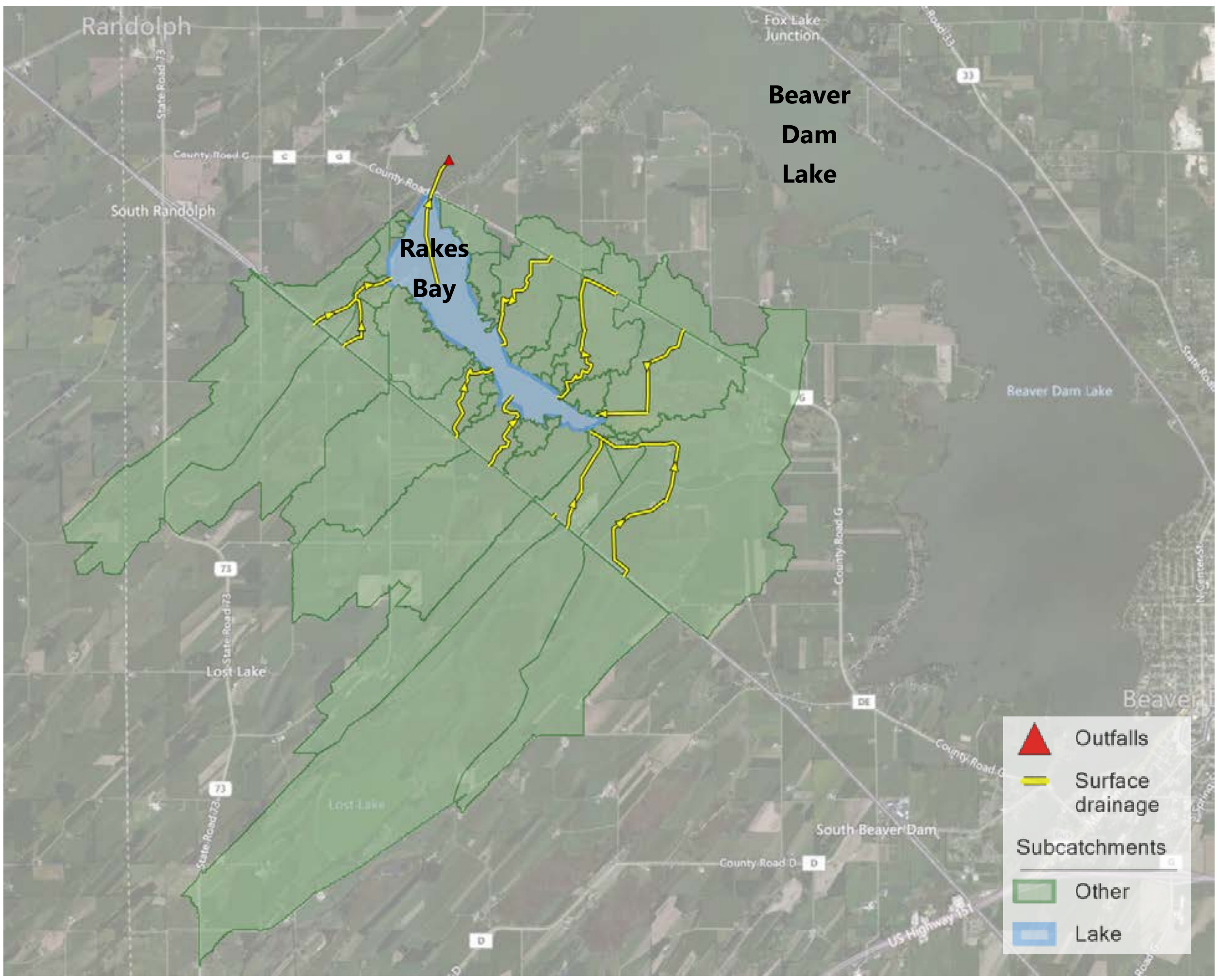
Prepared by: EOR

For Beaver Dam Lake Improvement Association, November 2021.

Rakes Bay Project Summary Memo



Cover Images

Rakes Bay SWMM model.

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VERSION REGISTRY AND CONTRIBUTORS

Issues and Revisions Registry

Identification	Date	Description of Issue and/or Revision
Draft Report	August 9, 2021	Draft Report for City review
Revised Draft Report	September 10, 2021	Draft Report with revisions based on City comments
Revised H/H Model Report	October 8, 2021	Summary of final updates to H/H Model following meeting with DNR Staff
Project Summary Memo	November 8, 2021	Adding project background, 2021 data collection, Rakes Bay drawdown information, Appendix A: 2018 monitoring
Revision 1	November 22, 2021	Updated cover graphic with legend, and add upstream flood extent and duration analysis to Section 4.2

Primary Authors (EOR)

Nick Hayden, MS, PE, GISP

Joe Pallardy, MS

Kim Walsh

Significant Contributors

Steve Gaffield, PhD, PE, CFM

ACRONYMS

DEM – Digital Elevation Model

EPA – Environmental Protection Agency

GIS – Geographic Information Systems

NOAA – National Oceanic and Atmospheric Administration

NRCS – National Resources Conservation Service

SSURGO – Soil Survey Geographic Database

SWMM – Storm Water Management Model

1. PROJECT BACKGROUND

The Beaver Dam Lake Improvement Association (now Beaver Dam Lake District) has been completing various studies of in Lake and watershed conditions the past 5 to 10 years. These studies have included:

A Lake management plan prepared by Onterra that was completed and delivered to DNR in 2016. This plan identified in-lake phosphorus recycling, rough fish derivation and aquatic vegetation degradation as major issues on the lake.

Subsequently BDLIA was awarded a follow-up league protection agreement, part of which sponsored a University of Wisconsin-Madison water resource management practicum project that focused on the Beaver Dam Lake watershed (using GIS data and the EVAAL program) and nutrients within the lake itself, which provided additional data specific to Rakes Bay. The water resource management practicum project utilized data previously developed in a UW-Madison civil and environmental engineering graduate seminar.

Additionally, the DNR grant to BDLIA was used to conduct field monitoring of flow and water quality at multiple locations in the Beaver Dam Lake watershed and at the lake, including discharge monitoring at the Rakes Bay entrance to Beaver Dam Lake and at several tributary watershed outlets. This work was used in combination with previously collected data to provide a deeper understanding of the nutrient flows through the lake and concluded that watershed contributed phosphorus was very important.

Specifically with respect to Rakes Bay, the data collected in 2018 identified extremely high concentrations of phosphorus in Rakes Bay. Because Rakes Bay has such high TP concentrations, it has been identified as a significant source of phosphorus to Beaver Dam Lake. Since 2018, EOR has worked collaboratively with the BDLIA to evaluate potential implementation options targeted at reducing nutrient loading from Rakes Bay. The ability to reduce nutrient loading from Rakes Bay relies heavily on the establishment of a stable clear- water macrophyte dominated state. Previous implementation efforts in Rakes Bay (e.g. carp barriers) have not survived, due to maintenance and operational issues.

EOR and representatives from the BDLIA conducted a diagnostic evaluation of the Rakes Bay subwatershed (Figure 1) on June 17, 2020 to evaluate potential implementation options. Prior to the field visit, EOR recommended a winter drawdown of Rakes Bay to kill common carp, consolidate lake sediments, and promote increased aquatic plant growth that in turn would maintain a more stable clear-water state. These aquatic plants would then provide food and habitat for waterfowl and other wildlife including desirable gamefish species like northern pike. However, the June 2020 site visit made it clear that a one-time drawdown would likely not achieve desired effects on a long-term scale given that contributing areas to Rakes Bay are highly ditched, channelized and ultimately very flashy in nature.

An integrated solution is required to restore Rakes Bay that included both improving the vegetation and aquatic habitat conditions within the Bay, combined with an approach to improve the quality of runoff water delivered from the watershed into the Bay. This solution will include a strategically designed wetland restoration to address the largest source of phosphorus to Rakes Bay and a culminating winter drawdown of Rakes Bay. Fortunately, there are relatively few landowners and a significant amount of State-Owned lands within the Rakes Bay subwatershed, which makes implementing this solution feasible.

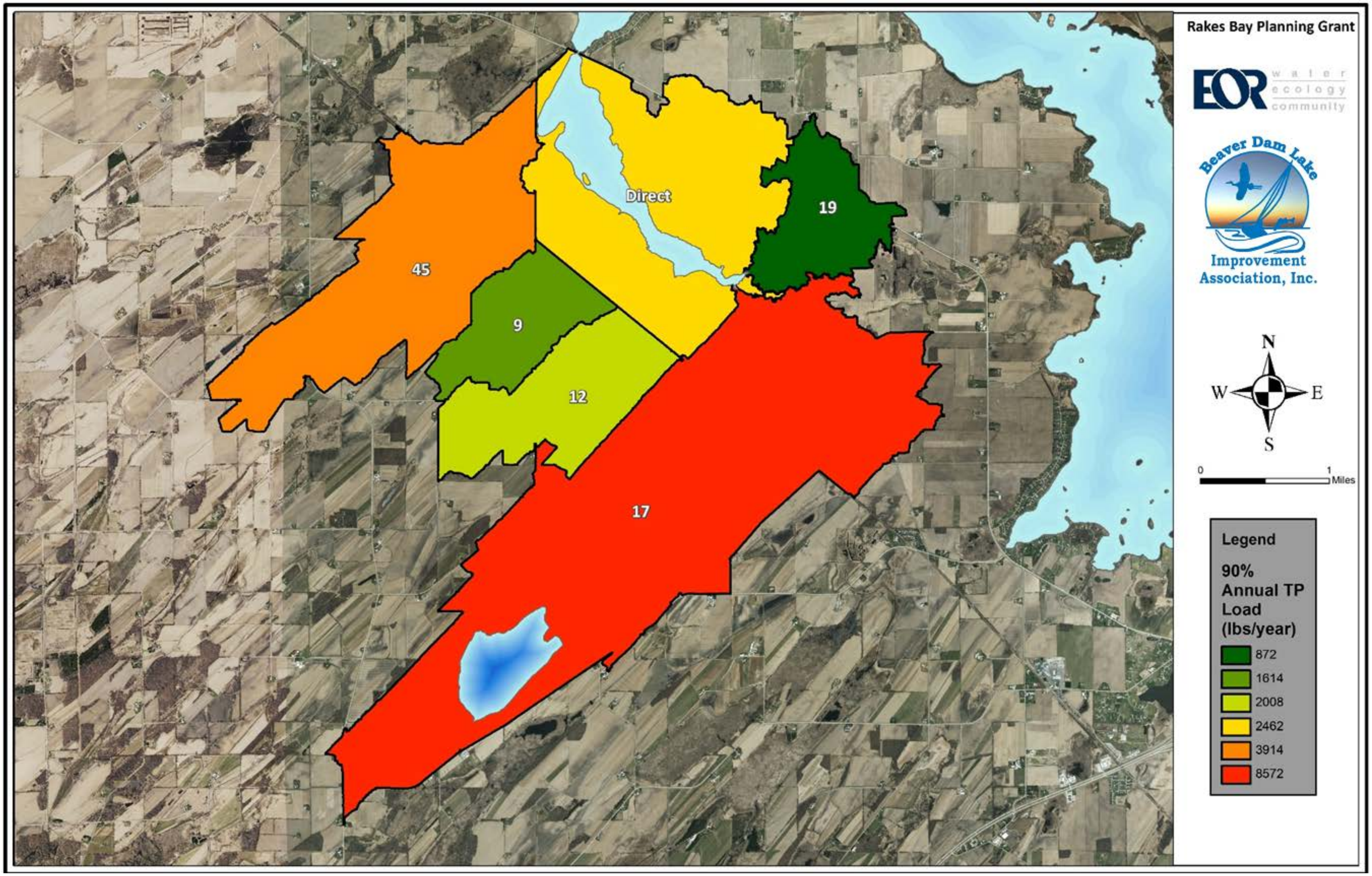


Figure 1. Rakes Bay Subwatershed Annual Phosphorus Loading (lbs/year).

2. 2021 DATA COLLECTION

2.1. Lake Management Planning Grant

In 2020, EOR worked with the BDLIA to secure a Lake Management Planning Grant to fund the development of specific project designs, including the development of engineering and construction plans and specifications necessary to identify and implement a comprehensive, integrated solution for Rakes bay.

The proposed plans are based on flow/stage monitoring data and water quality samples collected at the largest tributaries to Rakes Bay, which were used as inputs to a watershed and drainage, combined hydrology and hydraulics (H&H) model of the Rakes Bay subwatershed (See Section 3).

2.2. 2021 Beaver Dam Lake Monitoring Data

In 2021, the average in-lake Phosphorus (P) concentration for Beaver Dam Lake (BDL) was 113 ug/L, well below the average P concentration from 2007-2021 of 199 ug/L. The 113 ug/L observation was also the lowest average in-lake P concentration on record. This data provides additional evidence to suggest that in years with average rainfall, Rakes Bay is a significant contributor to Beaver Dam Lake for the following reasons:

1) According to the EPA's Antecedent Precipitation Tool, 2021 was a dry year (moderate drought). Annual rainfall totals (January through October) were below the 30-year average during the majority of the growing season (Figure 3).
2) Below average rainfall totals resulted in very little outflow observed at monitored tributaries to Rakes Bay and from Rakes Bay to Beaver Dam Lake.
    a. In some cases, flow was observed to be flowing out of Beaver Dam Lake and into Rakes Bay (reverse flow).

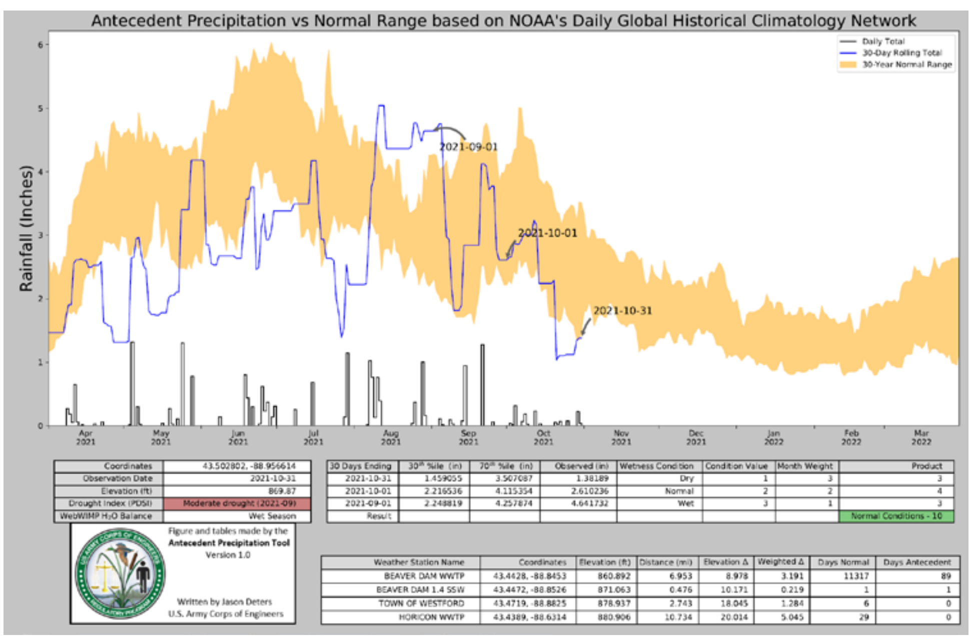


Figure 2. EPA Antecedent Precipitation through October 2021

2.2.1. Tributary Monitoring – Water Quality Results

Observed Total Phosphorus (TP) concentrations were consistently highest in subwatersheds 17D and 17C. As a point of comparison, the Wisconsin State Total Phosphorus Standard for streams is 75 ug/L. This information was used to identify best management practices that would treat the two tributaries (17 C, 17D) with the highest observed TP concentration.

Flow (discharge), stage, and water quality data collected from April-October, 2021 were used to calibrate a combined hydrology and hydraulics (H&H) model of the area draining to Rakes Bay.

Table 1. Water Quality Results - Lab Analysis Conducted at Wisconsin State Lab of Hygiene

Total Phosphorus Concentration (µg/L)			
Date	Site ID		
	17D	45	17C
4/28/2021	1490	220	872
5/13/2021	1710	203	1050
5/24/2021	1670	502	573
6/21/2021	2850	505	1209
8/9/2021	1770	395	1200
Average	**1,898**	**365**	**980**

2.3. Rakes Bay Phosphorus Budget

Water quality, flow monitoring data, and BATHTUB modeling of Rakes Bay confirmed that subwatershed 17 was the greatest external phosphorus (P) source to Rakes Bay. During wet years, the importance of subwatershed 17 to the overall P budget of Rakes Bay increases from 3,530 pounds/year, to more than 7,200 pounds per year and becomes the dominant source of phosphorus to Rakes Bay and ultimately to Beaver Dam Lake. This finding highlights the importance of addressing loading from both internal sources (Rakes Bay) and from subwatershed 17, the largest external source to Rakes Bay.

Component	Phosphorus Load (lb/yr)
Atmospheric Deposition	68.7
Internal Load	**10,676**
Direct Drainage Area	1,260
Watershed 12	902
Watershed 17	**3,532**
Watershed 19	417
Watershed 45	2,012
Watershed 9	712
Total Inflow	**19,580**
Total Outflow	**7,826**
Retained	**11,754**

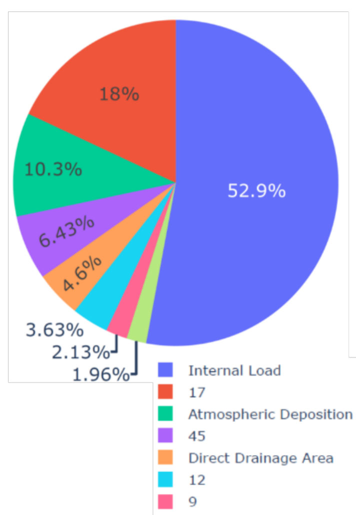


Figure 3. BATHTUB Water Quality Modeling Results During a Normal Precipitation Year

3. WATERSHED AND DRAINAGE MODEL CONSTRUCTION

A combined hydrology and hydraulics (H&H) model of the area draining to Rakes Bay (Dodge County, WI) was constructed and used to assess current runoff and impacts of proposed projects. The EPA's Storm Water Management Model (EPA SWMM) and related proprietary software are used for urban and rural H&H modeling and is accepted by FEMA for floodplain studies. EPA SWMM version 5.1.015 was used as the basis for the Rakes Bay model as it was a single package solution for both hydrology and hydraulics that could assess changes in hydraulic routing due to project storage modifications. A proprietary software (CHI's "PCSWMM") was used to assemble the one-dimensional (1-D) EPA SWMM model. The model was constructed mainly from the following GIS and other data sources:

- 2017 Dodge County LiDAR-based DEM
- 2021 Dodge County SSURGO soils data
- Aerial imagery streamed from Bing and WDNR
- Field measurements and observations (culverts, ditch depths, vegetation, soil characteristics)
- Daily rainfall from the Beaver Dam Wastewater Treatment Plant and hourly rainfall from the nearest hourly NOAA station (Juneau-Dodge Co Airport)

SWMM models have multiple rainfall infiltration method options and dozens of parameters that need to be estimated; the Rakes Bay model was constructed and parameterized based on the following methods:

- Modified Horton infiltration, using maximum and minimum infiltration rates based on Hydrologic Soil Groups mapped in the current NRCS SSURGO soils GIS data.
- Subcatchment hydrology:
    - Impervious fraction estimated based on aerial imagery
    - Depression storage and Manning's n "roughness" based on standard literature values for impervious and wetland / agricultural ground surfaces.
    - Slope based on resampling the County 2017 DEM from 2 ft resolution to 50 ft to remove vertical exaggerations, then averaging the slope of the 50 ft layer over each subcatchment.
- Drainage network:
    - Surface drainage – cross-sections representing the ditches and their adjacent wide, flat floodplains were constructed by sampling the DEM. The hydraulic network was coarse away from the proposed project areas, with the primary intent in those areas being to simulate runoff from subcatchments to Rakes Bay. In the area of the proposed project, additional cross-sections were added, and the DEM-based geometry was modified for the ditches based on field observations.
    - Culverts – culvert locations and dimensions were field-verified, particularly those along CTH CC and the railroad bed that drain to the project area and were used for water quality sampling and flow measurements.
    - Storage areas – the geometry of Rakes Bay and the numerous impounded areas on the upstream sides of the culverts were added based on the DEM and known lake information.
- Simulation options:
    - Unsteady dynamic wave flow routing

- One-second hydraulic routing time step for event storms; five second routing for calibration
- Five-minute reporting time step

The constructed model was tested and compared to runoff data collected at the railroad culvert just west of CTH CC in subwatershed 17 (see drawings). Rainfall during the monitoring period (spring and summer 2021) was below-average and flows typically did not exceed 10 cfs during events with a typical baseflow closer to 1 cfs. There was no on-site rain gauge available, so the best-available rainfall data was used. Observed rain events were generally low intensity, especially compared to typical design storms used for runoff modeling.

In order to better simulate the slow recession from storm events observed in this flat, wetland-dominated area, SWMM's shallow groundwater routine was turned on and configured. Once the model was calibrated, key design storms (2", 2-yr, and 100-yr) were run for 24-hour, MSE3 rainfall distributions with Atlas 14 rainfall totals. Results from the design storms and key calibration events are summarized in **Table 2**.

Table 2. Model Runoff Summary.

Event	Observed flow	Calibrated model flow at RR culvert
5/4/21, ~1.32"	6.8 cfs	9.5 cfs
5/24/21, ~1.3"	6.9 cfs	7.6 cfs
7/29/21, ~1.15"	7.8 cfs	10.4 cfs
2-yr design storm (2.68")	n/a	248 cfs
100-yr design storm (6.24")	n/a	1,767 cfs

4. PROPOSED CONDITIONS MODELING

The calibrated SWMM model was then used to design and simulate the impacts of the proposed project targeting decreased runoff from subwatersheds 17 D and 17C (see drawings). The focus of this modeling was primarily to assess:

- Increased wetland storage upstream of the proposed structures for small, more frequent rainfalls (2-yr design storm and smaller)
- Impacts to upstream property owners, particularly for the 100-yr design storm

4.1. Wetland Storage Impacts

The existing model was modified by adding two weir structures to the drainage network. These weirs are designed to reduce flow through the artificial ditches and back up water into the wide wetland floodplain. The cross-sections representing the ditches were modified to simulate a weir plate across the ~15 ft ditch channel at an elevation adjacent to the existing floodplain, with a narrow (1 ft.) stop-log notch at the center of the weir that extends all the way down to the existing ditch bottom. The purpose of this narrow gap is to not impound water during low baseflow. The modification to the ditch section at these cross-sections is small compared to the cross-sectional area of the wetland floodplains. For example, **Figure 4** shows the original and proposed ditch geometry compared to the overall cross-section at the southern ditch proposed weir location. This demonstrates the magnitude of blocking the narrow ditch compared to the overall wetland floodplain in the proposed project area.

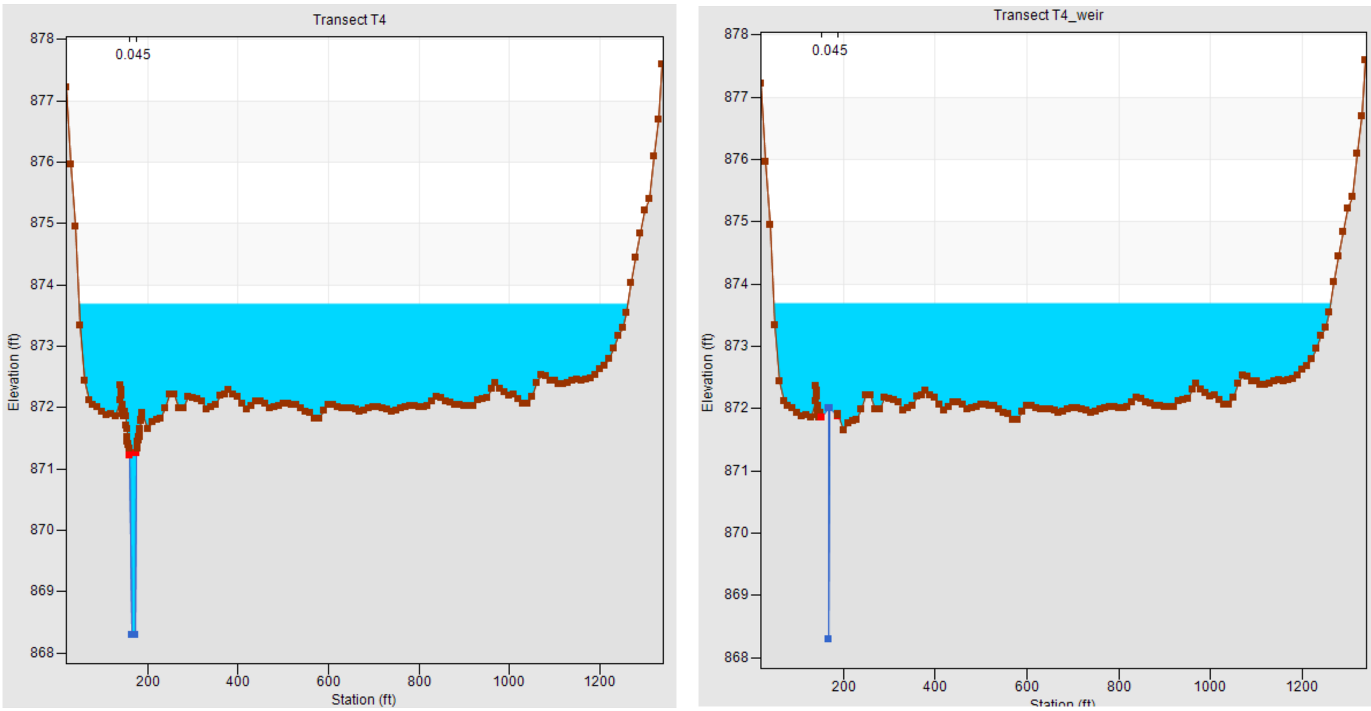


Figure 4. Existing (left) and Proposed (right) cross-sections at southern ditch weir.

Proposed impacts to total runoff to Rakes Bay from these subwatersheds for tested design storms is shown in **Table 3**. Substantial runoff volume reduction (~40%) for the small events is achieved, but for the large events the two small structures have less impact on total volumes, which is the expected result of targeting increased floodplain wetland storage for small events without impacting upstream structures and properties for large floods. Similarly, the weir structures reduce flow rates to Rakes Bay for small storms but have little impact for larger events.

Table 3. Runoff volume and peak flows for Existing and Proposed conditions.

Event	7-day runoff volume to Rakes Bay from ditch			Peak flow rate at ditch outlet	
	Existing (ac-ft)	**Proposed** (ac-ft)	**Percent reduction**	**Existing** (cfs)	**Proposed** (cfs)
2" design	175	98	44%	57	10
2-yr design (2.68")	222	135	39%	142	136
100-yr design (6.24")	648	542	16%	1389	1386

4.2. Upstream Impacts

The proposed conditions were assessed for upstream impacts during various flood events. The proposed weir structures would be on DNR-owned land, but there are private properties upstream of these lands along the two ditches that could be impacted. **Figure 5** shows the location of the proposed structures (as red Xs), primary property owners, and existing conditions 100-yr water extent.

Peak water surface elevations at the weirs and at the nearest upstream property boundaries are shown in **Table 4**. There are potential increases to water levels on upstream properties during smaller events, but they are modest (<0.5′) and typically mean that water levels in the ditch are slightly higher or that areas that are already wet floodplain get slightly deeper. There are no known structures in this immediate upstream area. More importantly, the weirs are not hydraulically important for large flood events – note that there is no increase to peak water elevations at 100-yr flows.

Table 4. Peak Water Surface Elevations (WSE) for design events, Existing (Ex.) and Proposed (Pr.) Conditions.

Event	South weir		North weir		Frank prop. boundary		Jordan prop. boundary	
	Ex.*	Pr.	Ex.	Pr.	Ex.	Pr.	Ex.	Pr.
2″ design	871.80′	872.05′ (+0.25′)	871.32′	871.76′ (+0.44′)	871.33′	871.75′ (+0.42′)	872.07′	872.11′ (+0.04′)
2-yr design (2.68″)	872.28′	872.34′ (+0.06′)	871.55′	872.19′ (+0.64′)	871.88′	872.27′ (+0.39′)	872.52′	872.54′ (+0.02′)
100-yr design (6.24″)	873.71′	873.72′ (+0.01′)	873.51′	873.53′ (+0.02′)	873.81′	873.81′ **(+0.00′)**	873.84′	873.84′ **(+0.00′)**

Changes in the duration and extent of flood impacts upstream were also assessed. For the extent, the maximum extent of flood waters within the upstream adjacent Jordan and Frank parcels at the peak of the flooding was calculated. For duration, the time it took floodwaters to drain back into the ditch after the rain event was calculated. For both the Jordan and Frank parcels, this occurs when the water surface falls to ~872.4′.

Results are shown in **Table 5**. The duration of flooding changed very little; the only significant change was that the 2-yr event now goes out of the banks on the Frank property for proposed conditions, but for fewer than two hours. The 100-yr duration results barely changed because the Rakes Bay water level continues to be the primary control preventing water from draining out of the floodplain, which did not change with the weirs in place. Flood extents for the 100-yr event did not change; for the 2-yr, the maximum extent increased by 0.1 acres on the Jordan parcel and 0.9 acres on the Frank property.

Table 5. Impacts to upstream flood extent and duration, Existing (Ex.) and Proposed (Pr.) Conditions.

Event	Jordan property				Frank property			
	Maximum inundation on parcel		Duration of flooding (out of ditch)		Maximum inundation on parcel		Duration of flooding (out of ditch)	
	Ex.	Pr.	Ex.	Pr.	Ex.	Pr.	Ex.	Pr.
2″	-	-	-	-	-	-	-	-
2-yr (2.68″)	12.6 ac	12.7 ac	2.2 hrs	2.3 hrs	-	0.9 ac	-	1.4 hrs
100-yr (6.24″)	14.3 ac	14.3 ac	34 hrs	34 hrs	14.8 ac	14.8 ac	32 hrs	32 hrs

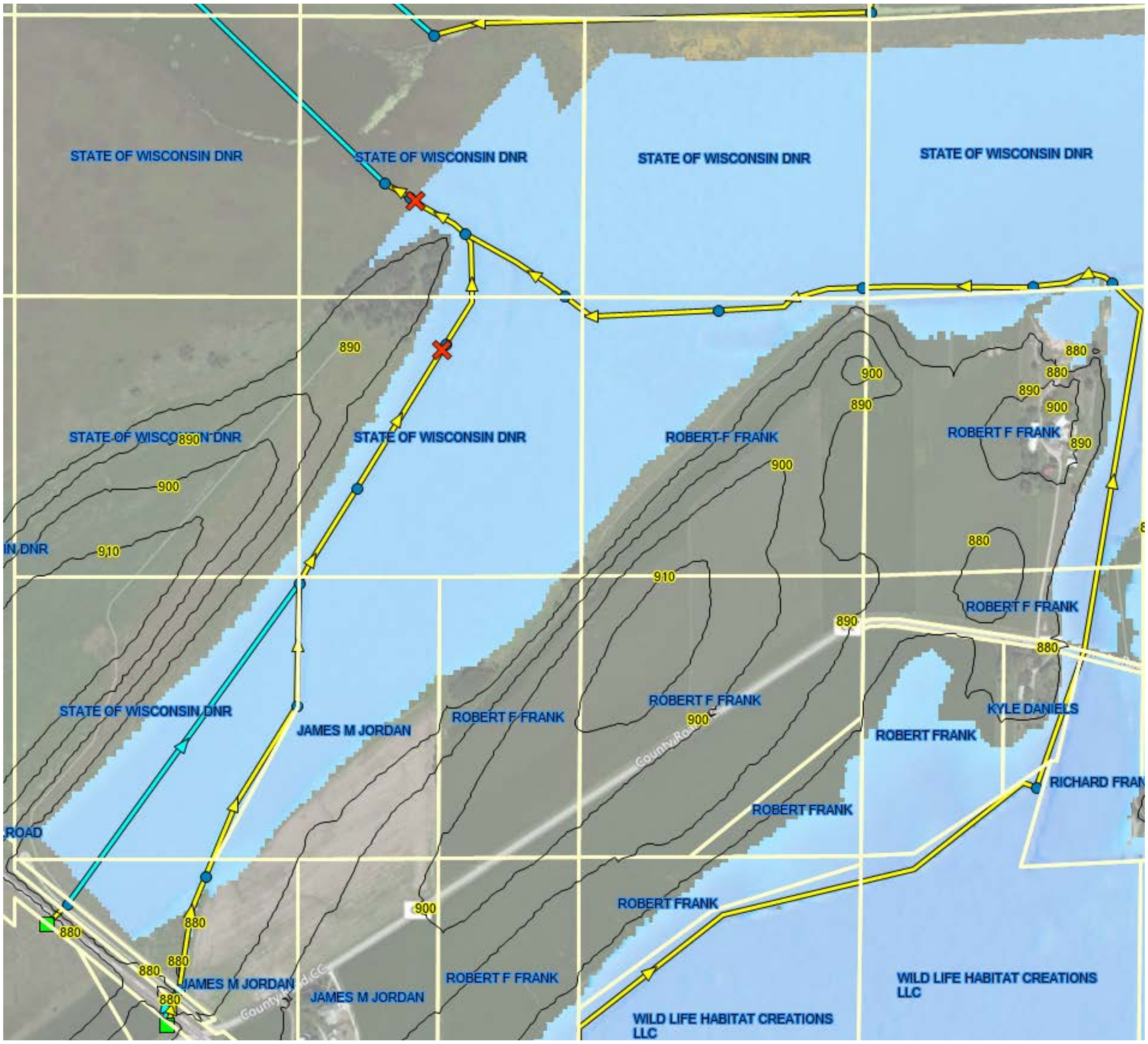


Figure 5. Property ownership, existing 100yr flood extent, and proposed structure locations (red Xs).

4.3. Conclusion

Based on these model results, it appears that the proposed structures, as currently designed, will meet the goals of increased flood storage for small events without having adverse upstream impacts during large flood events.

5. RAKES BAY DRAWDOWN

5.1. Purpose

Shallow lakes Like Beaver Dam Lake exist in one of two states, the clear-water macrophyte dominated state or the turbid-water algae dominated state. A drawdown of Rakes Bay would help to consolidate lake sediments and promote increased aquatic plant growth that in turn would maintain a more stable clear-water state. These aquatic plants would then provide food and habitat for waterfowl and other wildlife including desirable gamefish species like northern pike and yellow perch. The following benefits have been identified as a result of a drawdown of Rakes Bay.

- ✓ A 2021 WDNR Fisheries survey observed a large population of carp present in Rakes Bay. Elimination of carp will result in documented increases in water clarity.
- ✓ Watershed modeling indicates a high internal load from Rakes Bay – suggesting a high return on investment in comparison with other projects.
- ✓ Highly visible project with public support
- ✓ Allow native aquatic plant communities to establish a clear water, aquatic plant dominated state to promote fishery production for the main body of Beaver Dam Lake
- ✓ Increase economic value of Rakes Bay by restocking with desirable fish species that can provide top-down control over future carp populations.
- ✓ Benefit wildlife populations through increase in habitat for waterfowl and migratory shorebirds
- ✓ Create local jobs

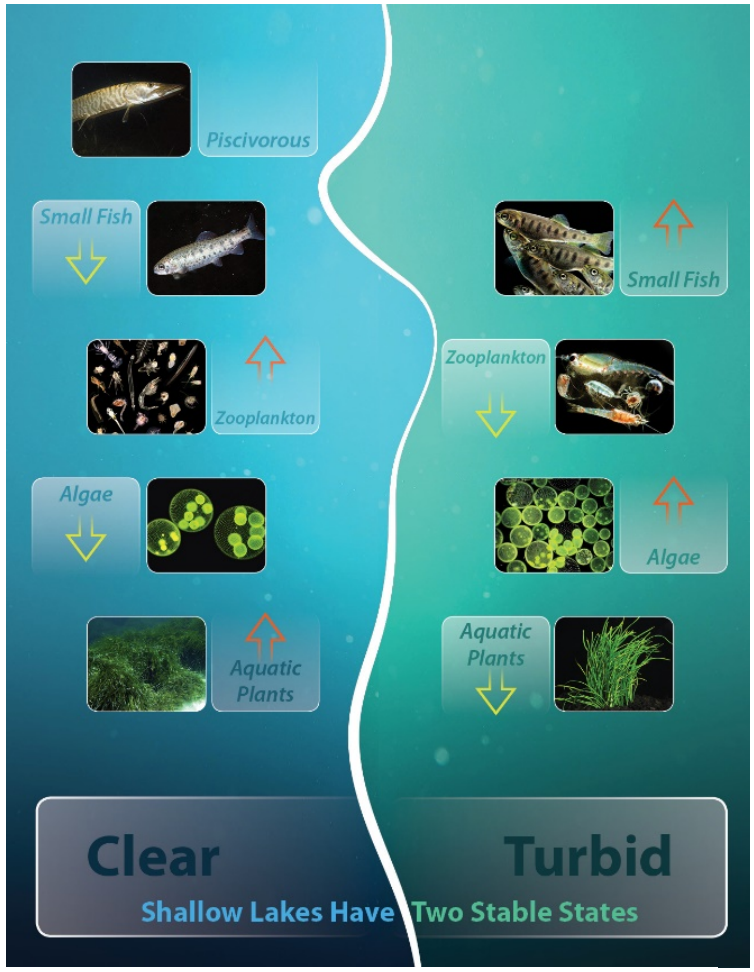


Figure 6. Alternative states of shallow lakes.

5.2. Drawdown Goals Defined

A successful Rakes Bay drawdown will actively remove water from Rakes Bay to expose the lake bottom to the air in order to:

- ✓ Oxidize and consolidate sediment
- ✓ Kill undesirable fish, primarily carp
- ✓ Improve and maintain wildlife habitat and water quality in Rakes Bay via restoration of an abundant and diverse emergent and submerged aquatic plant community

5.3. General Project Concept

The conceptual plan is to dewater Rakes Bay with a temporary berm placed at the outlet from Rakes Bay to Beaver Dam Lake at the Highway G Bridge. A pumping system would be installed to dewater Rakes Bay initially with several maintenance pumping episodes to augment the initial drawdown. The frequency of maintenance pumping is ultimately dependent on the duration and frequency of rain events as well as contributions from groundwater. Ultimately, the drawdown must be of sufficient duration and depth to accomplish both fish removal and sediment consolidation.

5.4. Duration of drawdown

The drawdown would likely begin in mid-September of 2022 and last until mid-April of 2023. The timing of this drawdown must allow sufficient time for reptiles and amphibians to adjust to overwintering locations. The duration of the drawdown would be of sufficient duration to thoroughly consolidate sediment and remove rough fish. A fisheries survey completed in spring of 2023 would validate if carp have been eliminated. Pending results from the fishery survey, the physical barrier would be removed and a carp barrier could be installed.

5.5. Feasibility

The approximate lakebed elevation at the outlet of Rakes Bay is 866 feet. The maximum operating order for the dam underneath County Road G is 871.1 feet or a difference of 5.1 feet. The maximum depth of Rakes Bay is 6 feet. Given that, the vast majority of Rakes Bay is less than 5 feet deep (Figure 7), the majority of the Bay can feasibly be drawn down. The deepest portions of the Bay may retain some water; however, any remaining water would not be deep enough to support carp. Following drawdown and reestablishment of native vegetation, Rakes Bay will be restocked with gamefish to provide top-down control of carp, aeration equipment will also be installed to prevent winterkill and the release of phosphorus from lake sediments.

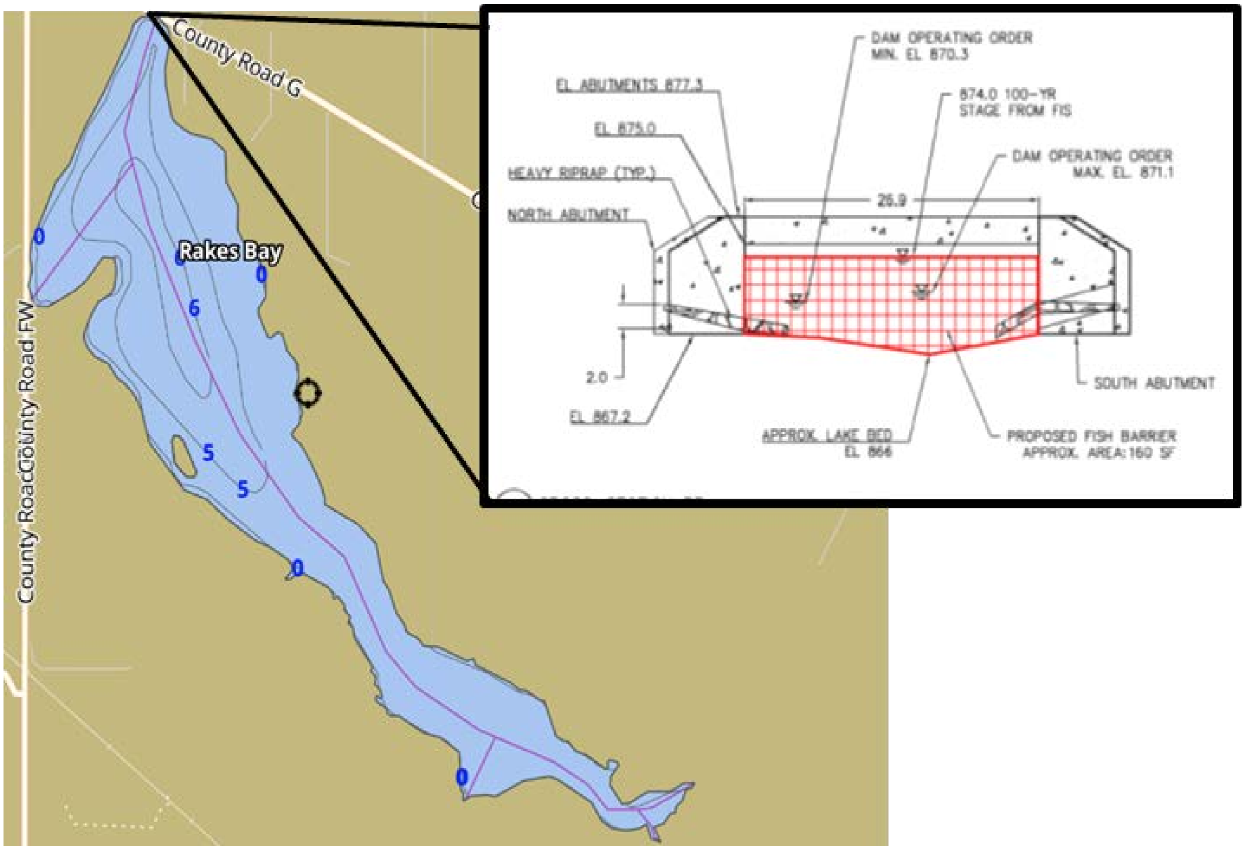


Figure 7. Rakes Bay bathymetry data

5.6. Pumping Rate Calculations

EOR conducted a preliminary evaluation of initial volume estimates currently present in Rakes Bay (Table 6) and the initial pumping rates (Table 7) required to draw Rakes Bay down to within 1 foot of the lakebed elevation. This is equivalent to reducing the lake surface from its current elevation at approximately 870-871′ down to approximately 867-868′.

Further, maintenance pumping will also be required to maintain a persistent draw down. Average annual runoff volume derived from the 10,700-acre Rakes Bay drainage area during a year with normal precipitation is 2,675-acre feet. Table 8 shows maintenance pumping rates. Table 9 provides a statement of probable costs associated with the drawdown project.

Table 6. Initial Volume Estimates

Area			Incremental Volume		
Elevation	**Acres**	**Sq. Ft**	**Ft^3**	**Ac-Ft**	**Gal**
871	362	15,769,000	30,644,880	703.5	229,239,621.8
868	107	4,660,920	2,874,960	66	21,506,194.29
867	25	1,089,000	566,280	13	4,236,068.571
866	1	43,560	0	0	0
To pump from 870-871′ to 867-868′				**418**	**136,126,005**

Table 7. Initial Pumping Rates

Unit of time	Pumping Rates		
	4000gpm	8000gpm	16000gpm
Minutes	342,032	17,016	8508
Hours	567	284	142
Days	24	12	6
Weeks	3.4	1.7	0.8

Table 8. Maintenance Pumping Rates

Unit of time	Pumping Rates		
	4000gpm	8000gpm	16000gpm
Minutes	217,913	108,957	54,478
Hours	3,632	1,816	908
Days	151	76	38
Weeks	22	11	5

Table 9. Statement of Probably Construction Cost

Statement of Probable Construction Cost				
Project: Beaver Dam Lake - Rakes Bay Drawdown				
Project Element	Quantity	Unit	Unit Rate	Cost
Construction Elements				
Mobilization	1	ls	10,000	$10,000
Initial Pumping	4	wk	15000.00	$60,000
Maintenance Pumping	20	wk	15000.00	$300,000
Crushed Stone Berm Construction	400	tons	34.00	$13,600
Berm Removal	400	tons	25.00	$10,000
Grading of Drainage Ditches	1	ls		$20,000
Subtotal, Construction Elements				$413,600
Site investigation and survey				$5,000
Permitting				$12,000
Engineering design services				$15,000
Construction time services				$7,000
Subtotal, engineering services				$39,000
Estimating Contingency	15%			$25,000
TOTAL PROBABLE CONSTRUCTION COSTS				$452,600

5.7. Pending Evaluations

EOR is currently using the PC-SWMM model and groundwater equations (e.g., Darcy's Law) to identify any hydrologic/hydraulic and logistics issues associated with a temporary drawdown of Rakes Bay. The ultimate goal of this evaluation is to proactively identify any plausible issues associated with a future draw down of Rakes Bay. EOR is also evaluating potential options to protect the drawdown project in the future. Potential options include a cofferdam, fish barriers (fixed or electric), or a v-notched weir with stop logs that would allow for future drawdowns. Results from flow and stage monitoring data conducted in 2018 suggest a weir may not be possible, because Beaver Dam Lake sometimes reverse flows into Rakes Bay (Appendix A).

APPENDIX A. 2018 MONITORING

Montgomery Associates
Resource Solutions, LLC

MEMORANDUM

To: Bill Foley, Beaver Dam Lake Improvement Association

From: Rob Montgomery, Gabe Montgomery

Date: December 30, 2018

Re: 2018 monitoring at Rakes Bay entrance

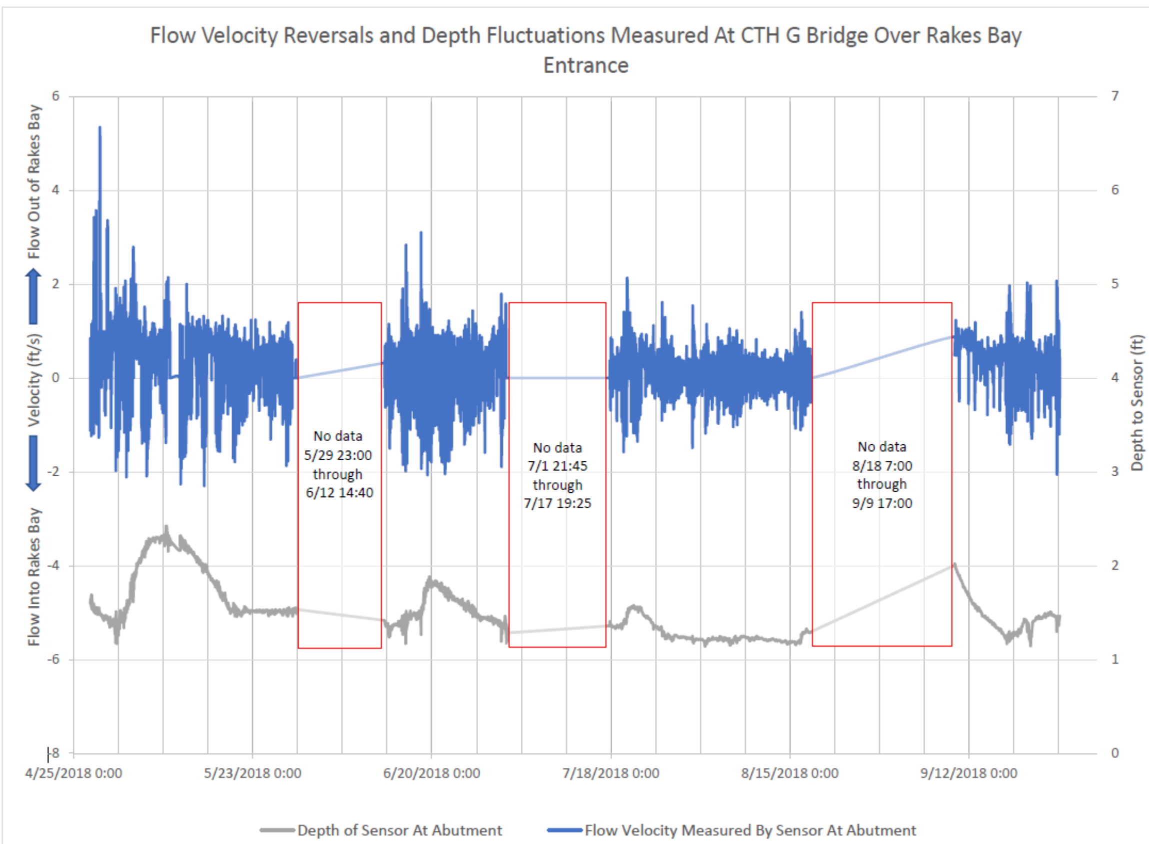
WATER LEVEL AND VELOCITY MONITORING AT THE ENTRANCE TO RAKES BAY

As part of the DNR Lake Planning Grant work for 2018, we installed velocity and water level sensors at the CTH G bridge at the entrance to Rakes Bay. BDLIA had obtained permission from the County highway department to install this equipment.

We installed 2 ISCO 2150 velocity/depth sensors and data logging modules, housed in a waterproof cabinet attached to the southeast abutment retaining wall of the bridge. One velocity/depth sensor was mounted on the east abutment retaining wall underneath the bridge, and the other sensor was mounted in approximately mid-channel. Duplicate sensors were installed to provide redundancy in collected data. Data was collected beginning on April 27, 2018 and data collection ended on September 26, 2018. Data was downloaded periodically from the data logging modules. Several time periods of lost data due to data logger cable problems were encountered, but data was collected during most of the boating season, including times of high and average water levels. The collected water level data at rakes Bay correlated well with the Beaver Dam Lake water level data collected by the City of Beaver Dam. A summary of the elevation and velocity data collected for the most reliable sensor, that mounted on the abutment side wall, as shown in the figure below.

Velocity elevation sensor mounting on the CTH G southeast abutment wall. The data loggers were installed in the locking cabinet. The flexible piping contains the cables for the sensors located beneath the bridge.

The velocity data indicated frequent and substantial fluctuation of velocities into and out of Rakes Bay, confirming visual observations. The observed maximum flow into the bay was slightly greater than 2 ft./s. In contrast the maximum velocity of flow out of Rakes Bay approached 6 ft./s. The variation of velocities was rapid (many times per day, typically) and was not correlated with the presence of generally high or generally low water levels on Beaver Dam Lake which occurred typically over days. Rather, the velocities appear to be driven by much more frequent (hourly) variations in water levels in Beaver Dam Lake adjacent to the rakes Bay entrance.



The correlation between lake water level and the velocity of flow into and out of Rakes Bay is illustrated in the several figures below, which show fluctuations over approximately one-day timeframe. Observations are:

- Velocities reverse and change magnitude over an interval of minutes, in most cases related to small fluctuations (less than 0.1 feet) in Beaver Dam Lake. When water levels increase, flow enters rakes Bay, and when it drops, water leaves the bay.

119 South Main Street • Cottage Grove, WI 53527 ph 608.839.4422 fx 608.839.3322 • www.ma-rs.org

Montgomery Associates
Resource Solutions, LLC

- During times of substantial net flow into Rakes Bay, the flow and velocity fluctuations illustrated are superimposed on net outflow from the bay – as shown on the upper figure on the next page.

- During times of no inflow, the velocity fluctuations often result in reversals, where flow periodically enters the bay and later discharges from the bay, often fluctuating in this way many times per day.

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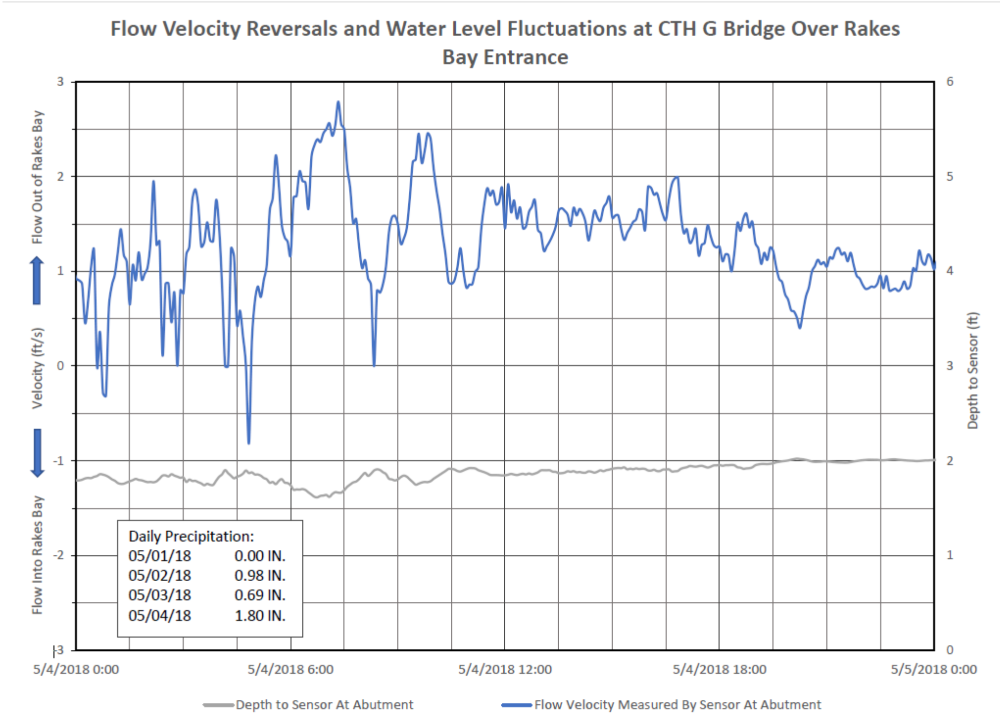
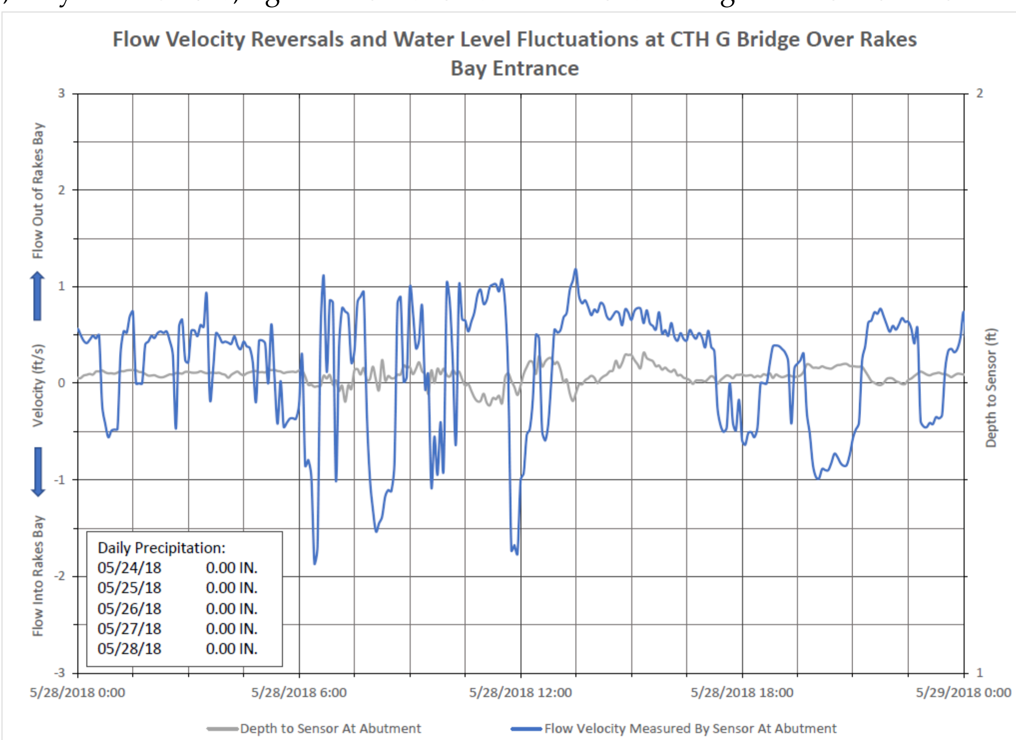


Figure above shows velocities and water level fluctuations for a time of substantial runoff into rakes Bay, May 4 and 5 2018; figure below shows fluctuations during a time of no runoff inflow.



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