MAXIMIZING THE ECONOMICS OF CLEAN WATER USING A HYDRAULIC DREDGE AND A MECHANICAL DEWATERING PLANT: CASE STUDY OF LAKE DELAVAN, DELAVAN WISCONSIN

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ABSTRACT

The Delavan Lake North Inlet Dredging Project, performed in Delavan Lake, Wisconsin in 2011, involved hydraulic dredging to remove approximately 34,407 cubic meters (45,000 cubic yards) of nutrient rich sediment and "mechanical dewatering" the solids, which were hauled and used in the reclamation of a 16.2 hectare (40 acre) quarry site. The extracted water was cleaned and returned to the main part of the lake with 6-18 mg/l suspended solids – lower than the average lake concentration of 18-22 mg/l suspended solids. The phosphorus-enriched sediment was removed from the inlet to prevent it from washing down into the main part of the 850 hectare (2,100 acre) lake. That section of the inlet drains about half of Delavan Lake's 10,522 hectare (26,000 acre) watershed and contributes an estimated 60% of the phosphorus entering the lake. Approximately 15,127 kilograms (33,350 pounds) of phosphorus was removed from the inlet as a result of the dredging project. One pound of phosphorus can grow 136-227 kilograms (300-500 pounds) of wet algae. Removing the inlet's sediment and its cache of phosphorus will help improve water quality and prevent excessive algal growth that diminishes the economics of recreation. The dredging and mechanical dewatering systems deployed in Delavan were more efficient and economical than the typical "pump and dump" operation normally associated with projects of this size. In Delavan, the portable dewatering equipment fit into a small footprint behind the local fire station (less than 1/2 acre in size), produced drier sediment which equated to lower truck hauling costs, and the restoration costs for this site were a fraction compared to a basin dewatering site that relied on earthen settling ponds.

Keywords: Solids control, phosphorus removal, water quality, flocculation, re-use

INTRODUCTION

The Economics of Clean Water

Delavan Lake residents in Walworth County have worked hard to improve their lake's water quality during the last three decades. The Delavan Lake Sanitary District formed and oversaw the installation of wastewater collection sewers around the lake in the 1980's. That project cost $ 50 million and received federal and state funding. The sewers helped eliminate wastewater discharges from faulty residential septic systems into the lake. The town and city undertook an ambitious $ 7 million massive lake rehabilitation project that was completed in 1992. The lake's level was lowered and the entire fish population was killed to remove carp. Alum was added to the bottom to help trap phosphorus in sediments. Three ponds were constructed to capture sediment and phosphorus from a tributary, Jackson Creek. A peninsula was constructed near the inlet to divert sediment-laden water from the main part of the lake. A dam near the outlet was reconstructed and more desirable game fish were restocked. Those lake rehabilitation actions increased water clarity to a depth of 7.93 meter (26 feet) and eliminated carp and severe blue-green algal blooms.

In 2005, the Delavan Lake Improvement Association and the University of Wisconsin-Whitewater, released a comprehensive economic study, "What is the Value of a Clean and Healthy Lake to a Local Community?" The study calculated that "$77 million is generated annually as a result of Delavan Lake and its improved water quality." The economic analysis estimated that 812 jobs were generated, the average value of lake shoreline property appreciated $177,000 between 1987 and 2003, and the aggregate land value increased $99 million. The study states,

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"Delavan Lake is a crucial component to the financial, physical and social fabric of the region. Delavan Lake affects not only the quality of life for local residents, but also has regional economic amplifications….Deterioration of lake water (water clarity,milfoil) could be expected to lead to reductions in time spent in Delavan by property owners and visitors, which in turn would have economic implications for the local economy."

Between 2005 and 2011, the Town of Delavan conducted three maintenance projects to support the original massive lake rehabilitation projects. The North Inlet Dredging Project was the last of the maintenance projects and Town of Delavan Administrator John Olsen explains the town's rationale for the $1.6 million project: "Following several public meetings, the town board and lake committee undertook the project understanding that a clean and healthy Delavan Lake is one of the town's single most important assets", Olsen says. "Maintenance steps taken to help protect that asset will yield multiple and compounding economic and social benefits to the local economy."

The Delavan Lake North Inlet Project

The Delavan Lake North Inlet Project improved the quality of water flowing into Delavan Lake and restored boating access into the Inlet area and the lake. The 1.46 million project restored the ability of the 85-hectare (210-acre) Inlet area to filter eroded topsoil and nutrients that enter the lake through Jackson Creek. The sediment dredged from the north portion of the Inlet was mechanically dewatered and the clear water was returned to the lake via pipeline. The remaining phosphorus-rich topsoil was hauled to a nearby sand and gravel facility for reuse.

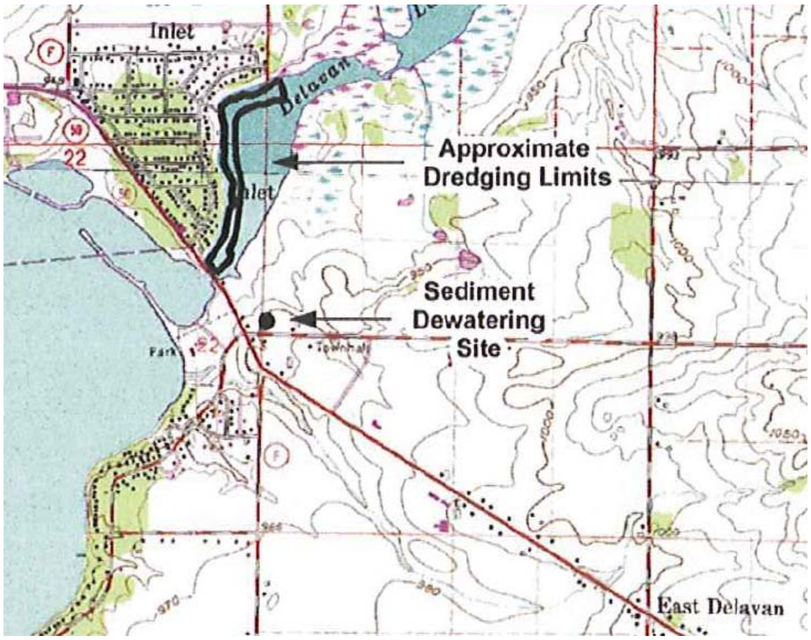

Figure 1. North Inlet General Site Map.

Primary Source of Lake Sediment

Sixty-eight percent of the water in the lake comes from the Inlet and the 914.6-m (3,000-ft) channel leading to it. The Inlet and the channel are fed by the 10,522 hectare (26,000 acre) Delavan Lake Watershed. The Inlet and Mountain Road sedimentation ponds located upstream of the Inlet act as filters for 70 percent of the run-off water entering the lake. These lake enhancements will now remove as much as 50 percent of the sediment and phosphorus entering from Jackson Creek. A total of 26,396 cubic meters (34,522 cubic yards) of accumulated sediment was removed from the two ponds. The Inlet had accumulated so much sediment that it lost about 56 percent of its natural capacity and became less effective at cleansing the water flowing into the lake.

Tropic State Index (TSI)

In order to be considered a healthy lake, Delavan should maintain a Tropic State Index (TSI) of 60 or less. This universally accepted scale rates phosphorus and chlorophyll levels and water clarity. Phosphorus is the key element that should be controlled to maintain low levels of algae growth. Delavan Lake's TSI rating has declined since the early 1900's, but has remained relatively constant since 2007, when the push for more work accelerated. In 2008, the Delavan Town Lake Committee took the initiative and spearheaded the effort to renovate and rebuild three of the primary features of the 1989 Lake Rehab Project. The Inlet dredging, the third of these projects is designed to keep the TSI rating in the 55 range and possibly improve it even more.

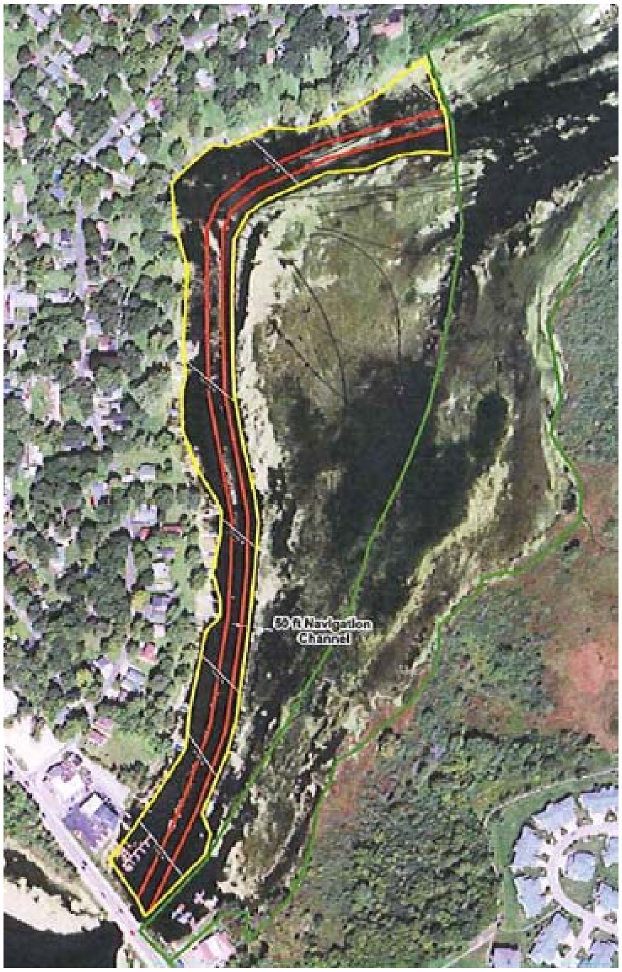

Figure 2. Overview photo indicating 3,000 ft. navigation channel (red), the adjacent near shore area (yellow), and the WDNR "Sensitive Area" (green) located upstream of the Route 50 bridge.

Project Design - Dewatering Alternatives

HDR Engineering of Springfield, Illinois, designed the project, the estimated dredging volume for the North Inlet Dredging Project has historically ranged from 32,113 to 56,580 cubic meters (42,000 to 74,000 cubic yards). Based on survey findings, the volume of sediment estimated to be removed within the allowable WDNR dredging limits is 31,359 cubic meters (41,014 cubic yards). This volume of sediment would most efficiently be removed using an 8-inch or 254-millimeter (10-inch) diameter discharge pipe. Although several suitable upland sites located west of the inlet have been identified and confirmed to be suitable for storing and dewatering the dredged sediment, landowner cooperation had not been achieved. In order to provide adequate space to store and dewater approximately 31,359 cubic meters (41,014 cubic yards)of dredged sediment in earthen sediment dewatering facility (SDF), the post dredging and dewatered use of the dredged sediment must be confirmed. If there is a necessity to re-grade the dried sediment within the limits of the dewatering site to allow surface drainage and beneficial or agricultural reuse of the site, then the height of the earthen berms should be limited to less than 1.83 or 2.44 meter (6 or 8 feet) so that the sediment can be dewatered and spread out in thinner layers.

Since hydraulically dredged sediment temporarily increases in volume by approximately 20 percent due to a “bulking factor”, the size and design of any SDF should provide sufficient storage volume to account for this bulking phenomenon. Therefore, any upland site to be considered for sediment storage and dewatering should be able to accommodate as much as 37,631 cubic meters (49,217 cubic yards) of bulked sediment volume, while meeting the WDNR discharge requirements for the clear effluent water returning to the lake after the sediment settles. For example, an earthen dewatering pond with an interior area that is 10 acres in size can store approximately 12,335 cubic meters (16,133 cubic yards) for every vertical 0.3 meter (1 foot) of sediment placed. Since the estimated bulked volume is 37,631 cubic meters (49,217 cubic yards), the average thickness of dredged sediment placed within the SDF is 0.93 meter (3.05 feet). A typical SDF would require an additional 0.61meter (2 feet) of ponding water depth to allow settling, plus 0.61meter (2 feet) of freeboard to the top of the perimeter dike. Since the material for constructing the earthen dikes would be excavated from within the impounded area, the average dike height would be approximately 1.83 meter (6 feet) higher than the surrounding ground elevation depending on the topography of the selected SDF site.

The most cost effective approach to removing this volume of sediment is to hydraulically pump the sediment and water slurry into an earthen sediment dewatering facility (SDF) as described above. However, this scenario is dependent on securing or leasing a sufficiently sized parcel of open land that is nearly level or gently sloping and is located outside of the floodplain, with no wetlands on the site. It is also desirable to be within one mile of the targeted dredging area with pipeline access and a minimum number of road crossings. Longer pumping distances are certainly feasible, however, a booster pump would be required and higher dredging costs would be incurred as a result. Several potential SDF sites located west of the inlet were initially evaluated and were determined to be suitable. However, landowner cooperation had not been positive. One additional site located to the east had been preliminarily evaluated and determined to be of suitable size and layout, but no confirmation of landowner cooperation had been received.

Since the dewatered sediment is normally required to be spread out and graded to allow site drainage and beneficial reuse of the site, the dimensions suggested above allow post dredging site reclamation to be completed more efficiently than for a smaller site with higher perimeter dikes and greater vertical sediment placement within the SDF. The estimated length of time that a site would be required for the North Inlet dredging project would likely range from three to four years depending on post dredging rainfall patterns. It may be possible to construct the earthen dewatering facility and dredge the inlet in one construction season, allow dewatered sediment to dry and consolidate the following winter and spring, and then spread and grade the dried soil late summer and early fall the following year. However, this two year dredging and site reclamation period is optimistic and a three year period is generally more realistic. The preliminary estimate of probable cost for dredging approximately 41,014 cubic yards of sediment within the allowable dredging area and storing the dredged sediment in an upland sediment dewatering facility (SDF) ranges from $461,814 to $616,179 (see Table 1).

The scope of engineering services for a future dredging and lake restoration project would include design, permitting, bid document preparation, and coordination of potential bidders. The probable cost range for site grading and reclamation is $50,000 to $75,000 and would likely be completed one to two years after dredging under a separate engineering/construction contract. The site reclamation can vary considerably and is ultimately dependent on the overall site area and reclamation requirements. If off-site hauling is required, costs are expected to be considerably higher.

Table 1. Estimate of probable sediment removal costs with SDF

Sediment Removal Work Task	Total Dredging Quantity	Estimated Cost
North Inlet Dredging – ($5.00 to $7.00/CY)	41,014 CY	$ 205,070 - $ 287,098
Dredge and Pipeline Mobilization		$ 60,000 - $ 80,000
Construct Sediment Dewatering Pond (10-12 acres)		$ 100,000 - $ 120,000
Subtotal		$ 365,070 - $ 487,098
Contingency (10%)		$ 36,507 - $ 48,710
Subtotal incl. Contingency		$ 401,577 - $ 535,808
Engineering, Permitting & Envir. Assessment (15%)		$ 60,237 - $ 80,371
Total Estimated Cost for Dredging with SDF		**$ 461,814 - $ 616,179**
Probable Site Reclamation Cost	1 L.S.	$ 50,000 - $ 75,000 (dependent on location and land owner requirements)

Due to a suitable upland storage and dewatering site not being secured, the use of alternative dewatering methods such as geotubes or mechanical dewatering systems was required. Either of these approaches is generally more expensive than constructing an earthen dewatering facility (see Table 2). However, in the event a suitable SDF site cannot be acquired or leased, these alternative dewatering approaches were considered. The dewatered material would have to be hauled to one or more locations, preferably for placement on an existing agricultural field. In order to use geotubes, which are large geotextile tubes that are placed in a series and hydraulically filled with sediment and water, several acres of land area would be required for a short period of time. If sufficient land area does not allow the placement of geotubes, an onsite mechanical dewatering system can be used on a smaller land area to mechanically dewater the sediment for temporary stockpiling and subsequent off-site hauling.

Table 2. Estimate of probable sediment removal costs with alternative dewatering

Sediment Removal Work Task	Total Dredging Quantity	Estimated Cost
North Inlet Dredging – ($18.00 to $22.00/CY)	41,014 CY	$ 738,252 - $ 902,308
Includes Dredging, Mobilization and Dewatering		
Contingency (10%)		$ 73,825 - $ 90,231
Subtotal incl. Contingency		$ 812,077 - $ 992,539
Engineering, Permitting & Envir. Assessment (15%)		$ 121,812 - $ 148,880
Total Estimated Cost for Dredging & Dewatering		**$ 933,889 - $ 1,141,419**
Offsite Hauling and/or Spreading if Required	1 L.S.	Variable ($5 - $15/CY)
Probable Site Reclamation Cost	1 L.S.	Variable (dependent on land owner requirements)

Either approach will cost approximately$26 per cubic meter ($20 per cubic yard) for dredging and dewatering, not including engineering, permitting, site reclamation and/or offsite hauling if necessary. These alternative approaches were considered only if an upland site cannot be secured that is large enough to accommodate a minimum 4-hectare (10-acre) earthen sediment dewatering facility (SDF). The cost of off-site hauling can vary from $6.5 to 19.6 per cubic meter ($5 to $15 per cubic yard) depending on the round trip haul distance to one of more approved land parcels. If a suitable upland location for on-site dewatering is available, the dewatered soil (sediment) may have to be spread in thin layers throughout the available land with low-compaction spreaders at an estimated cost of $6.5 per cubic meter ($5.00 per cubic yard). Whether hauling or spreading is required, it is important to note that volume reduction can be expected after the sediment is sufficiently dewatered. Since lake sediment measured in-situ within the lake consists of a high percentage of water, the volume of the dewatered soil is often reduced by 30 to 40 percent of the in-lake volume. Therefore, if approximately 31,359 cubic meters (41,014 cubic yards) (as measured in the lake) are dredged, it is anticipated that the dewatered volume will range from 19,115 to 22,938 cubic meters (25,000 to 30,000 cubic yards) of dewatered soil to be hauled and/or spread on available land.

Environmental Considerations

The Inlet has long been impacted by nutrient rich sediment that has contributed to shallow water depths, excessive macrophyte growth, algae blooms, habitat degradation and severe impacts to recreational access. In addition to being impacted by sediment deposition and phosphorus loadings originating from external or watershed based sources, the Inlet and adjoining Delavan Lake has been subjected to reoccurring high wind events and boat induced activity that has disturbed and re-suspended the soft, shallow nutrient rich sediment back into the water column allowing phosphorus to become re-mobilized to contribute to eutropic conditions within the Inlet and into the main body of the lake. The extent of the project dredging limits was restricted by the presence of high quality aquatic habitat that developed in many areas of the highly vegetated, eastern portion of the Inlet and had been designated as a WDNR Sensitive Area, thus limiting the allowable extent of the Inlet dredging efforts. However, this historically vegetative “Sensitive Area” portion of the Inlet also provides many benefits besides aquatic habitat. The rooted macrophytes help to stabilize the underlying soft sediment and assist in limiting sediment and phosphorus re-suspension during high summer wind events, while providing a filtering mechanism for incoming suspended solids and phosphorus.

Phosphorus Inactivation through controlled alum treatments, similar to the relatively successful efforts implemented within the deeper hypo limnetic main body of Delavan Lake in 1990, was considered for the Inlet, but was not deemed to be viable for various reasons. The Inlet is a shallow unstratified, sediment laden forebay with extensive aquatic macrophyte coverage that is subjected to reoccurring external sediment and nutrient loadings. These basic conditions, that include a high watershed to lake size ratio and subsequent sediment deposition rates, greatly reduce the effectiveness and longevity of alum treatments by rapidly covering the alum floc that was applied. In Addition, the extensive macrophyte growth within the Inlet, which includes Eurasian water milfoil and many native species, would likely limit effectiveness by intercepting alum floc and contributing to uneven distribution on the sediment surface. It has also been observed that the extensive organic carbon present in high density macrophyte zones can occupy binding sites for the alum floc, further limiting the effectiveness of each application. In addition to being a relatively ineffective and costly alternative for controlling phosphorus within the Inlet, alum treatments were not determined to be an environmentally acceptable solution due to the presence of the adjacent designated WDNR Sensitive Area and its potential impacts to larval fish and micro-invertebrates thriving within the high quality aquatic habitat.

The Inlet dredging project will complement the recently re-designed and renovated Mound Road wetland complex that was upstream of the Inlet to function as an enhanced sediment and nutrient trap to assist in protecting Delavan Lake from external, watershed based nutrient loadings. Additional watershed-based projects designated to reduce soil erosion and runoff from agricultural and construction based sources, stream bank and channel instability, and other in-lake management alternatives described in the Delavan Lake Management Plan are strongly recommended for future consideration and implementation.

DELAVAN LAKE NORTH INLET PROJECT OBJECTIVES

The primary objectives of Lake Delavan were:

- Deepen the Inlet channel to 1.83 meter (6 feet) in the south end and 1.52 meter (5 feet) in the north end.
- Remove approximately 34,407 cubic meters (45,000 cubic yards) of sediment dredged from the Inlet.

- Remove approximately 15,127 kilograms (33,350 pounds) of phosphorus, bound in the nutrient rich sediment.
- Mechanical dewater, load and transport reclaimed sediment within less than 0.2 hectare (1/2 acre) of usable space.
- Utilize only lake water in dewatering and return it back to the lake under 30 ml/l T.S.S, per permit requirements.
- Reduce the propensity of soft, flocculent sediment to become re-suspended into the water column as a result of wind and boat induced disturbance.
- Increase water depth within the channel Inlet to improve sediment and nutrient trapping capability for future loading and increased benefit to aquatic habitat.
- Project Budgeted at 1.46 million to be completed within 120 days.

DREDGING AND DEWATERING EQUIPMENT

The Town of Delavan solicited bids four times over 18 months, and the fourth solicitation brought an acceptable bid from JND Thomas Company, Inc. of Riverdale, California and Daytona Beach, Florida, to dredge and mechanically dewater up to 34,407 cubic meters (45,000 cubic yards) of sediment from the Delavan Lake North Inlet. The total project cost of 1.464 million was paid by the Town of Delevan. The town's share is $ 1.34 million in local taxes, with the City of Delavan contributing $ 125,000 and the Wisconsin Waterway Commission contributing $ 100,000. The project was to be completed with 120 days of the starting date.

Mobilization

All dredging, dewatering and support equipment is trucked onsite utilizing non permitted commercial hauling. The site preparation was two days, equipment set up was 6 days and testing was completed in four days totaling 12 days from start to finish. Onsite personnel consisted of one project manager, two supervisors and six employees. Outside contractors were used for electrical hook up into city power. (See figures 3 through 7)

Figure 3. Placement of the 42-foot long DSC 8-inch "Moray" swinging ladder dredge.

Figure 4. Unloading of HDPE dredging pipe used for pumping sediment and return water to the lake.

Figure 5. Placement of two additional components for screening and hydro cyclones.

Figure 6. Placement of the portable clarifier tank (in lowered, transport position)

Figure 7. Placement of the portable belt presses.

Dredge

JND Thomas deployed a 203 millimeter (8 inches) DSC Moray swinging ladder dredge with GPS positioning capability. (See figure 8) The dredge can operate at minimum water depth of 76.2 centimeters (30 inches). The major advantage of the "Moray" dredge is its ability to work in tight areas by utilizing travel and positioning spuds instead of cables for movement. The dredge is capable of dredging depths up to 18 feet with nominal flow rates up to 0.16 m3/s @56.4 TDH in meters (2,500 gpm @ 185 TDH in feet. The cutter head is a sealed planetary drive, 610 millimeter (24 inch) inside diameter 5-blade basket cutter with replaceable serrated edges. Nominal production capacity for the Moray dredge is 90 in-situ yards per hour in combination with 203 millimeter (8 inch) HDPE floating and submerged discharge pipe. JND used a Carolina Skiff to assist in moving the dredge and to provide fuel and pipeline support. Sediment surveys were managed by HDR Engineering through the use of staged cross section survey maps. (See Figure 9)

Figure 8. Eight inch DSC Moray swinging ladder dredge positioned in Lake Delavan North Inlet

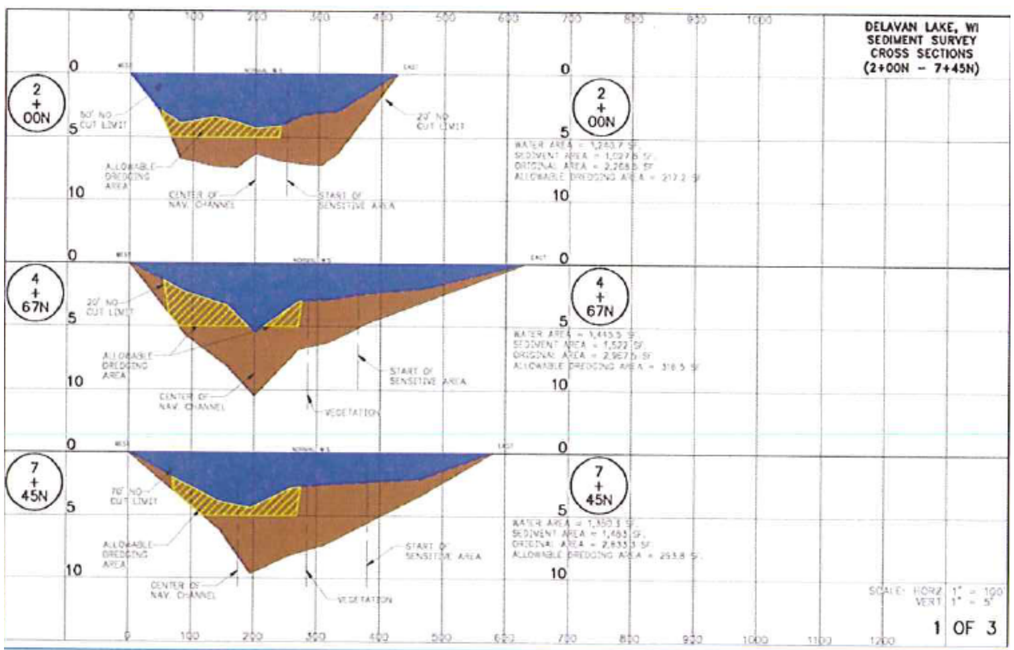

Figure 9. Sample of HDR Engineering dredging survey cross section.

Mechanical Dewatering

JND Thomas utilized a combination of portable mechanical separators, mixing and clarification tanks in sequence while utilizing lake water for washing belts on the presses. (See Figure 9) The dredge maintained a continuous supply of material pumped through 203 millimeter (8 inch) HDPE fused pipeline that was either floated or submerged, depending upon lake traffic. The material was first flowed over two sets of Dual Tandem Shakers with 7.43 square meters (80 square feet) of surface area removing any debris over 6.4 millimeters (¼ inches) in diameter. The remaining water and material fall into the first mix tank and are pumped into four – 35.6 cm (14 inch) Hydro Cyclones which make a second cut of 225 mesh, drying and removing the larger material on two Linear Motion shakers. The remaining slurry of fines and clays falls into the second holding tank and pumped into the Clarifier

Tank where a polymer flocculent is added. The Clarifier will recover ultrafine suspended solids which have been flocked and thickened. The condensed slurry is captured and directed to four belt presses working in tandem. The belt presses take the thickened fines and press the remaining water out to create a "cake" like material averaging 45% solids. The dewatered "cake" is mixed with the larger removed particles from the prescreening processes and stacked on site until loading for re use.

Clean, clear water exited the clarifier by slowly passing over weirs constructed into the exit chamber of the clarifier. The clean water would gravity flow into a final polishing tank where it could be monitored and released back into Lake Delavan. Turbidity testing was performed throughout the project with a DR-850 HACH Turbidity Meter resulting in the average turbidity of return water averaging 6-18 mg/l T.S.S., well below the lake average of 18 – 22 mg/l. T.S.S.

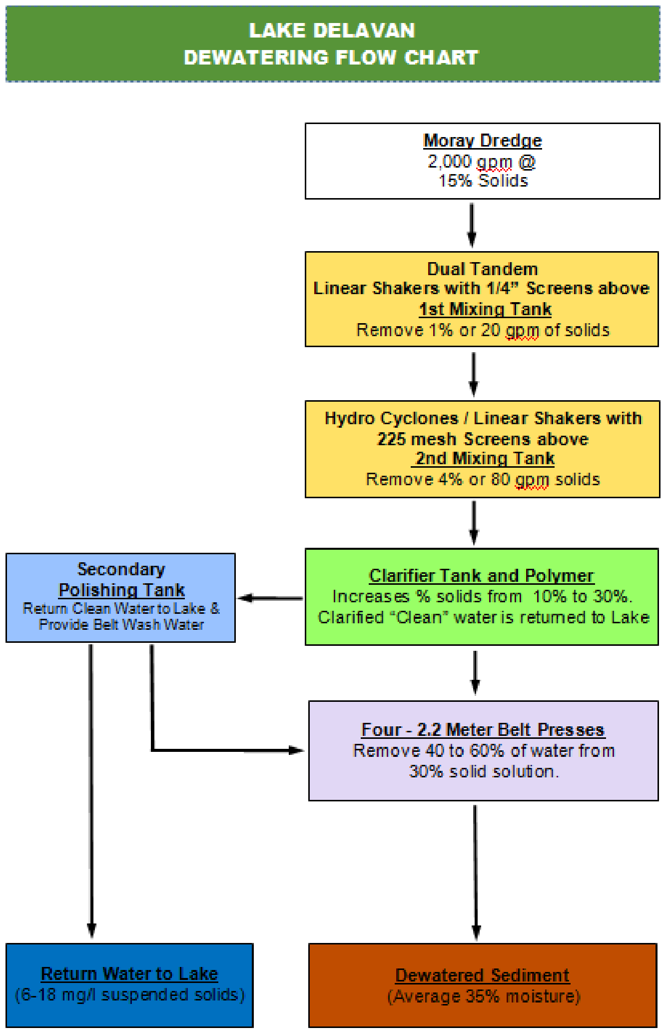

Figure 10. Dredging and mechanical dewatering project schematic

Proportion of Solids and Water in Lake Sediment

The proportion of solids and water in lake sediment varies depending on the physical characteristics of the sediment and the hydrology and morphometry of the lake environment. Undisturbed core samples of the Delavan Inlet sediment were found to range from 25 to 30 percent solids and 70 to 75 percent water. The in-situ or in-lake concentrations are important because the volume occupied by water is inversely proportional to the solids content.

(See Figure 11) Onsite tests have indicated that the dewatered soil contains approximately 60 percent solids or 40 percent water versus pre-dredging in-situ concentrations of only 25 to 30 percent solids.

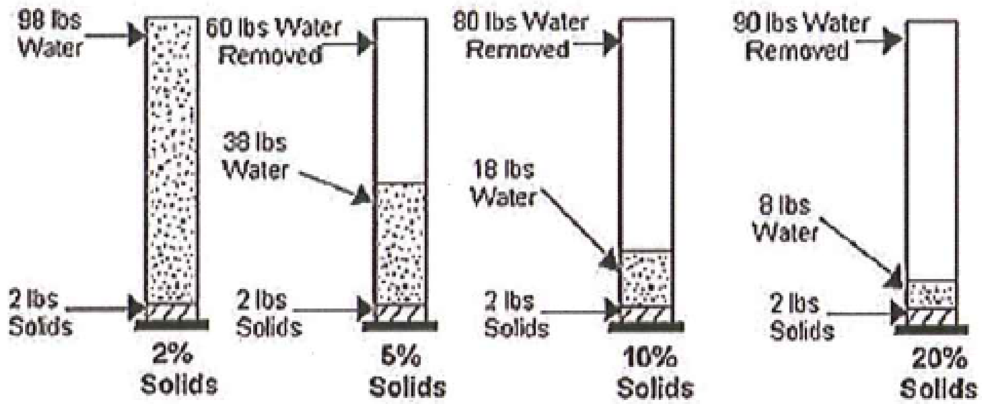

Figure 11. Illustration of a measured volume being reduced by removing water, which also occupies void space in the sediment

Figure 12. The photos above provide a visual representation of the soil/sediment consistency from Lake Delavan. (center bucket photo) In-Situ sediment, (top three photos) representing the mixture being introduced into the Clarifier, and remaining photos indicating dewatered sediment.

Figure 13. Portable polymer injection system.

Figure 14. Return lake water after exiting the dewatering system.

Figure 15. Dewatered sediment off the belt presses.

Figure 16. Sediment loaded into trucks for re-use, 1 of 1,489 truckloads.

Figure 17. Sediment re-use in the reclamation of a quarry site.

Figure 18. Before and after pictures of the dewatering site.

CONCLUSIONS

The economics of clean water relating to the financial, physical and social fabric of Delavan Lake were analyzed and verified at $ 77 million annually. The Delavan Lake North Inlet project was the third step of a major lake rehabilitation project designed to protect and enhance water quality by eliminating algal blooms and improving water clarity. Maintenance dredging and mechanical dewatering were critical to completing the final requirements necessary to maintain the health and economic vitality of the region. During the project, the Inlet channel was deepened between 1.5 and 1.8 meters (5 and 6 feet) and approximately 34,407 cubic meters (45,000 cubic yards) of sediment containing approximately 15,127 kilograms (33,350 pounds) of phosphorus was removed. The sediment was mechanically dewatered, loaded and transported within less than 0.2 hectare (½ acre) of usable space and only lake water was used for dewatering and returned back to the lake at an average of 18mg/l T.S.S, well below the 30mg/l permit requirements. As a result of the sediment removal, the propensity of soft, flocculent sediment to become re-suspended into the water column was reduced and the deepening of the channel improved future sediment and nutrient trapping capability as well as increasing the benefits to aquatic habitat. The overall project was completed under budget and ahead of schedule.

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