Balsam Lake is 2215 acres. The major contributing inflow for East Balsam Lake during the summer months is precipitation. Precipitation inflow for East Balsam Lake is effectively neutralized by evaporation outflow during the summer months. For an average year, there is a net loss (more evaporation than precipitation) of water from East Balsam Lake during June and July and a net gain of 0.3 cfs and 0.6 cfs for August and September.

The water quality of East Balsam Lake is poor during the summer months generally between June 15 and September 15; this is caused by various issues. East Balsam Lake has more stagnant water than the other portions of Balsam Lake; the retention time of East Balsam Lake is 2.0 years compared to 0.3 to 0.85 years for the other portions of the Balsam Lake complex. The dissolved oxygen levels in the lower depths drop below 2 mg/l during the summer months; this creates anoxic conditions that allow phosphorus to be released from the soil. The phosphorus levels in East Balsam Lake are higher than the other portions of the lake. The phosphorus loading of East Balsam Lake in comprised of 50% internal loading, 37% watershed runoff, and 13% from precipitation. The Secchi disk readings, which indicate water clarity, confirm that East Balsam Lake has lower water quality during the summer months than the other portions of the Balsam Lake complex.

Five engineered solutions were considered to improve the water quality of East Balsam Lake. The solutions considered were: dredging, flushing by weir, flushing by pumping and pipe, aeration, and alum capping.

Dredging would remove the phosphorus loaded sediment at the bottom of the lake. This is not a recommended solution due to high cost and environmental impacts of removing the lake bed material.

Flushing by weir would force the water from Lower Rice, Otter, and Harder Creeks to pass through East Balsam Lake and exit beneath HWY I. This is not a feasible option because additional flow would be needed to obtain the flow necessary to prevent algae blooms.

Flushing by pumping and pipe would pump water from “The Stumps” to the northern portion of East Balsam Lake. This would circulate the water better through East Balsam Lake improving the water quality there. This would cause the entire lake to reach a steady state and would likely decrease the water quality of the other portions of the lake. 430 cfs would need to be circulated to create the retention time of 6 day needed to prevent algae blooms. This solution is not feasible because of the amount of water that would need to be circulated to prevent algae blooms. This alternative is not recommended because of cost, safety concerns to residents and visitors, and environmental concerns. 29 cfs could be circulated to create a retention time similar to the other portions of East Balsam Lake and is presented as a unitary comparison value and not a solution. This solution is not recommended because it may not prevent algae blooms. If the recommended retention time of 6 days is not met, other factors such as shallow depths and internal phosphorus loading may still cause algae blooms.

Two other alternatives were considered but not fully developed. Aeration and forced mixing could improve water quality by de-stratifying the lake and adding oxygen near the bottom of the lake. This could be a viable option but further evaluation of this option is needed. Alum capping could be a feasible alternative. Alum capping adds alum to the lake, the alum flocculates with phosphorus, sinks to the bottom, and creates a layer that blocks the lake bed soil from releasing phosphorus. As with aeration, further evaluation and sediment sampling is needed to determine if alum capping is a feasible solution.

REFERENCES

BARR (2009), *Little St. Germain Lake Aluminum Sulfate Treatment Proposal (Little St. Germain Lake Protection and Rehabilitation District)*
http://www.littlesaint.org/misc_documents/barr_alum_proposal_03-09.pdf

BARR (2011), *Balsam Lake Water Quality Study (Balsam Lake Protection and Rehabilitation District)*
http://www.blprd.com/docs/2011BalsamLakeReportWaterQualityStudy.pdf

Duer, Michael (2010), *The Science of Mixing Water Storage Tanks (North Carolina Safe Water American Water Works Association conference presentation, Red Valve Co., Inc.)*
http://www.ncsafewater.org/Pics/Training/AnnualConference/AC10TechnicalPapers/AC10_Water/Water_M.AM_10.30_Duer.pdf

DNR (2003), *Alum Treatments To Control Phosphorus In Lakes: Wisconsin Department of Natural Resources*
http://www.littlesaint.org/misc_documents/alum_phosphorous_control_dnr.pdf

DNR (2014), *Wisconsin Draft 2014 Impaired Waters List, Wisconsin Department of Natural Resources*
https://prodoasjava.dnr.wi.gov/swims/downloadDocument.do?id=88321084

EPA (1981), *The Dilution/Flushing Technique in Lake Restoration, EPA-600/3-81-016*
http://nepis.epa.gov/Adobe/PDF/2000I8RO.PDF

Flygt (2014), *Flygt Vertical Pumps PL7000, LL 3000, WC, YDD, WMC, and VIT Submersible and Wet Pit Installation.*
http://www.wwdmag.com/sites/default/files/FB135-1799_Flygt_FPO_Global_Brochure_US_sm.pdf 3/26/2014

Medora Corporation (2014), *Lake and Raw Water Reservoir Circulators.*
http://lakes.medoraco.com/. 3/26/2014

Purdue (2014)*, Long Term Hydrologic Impacts Website, Purdue University*
https://engineering.purdue.edu/~lthia/

Rose, W.J. (1993), *Water and phosphorus budgets and trophic state, Balsam Lake, northwestern Wisconsin: U.S. Geological Survey Water-Resources Investigation Report 91-4125*
http://pubs.er.usgs.gov/publication/wri914125

Washington Department of Ecology (2014), *Algae Control Program. 2014*
http://www.ecy.wa.gov/programs/wq/plants/algae/lakes/lakerestoration.html 3/12/2014

Welch, E. B. (1981), *THE DILUTION/FLUSHING TECHNIQUE IN LAKE RESTORATION. JAWRA Journal of the American Water Resources Association, 17(4), 558-564.*
http://nepis.epa.gov/Adobe/PDF/2000I8RO.PDF