2018 Yahara Chain of Lakes Flooding

Technical Work Group Report

Photo of flooding in Tenney Park with Lake Mendota in the background. Courtesy of Rick Lange (Dane County Sheriff Office) performing drone footage of flooding in August 2018.

February 1, 2019

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1.0 Executive Summary

In 2018, the Yahara Lakes experienced widespread flooding resulting in millions of dollars of damage (Dane County Emergency Management, 2018). Flooding in the Yahara Lakes prompted Resolution 2018 RES-227 by Dane County Board of Supervisors that requested convening a technical work group to evaluate and model various scenarios to improve resiliency for future events. This report provides findings from the technical work group.

The Yahara River chain of Lakes presents challenges to water level management for preventing flooding. For example, the Yahara River chain of lakes is quite flat which hinders efficient and timely delivery of water through the lakes. In this report, the Integrated Nowcast Forecast Operation System (INFOS) is used to evaluate the delivery of water and how utilizing alternative strategies would minimize lake flooding in 2018. INFOS incorporates a suite of integrated models that feature hydrologic process for runoff and hydraulic river flows and water levels. Modeling was conducted to evaluate aquatic plant cutting, adaptation strategies, and flood mitigation measures to minimize flooding. The adaptation scenarios were defined as those that involve efforts to limit our vulnerability to flooding through measures while not addressing any underlining issues. Mitigation, in contrast, is measures that address the underlying issues related to flooding. Below is a list of seven scenarios that were identified by the technical work group and evaluated. It should be noted that these scenarios may have impacts to fisheries, wetlands, recreation, navigation, social, and economics.

Adaptation
  (a) Lower Lake Mendota one foot
  (b) Safely Manage Lake Mendota at 100 year water level
  (c) Remove all dams from the Yahara Lakes
Mitigation
  (a) Bridge Modification
  (b) Yahara River Dredging
  (c) Flow Reroute and Pumping
  (d) Combined (b) and (c)

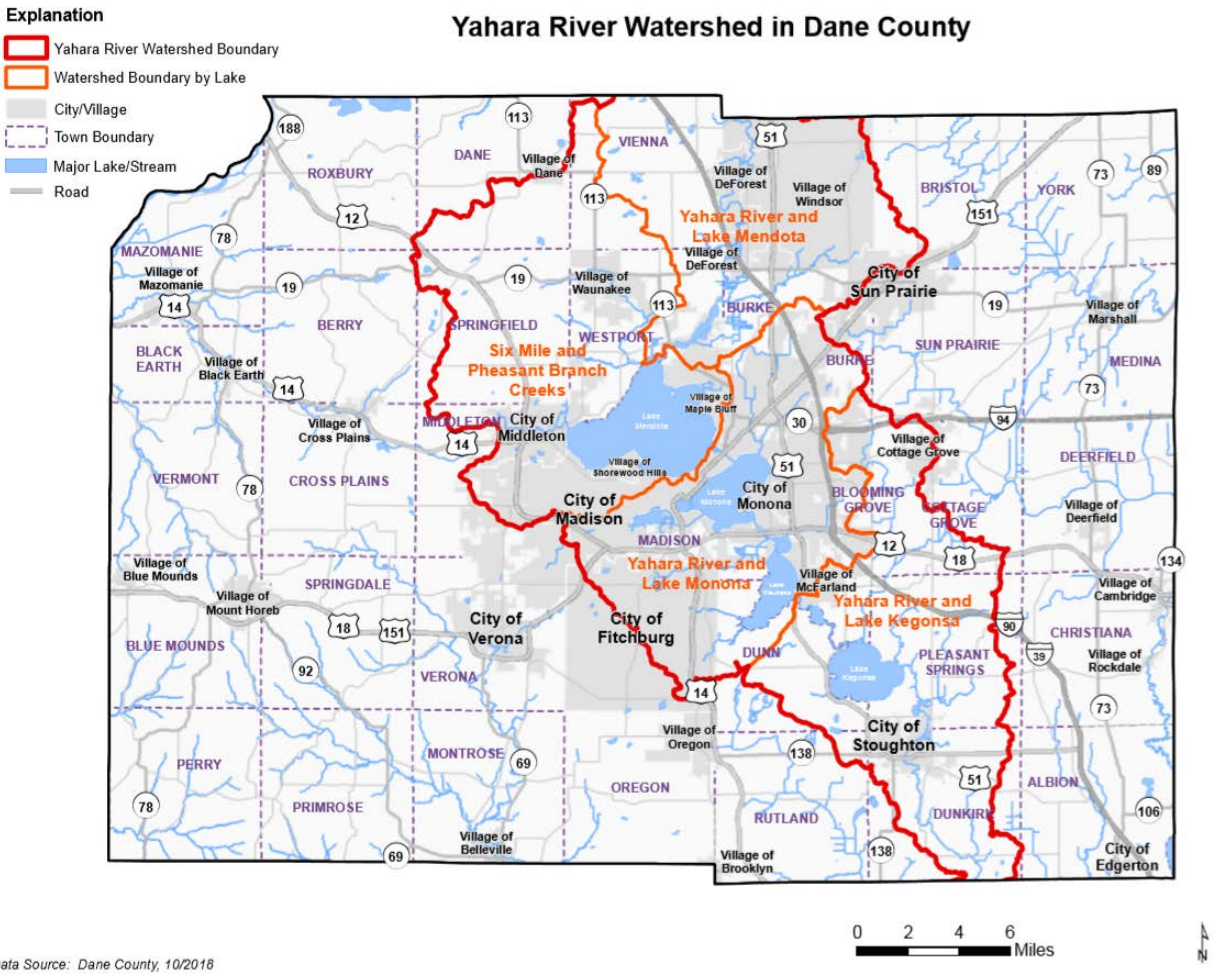
The final conclusions of the scenarios are as follows:

- The adaptation scenarios of lowering Lake Mendota provided little benefit to flooding (less than 2”). The flows through the lower lakes are limiting efficient release of water and are still prone to flooding.
- The adaptation scenario of safely managing Lake Mendota to 100 year levels increases Mendota 6” to provide relief to the lower lakes by decreasing Monona levels 6” but at the risk of using available capacity for storage from future rainfalls.
- The adaptation scenario of removing the dams increased flood levels on the lower lakes (approximately 2”).
- The mitigation scenario of bridge modification provided little benefit overall (approximately 2”) to flooding as most improvements are gained during low water conditions.
- The mitigation scenarios of dredging and pumping produced the best results for lowering flood levels (ranging from 7” to 21”) especially when used in combination.

This report will be used by a lake levels task force that will review findings and make policy recommendations.

2.0 Introduction

The Yahara Watershed (Figure 1) covers approximately one-third of Dane County and consists of a river chain of lakes including Mendota, Monona, Waubesa, and Kegonsa.



Data Source: Dane County, 10/2018

Figure 1: Yahara River Watershed in Dane County

Flooding in the Yahara Lakes has commonly occurred in recent and past years. For example, a 1954 article written in the Wisconsin State Journal (see Appendix) describes flooding that occurred and the importance of remove obstructions to improve water flow. The top ten highest water levels recorded for Lake Mendota since 1916 from high to low occurred in years 2000, 2008, 2018, 1993, 1959, 2007, 2004, 1980, 1978, 1996. Similarly, the top 10 highest water levels for Lake Monona occurred in years 2018, 2008, 2000, 2013, 2007, 1929, 1996, 1937, 1993, 1950. Interestingly, while lakes Mendota and Monona experience different years of flooding, seven of the top flood levels occurred in the past 25 of 103 years of record data for both lakes. Furthermore, the annual discharge of water at the outlet of Babcock Dam on Lake Waubesa has been increasing since 1931 as shown in Figure 2 by the blue trend line. The annual volume of water discharged in 2018, depicted by the red outline dot in Figure 2, is 323,000 ac-ft/year which is more than double the 88 year average volume of 127,000 ac-ft/year. Flooding in the Yahara Lakes has become more frequent in recent years. These recent flooding events have resulted in millions of dollars of damage (Dane County Emergency Management, 2018).

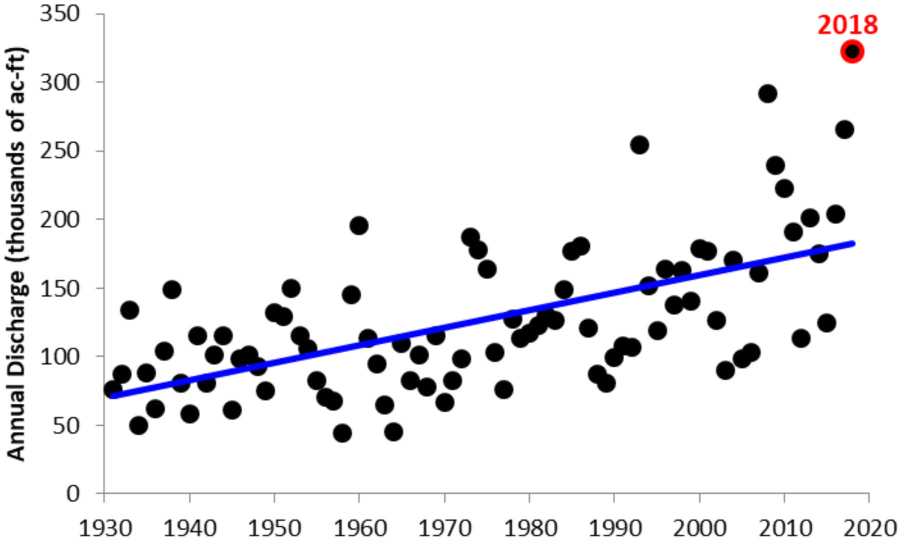


Figure 2: Annual discharge of flow at Babcock Dam at the Lake Waubesa outlet. The data has been adjusted to account for Madison Metropolitan Sewerage District effluent discharge to Nine Springs Creek (as an augmentation to river flows) subtracted out prior to effluent diversion to Badfish Creek in 1958.

In 2018, flooding in the Yahara Lakes prompted approval of Resolution 2018 RES-227 on October 8, 2018 by Dane County Board of Supervisors. The Resolution requested that a technical work group convene to evaluate lake level conditions, model various scenarios that include predicted climate changes, and to identify short-term and long-term approaches to improve resiliency for future events. The Resolution also called for the creation of a task force that will review findings of this report and make policy recommendations prior to March 31, 2019.

2.1 The Yahara Lakes and Flooding

The Yahara Lakes have summer minimum and maximum target lake level orders that were set by the Wisconsin Department of Natural Resources (DNR), per the request of the City of Madison and Dane County, in 1979 and can be found online at https://lwrd.countyofdane.com/Lake-Levels. The orders seek to balance competing interests, such as navigation, flood control, fisheries, and recreation. The water level orders do not specify how to achieve water levels through the operation of control structures (dams). Thus in 2010 the Dane County Lake Level Management Guide for the Yahara Chain of Lakes was developed in consultation with experts, approved by the Lake & Watershed Commission, and peer reviewed (Dane County Land and Water Resources, 2010). The management guide is intended to provide guidance for lake managers during all conditions with some attention on strategies to minimize flooding; however, the system remains susceptible to flooding due to increased stormwater runoff and limited flow capacity through the Yahara River.

The Yahara River enters Lake Mendota, links all four lakes, and exits the chain on the west shore of Lake Kegonsa (see Figure 3). The direct drainage of the watershed size into Lake Mendota, Monona, Waubesa, and Kegonsa is approximately 139,000 acres, 26,000 acres, 28,000 acres, and 35,000 acres, respectively. Lake levels on Mendota are controlled by Tenney Dam. The Tenney Dam consists of two tainter gates and one lock chamber. Water is released from Tenney Dam (Lake Mendota) into Lake Monona. Lake Monona is surrounded by an urban dominated watershed. After Lake Monona, water travels through an uncontrolled natural channel to Upper Mud Lake consisting of a large wetland complex discharging to Lake Waubesa. The outlet of Lake Waubesa is at Babcock Dam. Babcock lock and dam consists of two remote controlled sluice gates, two stoplog weirs, and one lock chamber. The Babcock Dam, on Lake Waubesa releases water through the Lower Mud Lake river-wetland corridor. Several features within the Lower Mud Lake River corridor exist including a historic Native American fish weir and sunken corduroy bridge. The last lake in the chain is Lake Kegonsa which is controlled by the LaFollette Dam. The dam consisting of one remote controlled sluice gate, two stoplog weirs, and one lock chamber.

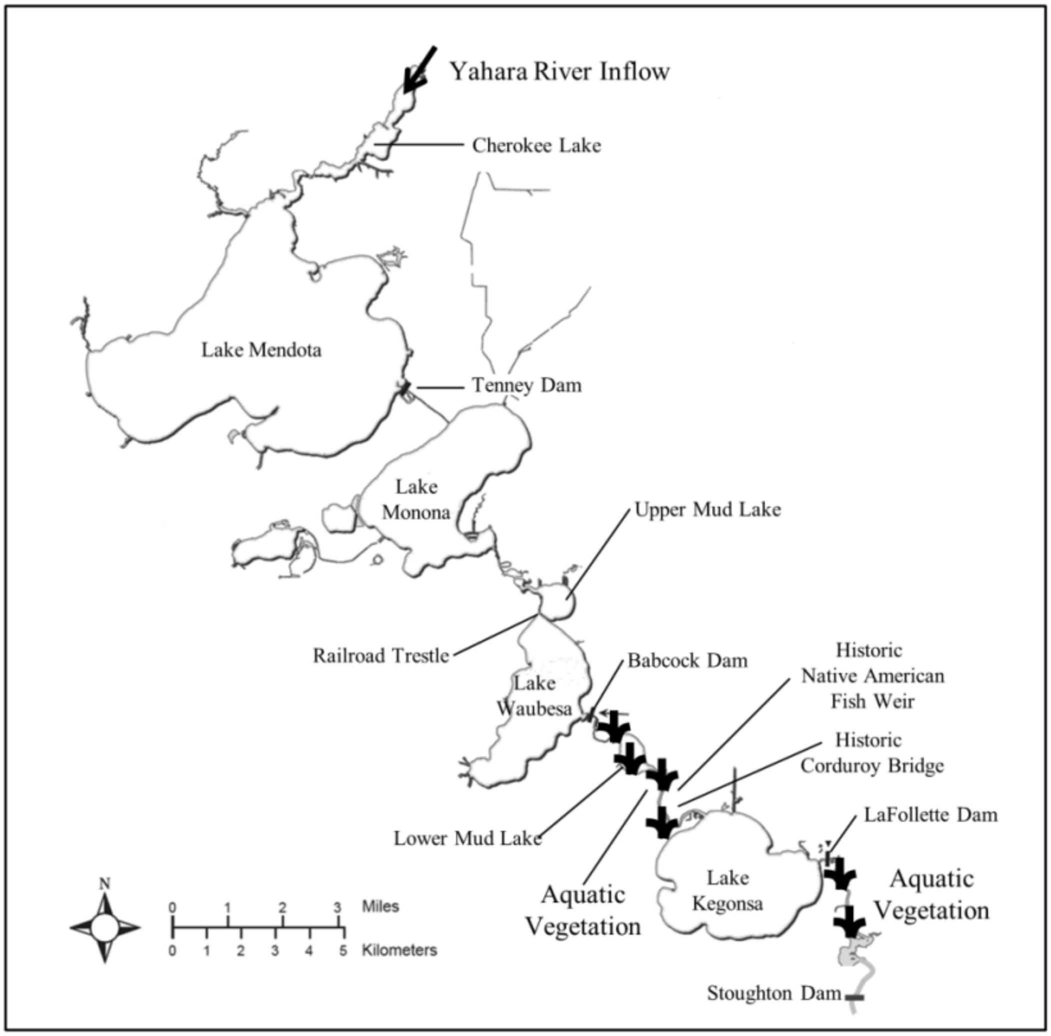


Figure 3: Yahara Lakes System

Delivery of water through the chain of lakes is impacted by several flow limitations in the rivers. Under normal conditions, the change in water levels between Lake Monona and Waubesa is 0.4 feet over 2 miles (0.004% slope). In comparison, between Lakes Waubesa and Kegonsa there is a drop of 1.5 feet over 4 miles (0.007% slope). In general, a steeper river can deliver more flow than a flat river. Other flow limitations also exist. Examples include narrow bridges and sediment deposits. Debris in the river, such as tree trunks and boulders, causes friction and slows water flow. Aquatic plants also cause friction and reduce water flow. The location and volume of aquatic plant growth is highly variable from year to year and is continuously evaluated throughout the growing season. Every year aquatic plants are harvested in the Yahara River between Lake Waubesa and Lake Kegonsa. During the 2018 flooding, Dane County performed cutting of aquatic plants between Lake Waubesa and Kegonsa and obtained an emergency permit from DNR to harvest additional aquatic vegetation in the Yahara River south of Lake Kegonsa to minimize flooding increasing flow from approximately 400 to 900 cfs.

Other factors that contribute to flooding include increases in runoff volumes due to urbanization, enhanced drainage of agricultural lands, wetland loss, and increases in the amount and intensity of rainfall. The extent of urbanization in the watershed plays an important role in the amount of water the lake receives. Urbanization greatly increases the amount of impervious surface such as roads, parking lots, and rooftops, greatly reducing the amount of water that infiltrates into the ground and hence increasing surface water runoff. Since 1970, the area of urbanized land has about doubled from 41,000 acres to 71,000 acres (Figure 4). Furthermore, over 50% of the wetlands that once existed in the Dane County portion of the Yahara Watershed have been drained (Lathrop et al., 1992), increasing the amount of runoff into the lakes. Much of the wetland loss occurred in areas that did not naturally drain into the lakes. In those areas, rainfall and snowmelt either evaporated or infiltrated to groundwater. Finally, extreme rainfall events are increasing nationally, especially over the last three to five decades. According to the Wisconsin Initiative on Climate Change Impacts, the average annual precipitation in Dane County has increased by approximately five percent since 1950 (WICCI, 2011). All of these factors contribute to increased runoff into the Yahara.

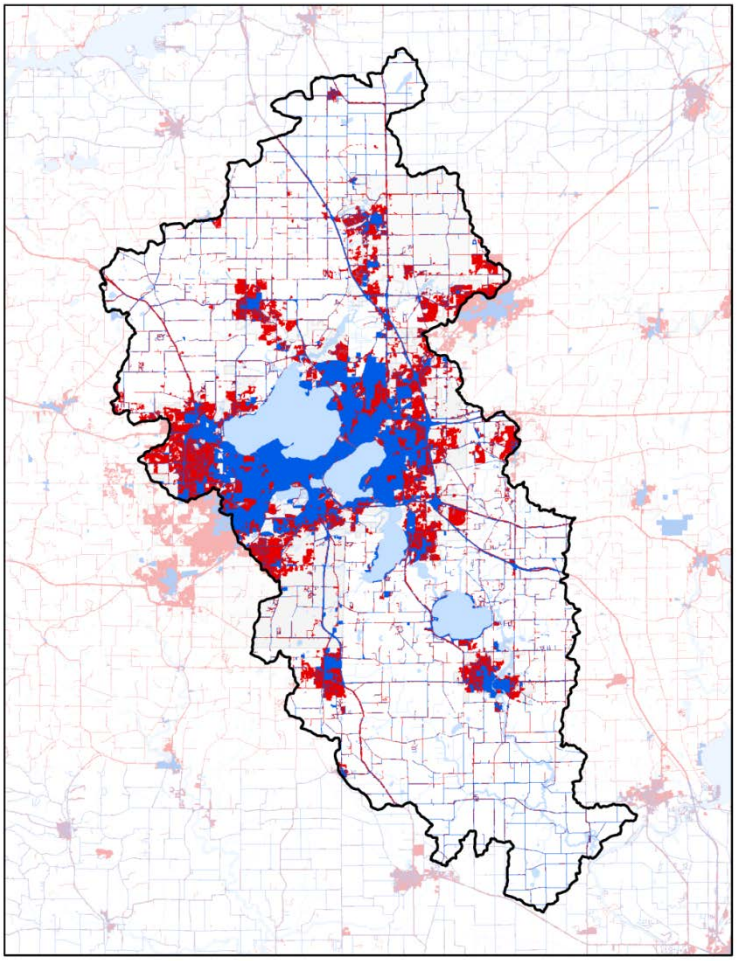


Figure 4: Urban Area in 2017 (red) compared to 1970 (blue)

2.2 2018 Water Levels and Management

In 2018, large flooding occurred and below describes the time history of water levels and management that occurred. Figure 5 below shows the lake levels in 2018 and their corresponding water levels above summer minimum. Starting March 1st, the DNR water level orders require lakes be at summer minimum targets following the first runoff event. Usually with average spring melt and low lake levels, the dam gates are closed to limit flow and raise water levels. In 2018, closing the lower dams at Babcock (Lake Waubesa) and Lafollette (Lake Kegonsa) was not necessary to raise water levels. Instead, the required increase of water levels occurred due to snow melt and rainfall runoff. For the remainder of 2018, the lower dams were completely open in full flow condition and have been since August of 2016.

In May, the Dane County Regional Airport (located in the Yahara River Watershed) received the second highest amount of rainfall on record (for the month of May). Despite all four lakes being at the summer minimum level at the beginning of the month, all four lakes rose above their summer maximum target. In mid-May, Lakes Mendota, Monona, Waubesa, Kegonsa were 0.73, 1.09, 0.83, and 0.61 feet above summer maximum. Flow from Lake Mendota was reduced in an effort to balance lake levels.

In June, flow from Mendota was reduced to approximately 50% of the flow in May to limit rising lake levels on the lower lakes. In early June, the water levels for Mendota, Monona, Waubesa, and Kegonsa were 3.2, 8.3, 7.6, and 12.0 inches above summer maxima. Due to high lake levels on Lake Kegonsa, Dane County Lake Management navigated the river from Lafollette Dam to Stoughton Dam to identify flow restriction areas such as aquatic plant growth, fallen trees, or blockages in the river. Abundant aquatic plant growth was discovered in several areas. An emergency aquatic harvesting permit was received from DNR to remove plants in the river from Lafollette to Stoughton Dams. In June, 330 and 199 loads of aquatic plants were removed in the Yahara River from Waubesa to Kegonsa and Kegonsa to Stoughton, respectively. Also, bottom depth measurements were conducted to identify areas of sediment accumulation. The measurements revealed that the water depth at a railroad trestle in Stoughton was approximately 3 feet deep while downstream water depths were 6 feet (a potential choking condition). In late June, thirty one dump truck loads of rock and debris were removed to increase the water depth by removing approximately 3 to 5 feet of sediment. Despite efforts to limit inflow from Lake Mendota and increase outflow from the lower lakes, water levels on Lake Kegonsa reached a record high of 845.74 on June 22.

In July, overall water levels declined, but remained 6 to 18 inches above summer maximum targets. The drop in water levels limited aquatic plant harvesting due to shallow depths and appropriate draft needed for operation of the harvesters, especially downstream of Lake Kegonsa. The harvesters cannot efficiently operate at water depths less than approximately 2 feet. As a result, the harvesters are not able to perform bank to bank cutting and are confined to a narrow area concentrated near the thalweg, otherwise known as the deepest part of the river. In July aquatic plant harvesting continued to the extent possible. In July, 40 and 4 loads of aquatic plants were removed in the Yahara River from Waubesa to Kegonsa and Kegonsa to Stoughton, respectively.

In August, the Yahara watershed received higher than average amounts of rain causing saturated conditions. Specifically, an intense rain event on August 20-21 occurred with parts of the watershed receiving over 10 inches of rainfall in less than 12 hours. Water levels in the lakes and subsequently in the Yahara River increased to support deployment of additional aquatic plant harvesters. In August, 211 and 113 loads of aquatic plants were removed in the Yahara River from Waubesa to Kegonsa and Kegonsa to Stoughton, respectively.

In September, additional rainfall occurred leading to new record water levels for Lakes Monona and Waubesa of 848.52 and 847.86, respectively. In September, 84 and 10 loads of aquatic plants were removed in the Yahara River from Waubesa to Kegonsa and Kegonsa to Stoughton, respectively. Near the end of September reduced biomass of aquatic plants were witnessed due to natural senescence.

For the calendar year of 2018, the Dane County Regional Airport received 50.47 inches of precipitation, 2.46 inches shy of the record annual rainfall amount (52.93 inches in 1881). However, other parts in Dane County received over 60 inches of rainfall. A summary of the record lake levels are presented in Table 1. The largest daily rainfall occurred August 20. The three lakes experienced record levels preceding this event. This exemplifies the fact that lake level flooding is not typically caused by single rain events but rather weekly or monthly rainfall (rainfall volume) which cause cumulative increases in water levels. Other flooding such as urban flooding is caused by flash flooding or an intense storm and not necessarily the cumulative rainfall volume. This report addresses lake level flooding; however, it is recognized that flash flooding was witnessed in 2018 and responsible for large damages across Dane County.

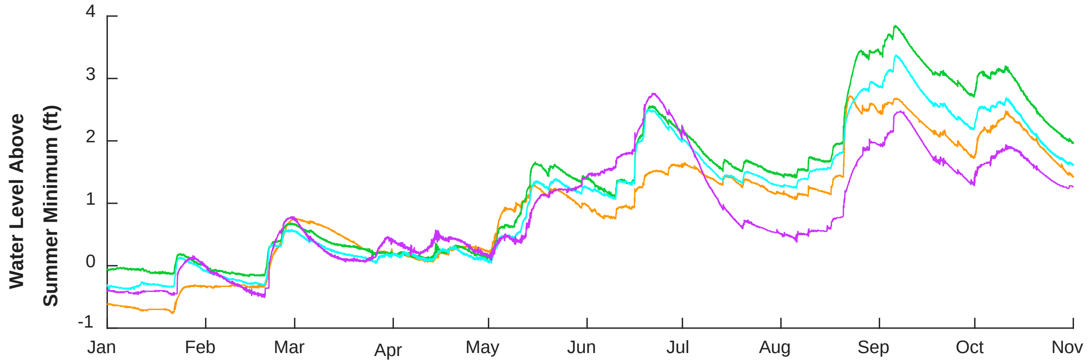


Figure 5: Water Levels above summer minimum for Lakes Mendota (orange), Monona (green), Waubesa (cyan), and Kegonsa (purple)

Table 1: Record Lake Levels and Dates

Lake Name	Date of New Record Water Level	New Record Water Level	Prior Record Water Level	Date of Prior Record Water Level
Mendota	2018 was 3rd Highest	N/A	852.74	06/06/2000
Monona	09/06/2018	848.52	847.86	06/16/2008
Waubesa	09/06/2018	847.86	847.22	06/17/2008
Kegonsa	06/22/2018	845.74	845.72	06/16/2008

3.0 Technical Approach

3.1 INFOS Framework

In this report, the Integrated Nowcast Forecast Operation System (INFOS) to evaluate how alternative strategies for managing the lakes would have performed in 2018. INFOS incorporates a suite of integrated models that feature hydrologic process for runoff and hydraulic river flows and water levels (Figure 6). The hydrologic model is used to predict runoff discharge from tributaries into the Yahara Lakes. Output results from the hydrologic model serve to provide water inputs to the hydraulic model. Specifically, hydraulic modeling is performed to determine flood inundation extents, lake water levels, and flow discharges in the river and has been successfully utilized for modeling the Yahara Lakes (Reimer and Wu, 2016). Further details on the modeling are provided in the appendix.

Model simulations are executed using a high performance computing (HPC) server. The modeling server is equipped with parallel computing to provide timely results. In the modeling configuration, the time ratio of run time to modeled time is 1:72. In other words, to simulate the 2018 year requires about 4 days of computing.

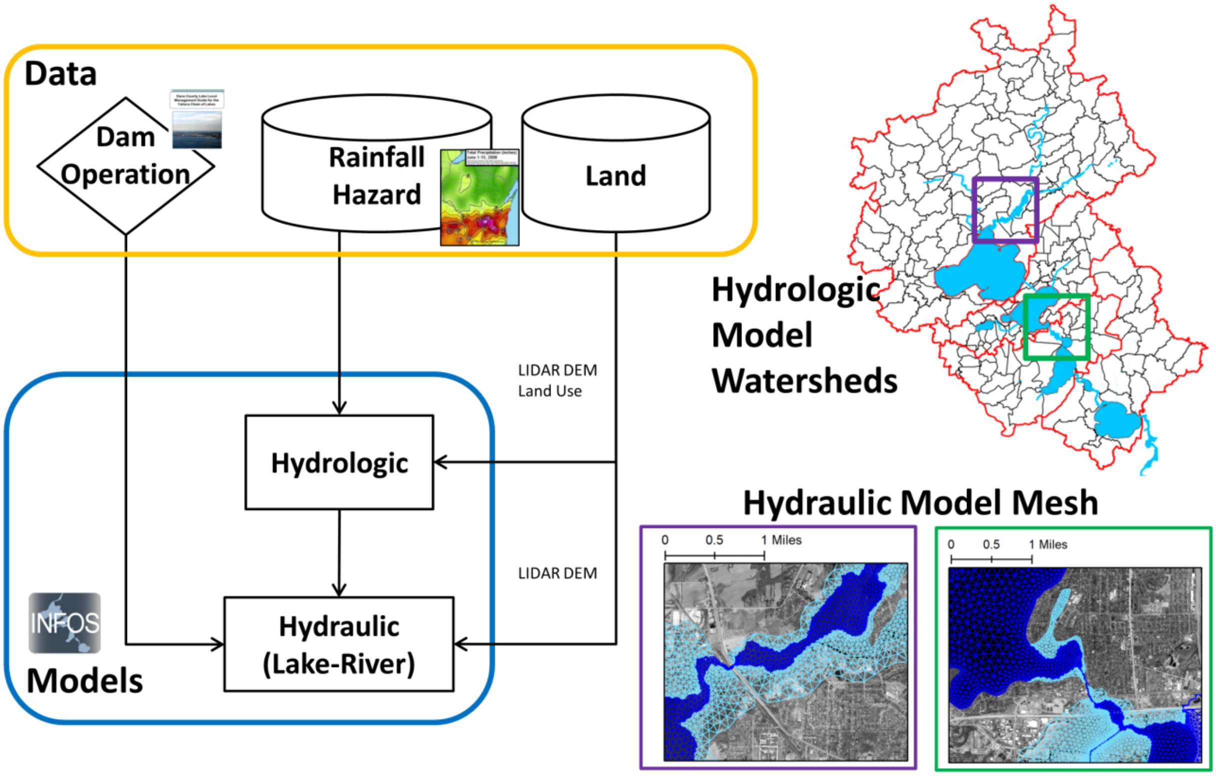


Figure 6: Modeling Framework

Given the time available to produce this report, the consensus from the workgroup was to use INFOS with the 2018 rainfall to explore and evaluate the efficacy of various scenarios for better managing the lakes during flood years. The 2018 rainfall was selected because it produced record setting water levels, and abundant data was readily available. The 2018 year is simulated from January to November and accounts for flood periods in late June and early September.

3.2 INFOS Model Performance

Model performance was evaluated using standard statistical techniques. Three statistics were used including root mean square error, Nash-Sutcliffe efficiency, and bias.

The Root Mean Square Error (RMSE) statistic is one of the commonly used error index statistics. The lower the RMSE than it means the better the model performance. It has the same units as the variable being predicted. An RMSE of zero results if the model perfectly predicts the observed values.

The Nash-Sutcliffe efficiency (NSE) statistic determines the relative magnitude of the residual variance (“noise”) compared to the measured data variance (“information”). NSE indicates how well a plot of simulated results versus observed measurements fits a 1:1 line. NSE ranges between $-\infty$ and 1.0 (1 inclusive), with NSE = 1 being the optimal value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance, whereas values <0.0 indicates unacceptable performance.

The bias statistic measures the average tendency of the simulated data to be larger or smaller than their observed counterparts. The optimal value of bias is 0.0, with low-magnitude values indicating accurate model simulation. Positive values indicate model underestimation bias, and negative values indicate model overestimation bias.

3.2.1 Comparison between Modeled and Observed Lake Levels

Statistics of modeling results for lake levels are presented in Table 2. The statistics indicate a very good fit with observed data. Also, the time-series of water levels comparing simulated results (blue line) and observed measurements (black circles) are shown in Figure 7. Overall, the simulated results respond appropriately to the rise and fall of observed lake levels.

Table 2: Lake level statistics

Lake	RMSE (feet)	NSE	BIAS (feet)
Mendota	0.06	0.99	-0.01
Monona	0.10	0.99	0.03
Waubesa	0.11	0.99	0.01
Kegonsa	0.13	0.98	-0.01

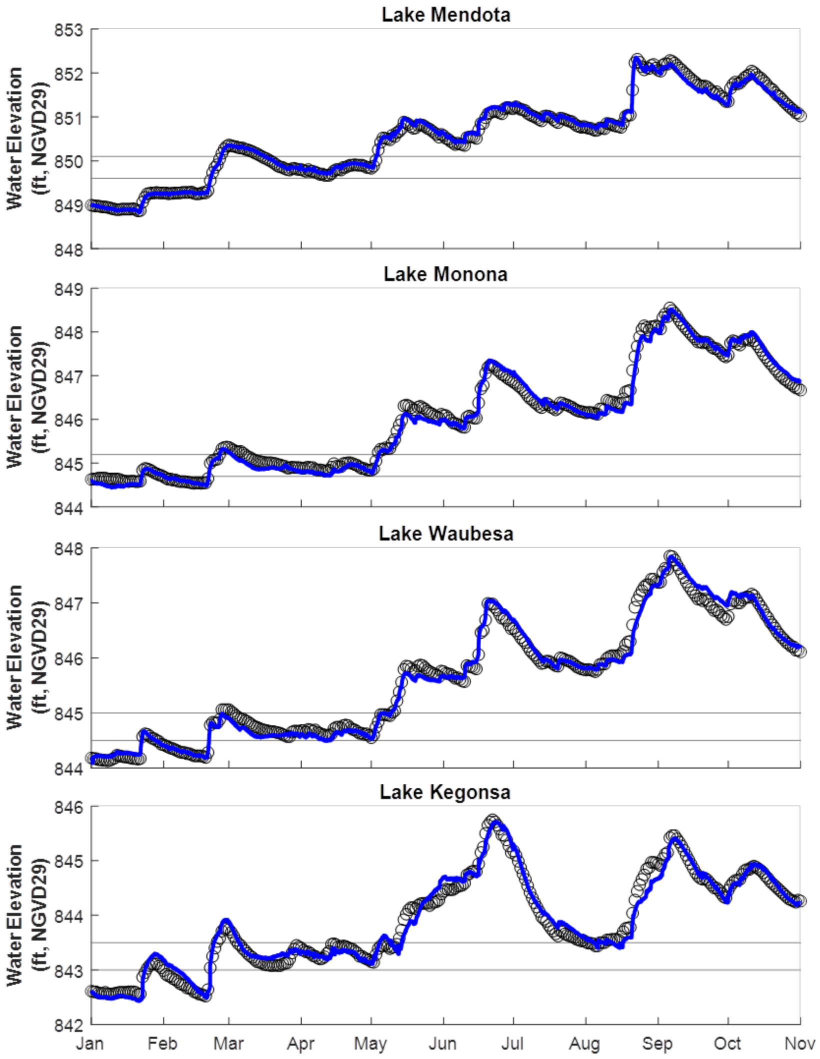


Figure 7: Water levels showing simulated results (blue line) and observed measurements (black circles)

3.2.2 Comparison between Modeled and Observed River Water Surface Profiles

Measurements of the Yahara water surface profile were conducted utilizing Real-time kinematic (RTK) GPS measurements. Measurements were performed during and after high water periods. Statistics of comparison of modeling results and observed measurement are presented in Table 4. The statistics indicate a very good fit with observed data. Also, the time-series of water levels comparing simulated results (blue line) and observed measurements (black circles) are shown in Figure 8 through 11 separated by different sections of the Yahara River.

Table 3: Yahara River water surface profile statistics

River Location	RMSE (feet)	NSE	BIAS (feet)
Mendota to Monona	0.06	0.99	-0.01
Monona to Waubesa	0.02	0.99	0.01
Waubesa to Kegonsa	0.07	0.99	0.04
Kegonsa to Stoughton	0.15	0.98	-0.10

The Yahara River water surface profile measurements between Lake Mendota and Lake Monona were performed by the City of Madison Engineering. Several days of measurements were performed by the City and Figure 8 shows the modeling and measurements of one day of measurement on August 24, 2018. The yellow dots in the aerial photo represent the measurement location while the corresponding water level is shown in the profile plot below. The red arrows indicate locations for reference. On August 24th, the water drop from Tenney Dam to Lake Monona is approximately 22 inches with an average slope of 0.033%. On August 24th, Tenney dam released approximately 730 cfs flow which is large compared to the 15 year average of 110 cfs. The large release rate in combination with high lake levels is attributed to causing water to back up through storm sewers connected with the Yahara River into streets and other area. The brown line represents the river bottom and a hump around Williamson Street is witnessed. In one of the mitigation scenarios for improving water levels, dredging is one possibility to remove the hump which could reduce water levels in the river. Overall, the model shows good agreement with the water surface profile during a peak flood time.

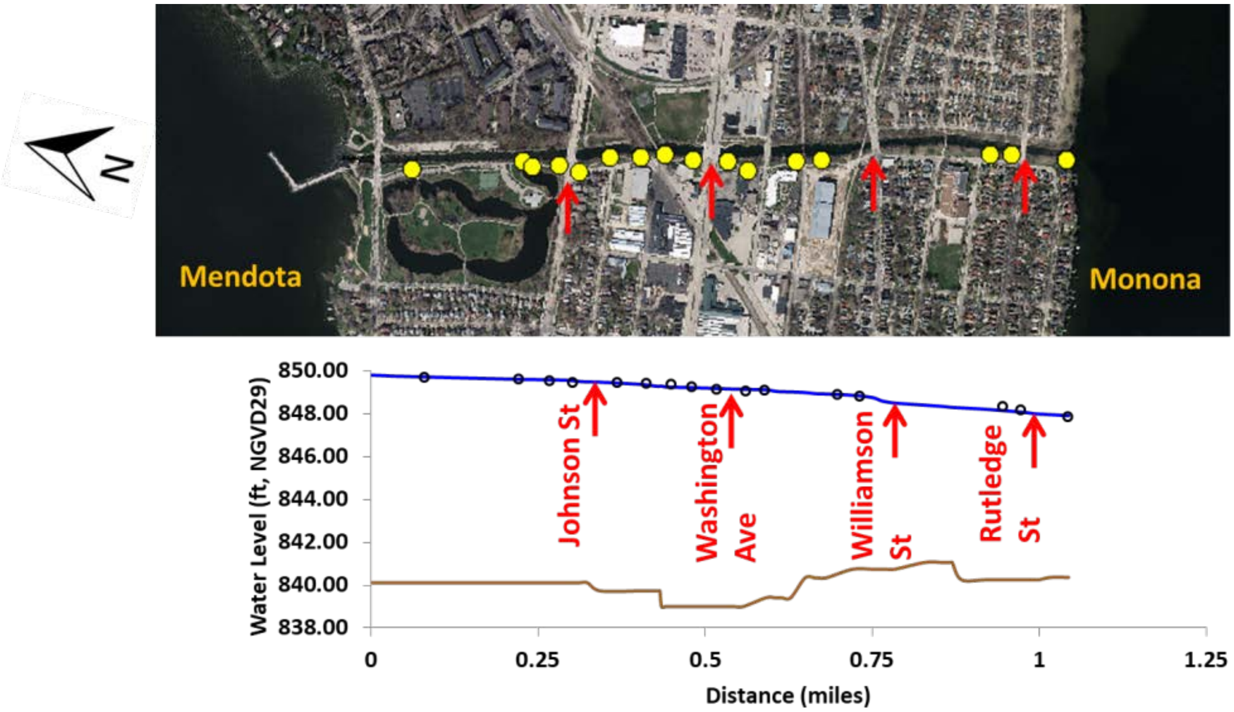


Figure 8: The Yahara River water surface profile between Lake Mendota and Lake Monona

he Yahara River water surface profile measurements between Lake Monona and Lake Waubesa were performed by Dane County Lake Management. In Figure, 9 modeling and measurements are compared for water levels on September 10, 2018. The yellow dots in the aerial photo represent the measurement location while the corresponding water level is shown in the profile plot below. The red arrows indicate locations for reference. On September 10th, the water drop from Lake Monona to Lake Waubesa is approximately 8 inches or an average slope of 0.006%. The water surface profile reveals most of the water level drop occurs in the narrow and shallow area at the Lake Monona outlet to approximately Broadway. It is witnessed that the bed slope of the river (brown line) is much flatter than the water surface slope. The water level drop in this area accounts for approximately 75% of the total drop over 25% of the length of connecting river. The model shows good agreement with the measured water surface profile data.

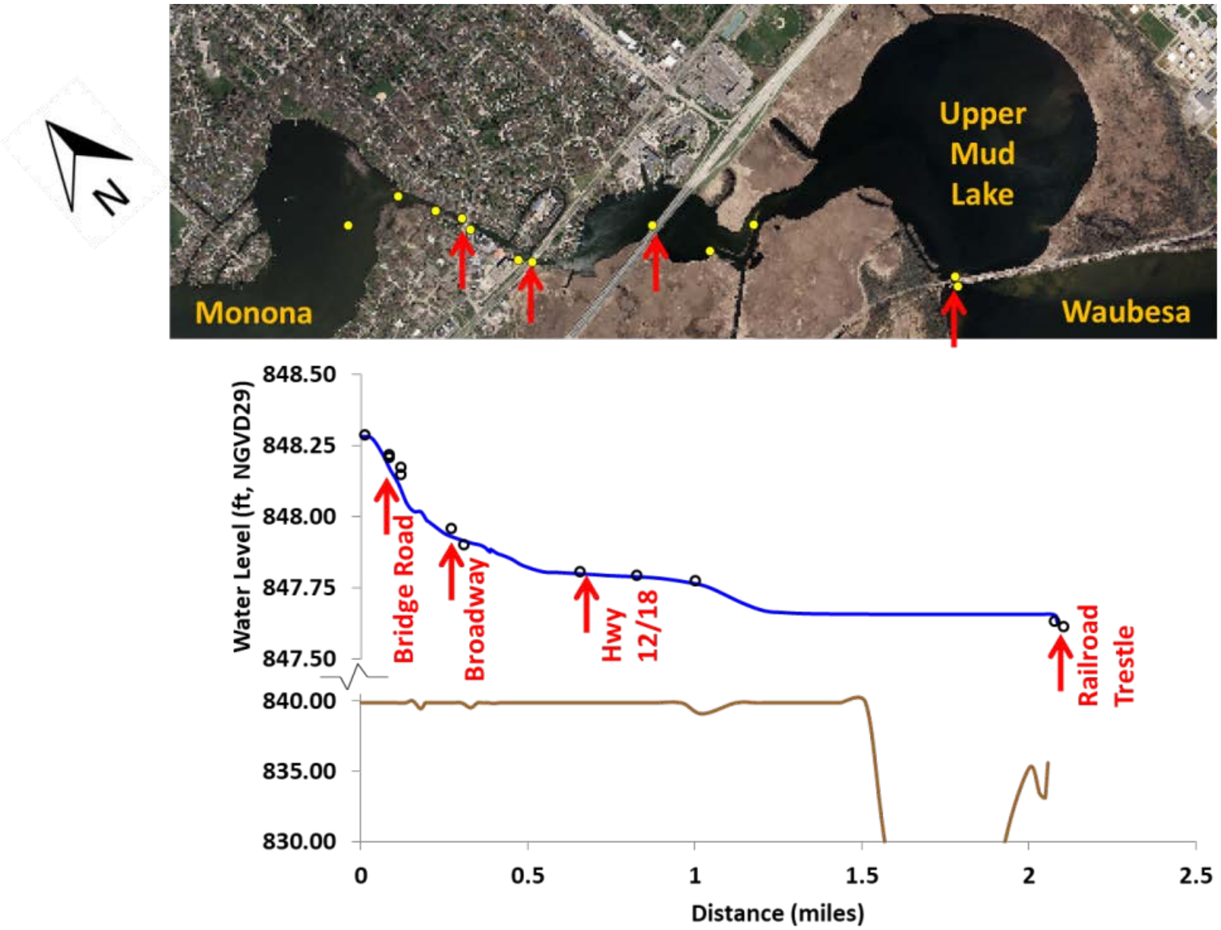


Figure 9: The Yahara River water surface profile between Lake Monona and Lake Waubesa

The Yahara River water surface profile measurements between Lake Waubesa and Lake Kegonsa were performed by Dane County Lake Management. In Figure, 10 modeling and measurements are compared for water levels on September 10, 2018. The yellow dots in the aerial photo represent the measurement location while the corresponding water level is shown in the profile plot below. The red arrows indicate locations for reference. On September 10th, the water drop from Lake Waubesa to Lake Kegonsa is approximately 26 inches or an average slope of 0.01%. Some notable features in water surface drop can be seen attributed to narrow and shall river geometries at Exchange Street and the Historic fish weir location. The brown line represents the river bottom showing irregularities in the bottom due to sediment accumulation and scour along the river. Also, it is witnessed that the bed slope of the river (brown line) is much flatter than the water surface slope. The model shows good agreement with the measured water surface profile data.

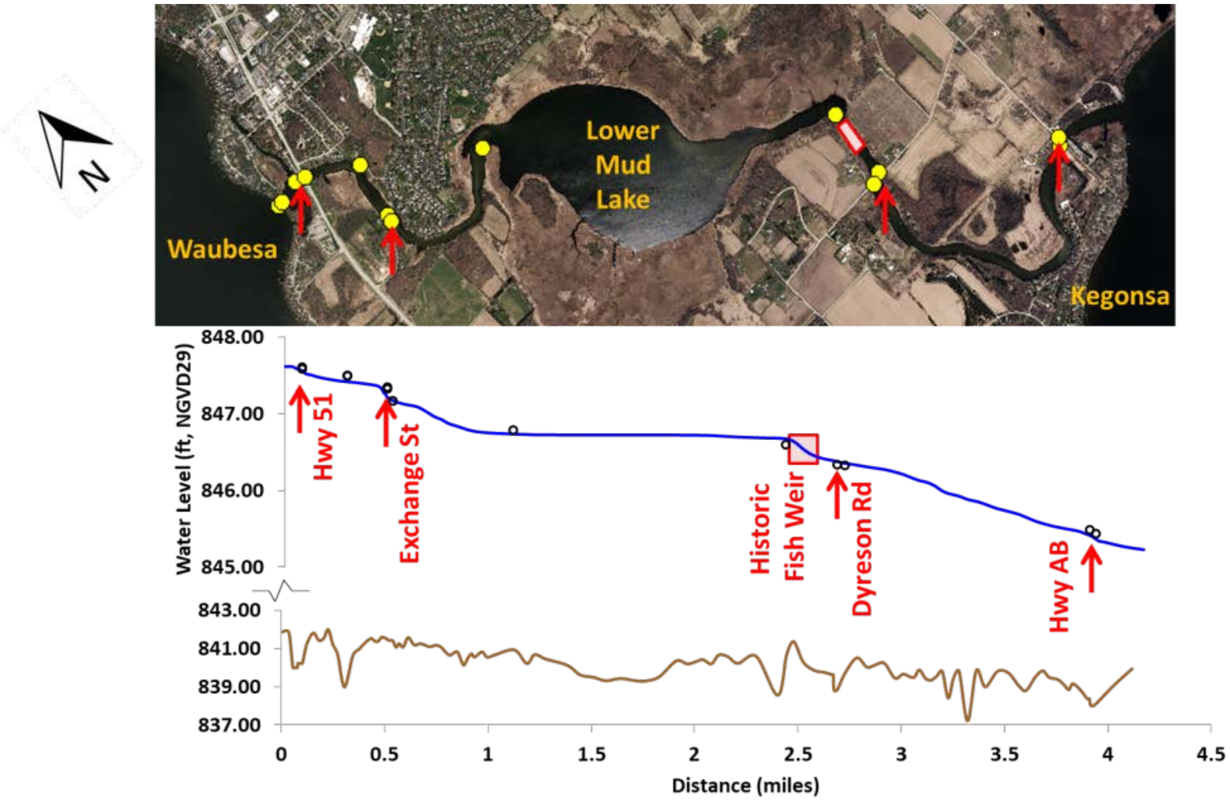


Figure 10: The Yahara River water surface profile between Lake Waubesa and Lake Kegonsa

The Yahara River water surface profile measurements between Lake Kegonsa and Stoughton dam were performed by Dane County Lake Management. In Figure, 11 modeling and measurements are compared for water levels on September 10, 2018. The yellow dots in the aerial photo represent the measurement location while the corresponding water level is shown in the profile plot below. The red arrows indicate locations for reference. On September 10th, the water drop from Lake Kegonsa to Stoughton dam is approximately 56 inches or an average slope of 0.018%. The brown line represents the river bottom showing irregularities in the bottom due to sediment accumulation and scour along the river. The model shows good agreement with the measured water surface profile data.

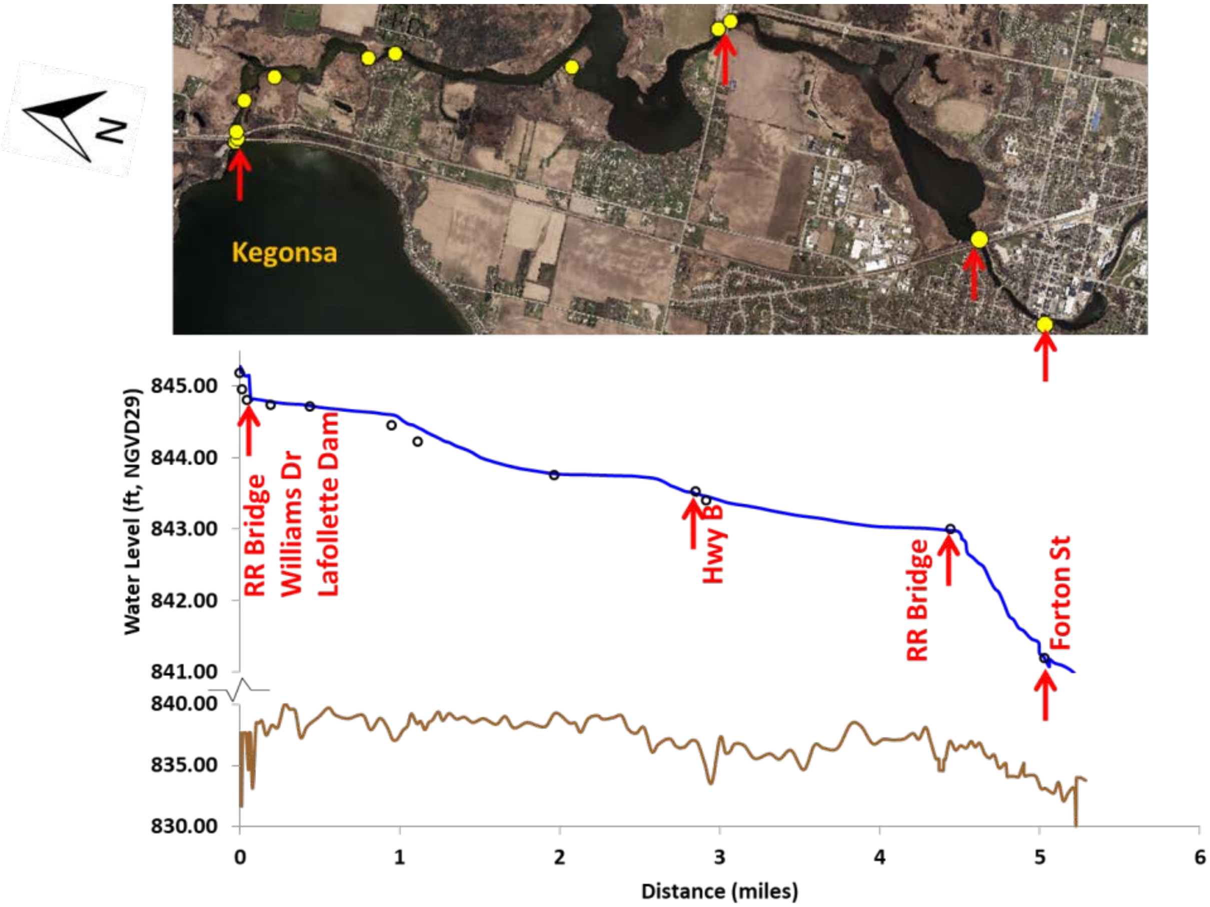


Figure 11: The Yahara River water surface profile between Lake Waubesa and Lake Kegonsa

3.2.3 Comparison between Modeled and Observed River Discharges

Statistics of modeling results for river discharge are presented in Table 4. The statistics indicate a very good fit with observed data. Also, the time-series of discharge comparing simulated results (blue line) and observed measurements (black circles) are shown in Figure 12. Overall, the simulated results respond appropriately to the increases and decrease of a wide range of discharges.

Table 4: River discharge statistics

Flow Location	RMSE (cfs)	NSE	BIAS (cfs)
Tenney Dam	24	0.83	0.66
Babcock Dam	23	0.93	0.42
Stoughton Dam	41	0.92	-0.99

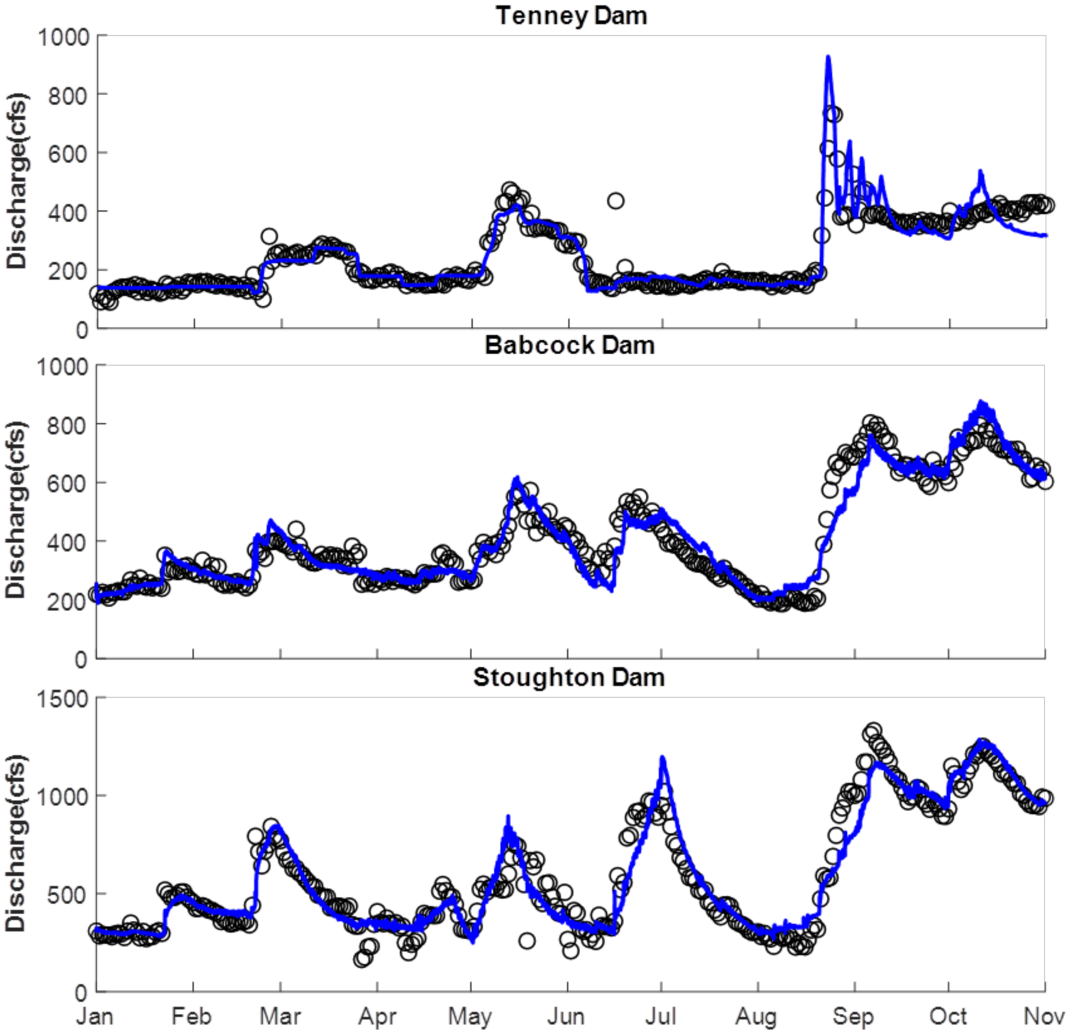


Figure 12: Discharge in the Yahara River showing simulated results (blue line) and observed measurements (black circles)

3.3 Scenarios

Since flood events are likely to continue, efforts to increase resilience to flooding are important to protect property and life. This requires implementing measures such as aquatic plant harvesting in the rivers to mitigate flooding. The removal of aquatic plants increases flow by reducing friction caused by the plants. In 2018, a total of 698 loads of aquatic plants were removed from the Yahara River. Modeling scenarios on aquatic plant removal and its role on flow and lake levels are discussed in the following section. Also, other adaptation strategies and flood mitigation measures are evaluated for reducing flooding in the Yahara Lakes. We define the adaptation scenarios as those that involve efforts to limit our vulnerability to flooding through measures while not addressing any underlining issues. Mitigation, in contrast, is addressing the underlying issues related to flooding. Below is a list of seven scenarios identified by the technical work group and their results are provided in the following sections:

Adaptation
  (a) Lower Lake Mendota one foot (flood storage or maintain lower)
  (b) Safely Manage Lake Mendota at 100 year water level
  (c) Remove all dams from the Yahara Lakes
Mitigation
  (a) Bridge Modifications
  (b) Yahara River Dredging
  (c) Flow Reroute and Pumping
  (d) Combined (b) and (c)

For all the scenario results presented in the following sections, two different plots are created. The first plot shows a time series of lake water levels comparing observed (blue) to the scenario (different color). The second plot shows a histogram for the number of days (y-axis) within the summer minimum/maximum range as donated by 0 and each six inch increment above or below the range (x-axis). For simplification, the summation of the daily water levels (in feet) above summer maximum is represented in the upper right hand corner of the histogram plot.

4.0 Results

4.1 Aquatic Plant Management

Aquatic plant removal is performed in accordance with harvesting permits issued by DNR. In collaboration with the DNR, Dane County Land and Water Resources Department developed harvesting priority maps and aquatic plant management plans. Dane County employs a plant scout to evaluate plant growth conditions and recommends appropriate harvesting, within the limits of the DNR permit. The most abundant plant removed in the Yahara River is *Vallisneria americana* (wild celery), a native plant. While removing wild celery is beneficial to increasing river flow, other research has documented the ecological importance it provides to aid in habitat for invertebrate communities and spawning for sport fish (Rogers et al., 1995). In 2018, aquatic plant harvesting in the Yahara River started the first week in June. Figure 13 provides the weekly history of harvesting loads removed in the Yahara River between Waubesa to Kegonsa (cyan bars) and Kegonsa to Stoughton (purple bars). Also, the lake water levels are shown comparing Lake Waubesa (cyan) and Lake Kegonsa (purple). In Figure 13, it can be seen that over 100 loads were removed between Lake Waubesa to Lake Kegonsa the third week of August, then two weeks later, Lake Waubesa water level peaked with harvest loads decreasing due to removal of abundant aquatic plants.

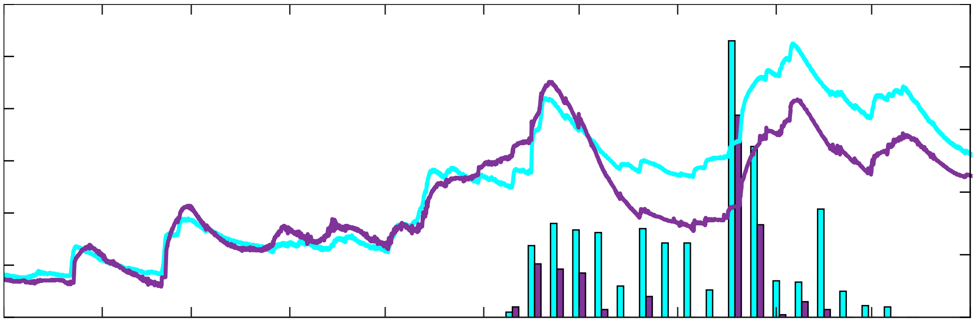


Figure 13: Aquatic plant harvesting loads removed in the Yahara River between Waubesa to Kegonsa (cyan bars) and Kegonsa to Stoughton (purple bars). Also, corresponding water levels above summer minimum are shown for Lake Waubesa (cyan) and Lake Kegonsa (purple).

To simulate aquatic plant growth and abundance in the model, a friction factor that is variable in time is used. Results of modeling revealed a maximum friction (n=0.14) occurred in mid-June for the river between Kegonsa and Stoughton. One modeling scenario was created which assumed the maximum friction factor remained during the entire summer and no further cutting is performed. A second scenario was created that assumed a minimum friction (n=0.06) which occurred in the month of April remained during the entire summer. It should be noted that this scenario is unattainable with mechanical harvesting. It may be possible to achieve this scenario using abundant chemical treatments to prevent aquatic plant growth; however, Dane County does not utilize chemical treatment of aquatic plants in the Yahara River. In Figure 14, these two scenarios of maximum friction (dark green), minimum friction (light green), and actual conditions (blue) are shown. The results show that a maximum friction factor would result in peak lake levels to increase 5”, 8”, and 11” for Lake Monona, Waubesa, and

Kegonsa, respectively. Alternatively, a minimum friction factor would result in peak lake levels to decrease 4”, 6”, and 4” for Lake Monona, Waubesa, and Kegonsa, respectively. While, there is improved benefits with reduced plants it should be noted that this scenario is unattainable.

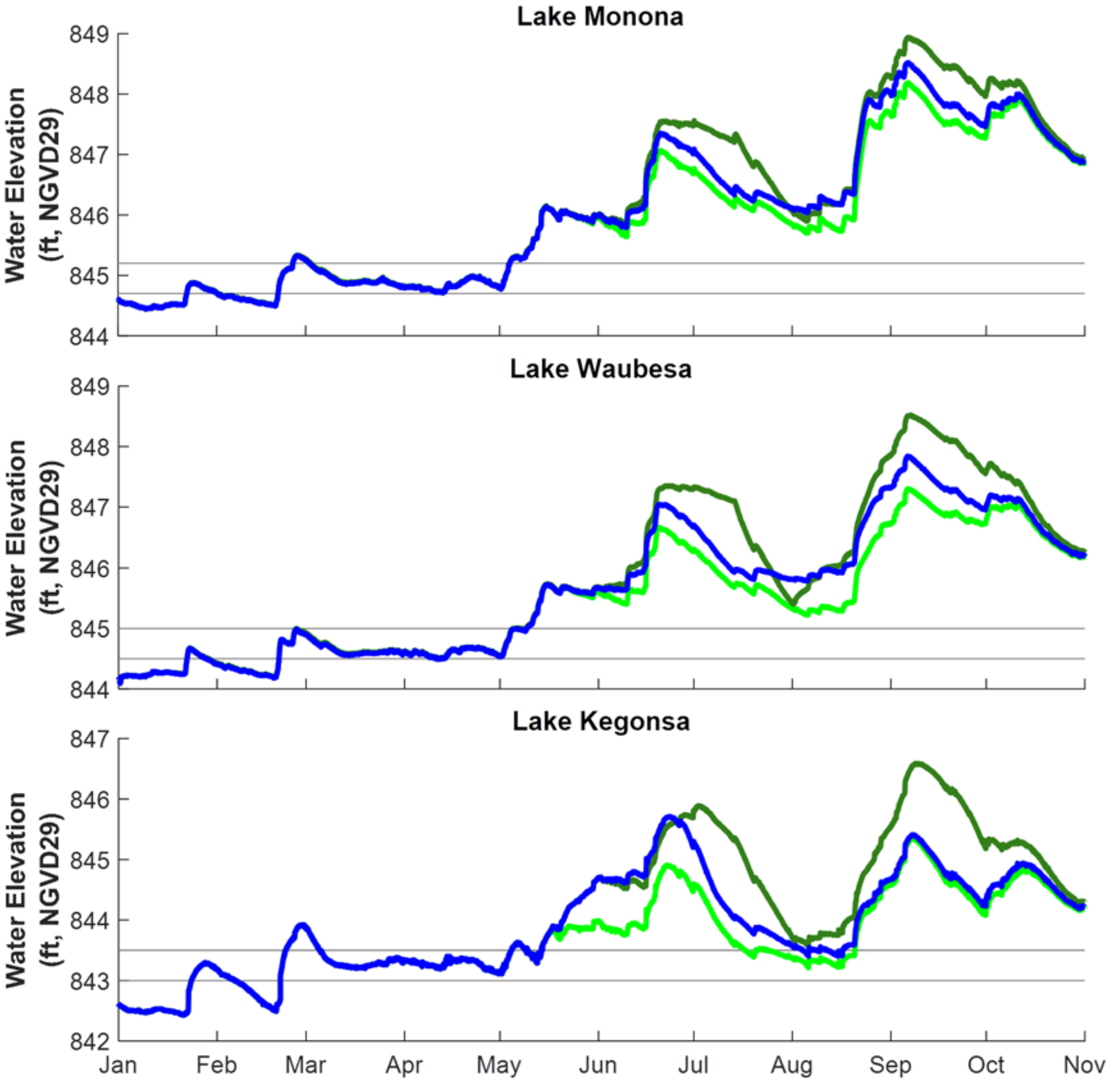
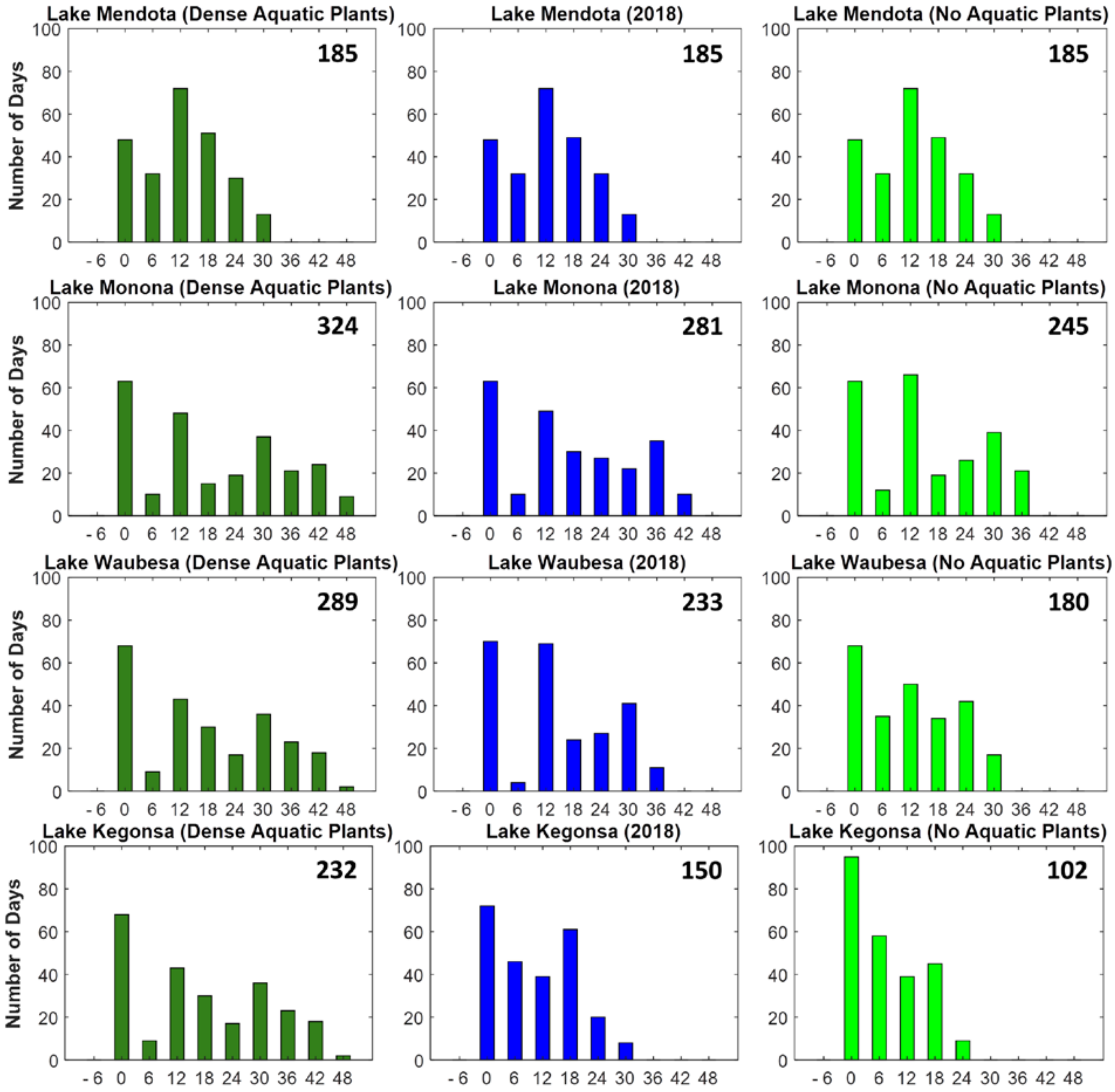


Figure 14: Aquatic plant management scenarios comparing dense aquatic plants (dark green), no aquatic plants (light green), and 2018 conditions (blue).



Lake Mendota (Dense Aquatic Plants)

Lake Mendota (2018)

Lake Mendota (No Aquatic Plants)

Lake Monona (Dense Aquatic Plants)

Lake Monona (2018)

Lake Monona (No Aquatic Plants)

Lake Waubesa (Dense Aquatic Plants)

Lake Waubesa (2018)

Lake Waubesa (No Aquatic Plants)

Lake Kegonsa (Dense Aquatic Plants)

Lake Kegonsa (2018)

Lake Kegonsa (No Aquatic Plants)

Figure 15: Number of days within water level ranges comparing dense aquatic plants on the left (dark green bars), 2018 in the center (blue bars), and no aquatic plants on right (light green). The x-axis shows the summer minimum/maximum water level range as denoted by 0 and each six inch increment above or below the summer range (x-axis).

4.2 Adaptation Scenarios

4.2-a Lower Lake Mendota one foot

The adaptation scenario of lowering Lake Mendota one foot was assessed for two possible management strategies of (1) maintaining Lake Mendota lower and (2) using Lake Mendota for flood storage. Figure 16 shows 2018 levels (blue line) compared to modeling results of maintaining Lake Mendota lower (dark orange line) and managing Lake Mendota for flood storage (light orange line).

When Lake Mendota is managed to maintain one foot lower, it poses consequences to the downstream lakes with water levels rising above summer maximum levels more often. As a result the lower lakes have higher fluctuations in lake levels due to the Tenney Dam quickly releasing water and not being used to buffer water to the lower lakes.

When Lake Mendota is managed one foot lower for flood storage, it presents a significant management challenge in wet years: when can one foot of increased storage be accomplished. In 2018, a large snow melt occurred during a runoff event in February then March and April months were relatively dry months compared to normal. For the scenario of providing flood storage, Lake Mendota was lowered one foot over the month of March. In reality, weather is unpredictable and creating one foot of storage on Lake Mendota could pose a risk of flooding on the lower lakes. During the remainder of the summer, it can be seen that the lake levels steadily increase due to the inability of the river system to convey the incoming flows. Overall minor improvements to peak levels are achieved with a drop of 2”, 2”, 2”, and 0.5” for Lakes Mendota, Monona, Waubesa, and Kegonsa, respectively.

In Figure 17, a histogram plot shows 2018 levels (blue bars) compared to modeling results of maintaining Lake Mendota lower (dark orange bars) and managing Lake Mendota for flood storage (light orange bars). The histogram plot shows the number of days (y-axis) within the summer minimum/maximum range as donated by 0 and each six inch increment above or below the range (x-axis). Overall, the histogram plot reveals that Lakes Monona, Waubesa, and Kegonsa would experience more days above the summer range than what was experienced in 2018.

Under this adaptation scenario, the following considerations have been identified:

- Lowering Mendota 1 foot would require a petition to DNR which would require the consideration of other aspects such as fisheries, wetlands, recreation, navigation, social, and economics impacts.
- Lowering Mendota 1 foot shows that there would be more days above summer maximum levels for the other lakes besides Lake Mendota. Furthermore, additional slow no wake days in the summer months is likely.
- Lowering Mendota 1 foot in March potentially coincides with critical fish spawning, which could be a threat to a healthy fishery.
- Lowering Mendota 1 foot and using it as a storage reservoir produces larger water level fluctuations that could result in dislocating wetlands and impacts to state threatened species, such as Sheathed Pondweed, White Lady’s Slipper, and Tufted Bulrush.
- Other biological, social, ad ecological impacts are likely as well when managing lake levels.

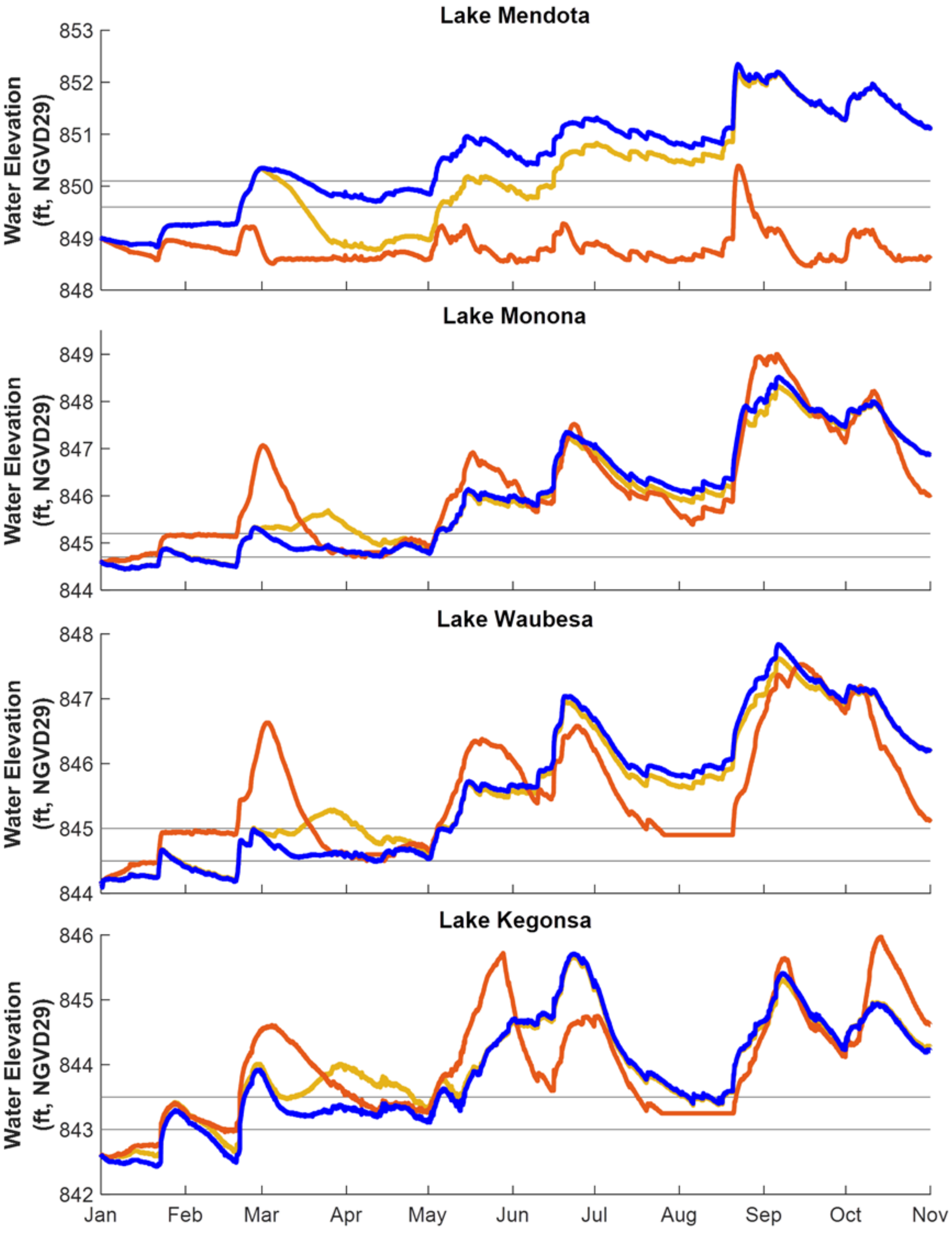


Figure 16: Water levels showing 2018 (blue line) compared to modeling results of maintaining Lake Mendota lower (dark orange line) and managing Lake Mendota for flood storage (light orange line). The two parallel gray lines represent summer minimum and maximum target levels.

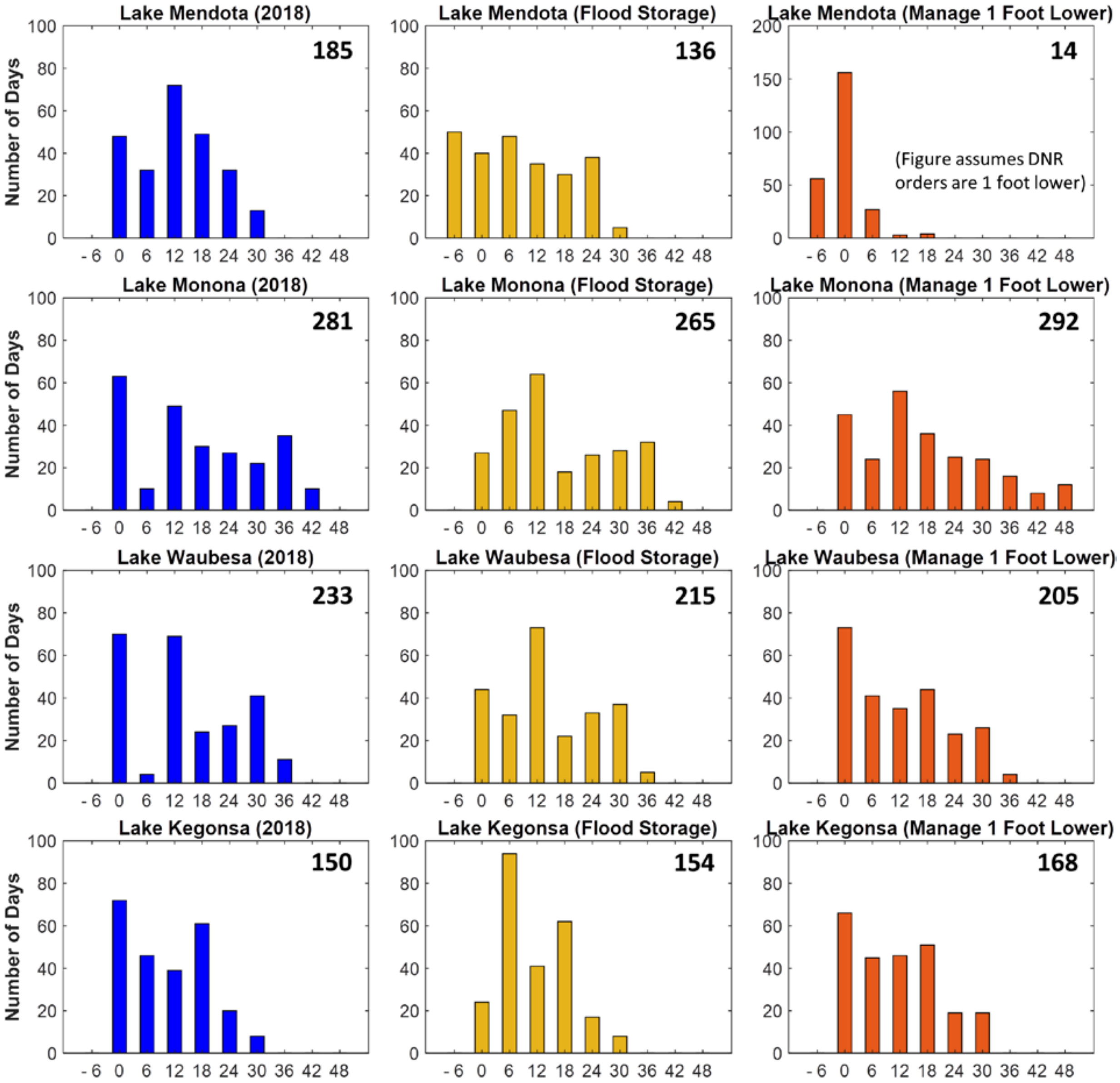


Figure 17: Number of days within water level ranges comparing 2018 levels on the left (blue bars) to managing Lake Mendota for flood storage (light orange bars) and maintaining Lake Mendota lower (dark orange bars). The x-axis shows the summer minimum/maximum water level range as denoted by 0 and each six inch increment above or below the summer range (x-axis).

4.2-b Safely Manage Lake Mendota at 100 year water level

The adaptation scenario of safely managing Lake Mendota to the 100 year water level is assessed. One challenging management question to address is timing.

Dam Breach Analysis safety

Once Lake Mendota storage has been used, any additional rain that would occur over its watershed would be directly passed onto the lower lakes, posing a potential flood risk for those lakes. In the modeling, the scenario is applied to alleviate flooding that occurred on September 6, 2018 where the black area in Figure 18 shows when storage on Lake Mendota is utilized. Figure 18 shows 2018 levels (blue line) compared to modeling results of increasing Lake Mendota water levels to the 100 year (cyan line). The modeling results show that when increasing Lake Mendota water level, it benefits the downstream lakes on September 6. However, the peak water level on Lake Kegonsa occurred on June 22, 2018 and the scenario does not alleviate flooding unless it is implemented in June. This scenario resulted in changing peak water levels of +6", -6", -6", and 0" for Lakes Mendota, Monona, Waubesa, and Kegonsa, respectively. In Figure 19, a histogram plot shows 2018 levels (blue bars) and the scenario of increasing Lake Mendota to the 100 year (cyan bars). The histogram plot shows the number of days (y-axis) within the summer minimum/maximum range as donated by 0 and each six inch increment above or below the range (x-axis). The histogram plot shows changes only occur on the extreme water levels by increasing more days above 30" above summer maximum on Lake Mendota and decreasing fewer days 30" above summer maximum on Lakes Monona and Waubesa.

Under this adaptation scenario, the following considerations have been identified:

- This scenario shows that storing water on Lake Mendota can provide some benefit; however, once storage is used up, water will need to be released downstream potentially creating a future flood risk on Lake Mendota and/or downstream lakes.

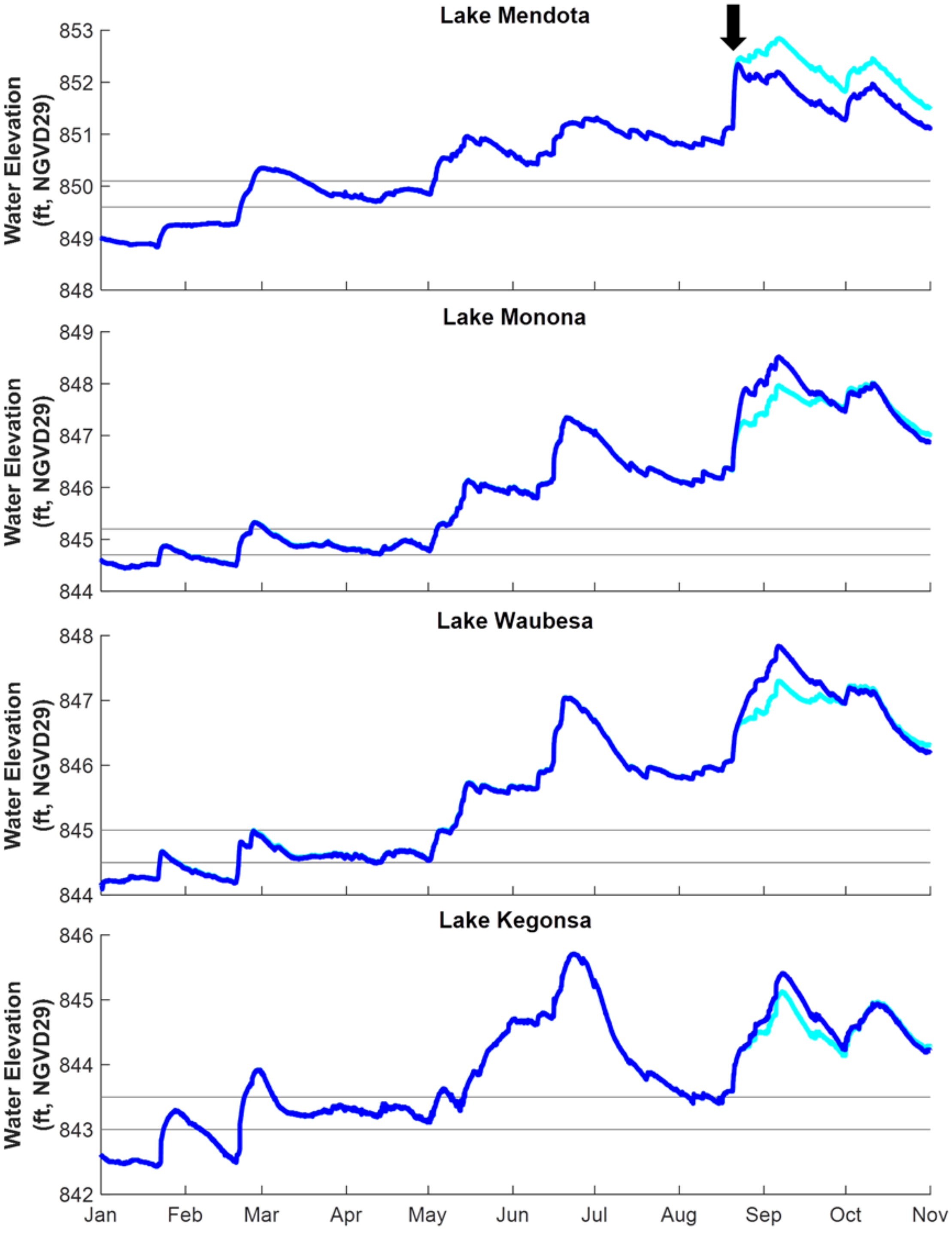


Figure 18: Water levels showing 2018 (blue line) compared to safely managing Lake Mendota to the 100 year (cyan line). The two parallel gray lines represent summer minimum and maximum target levels.

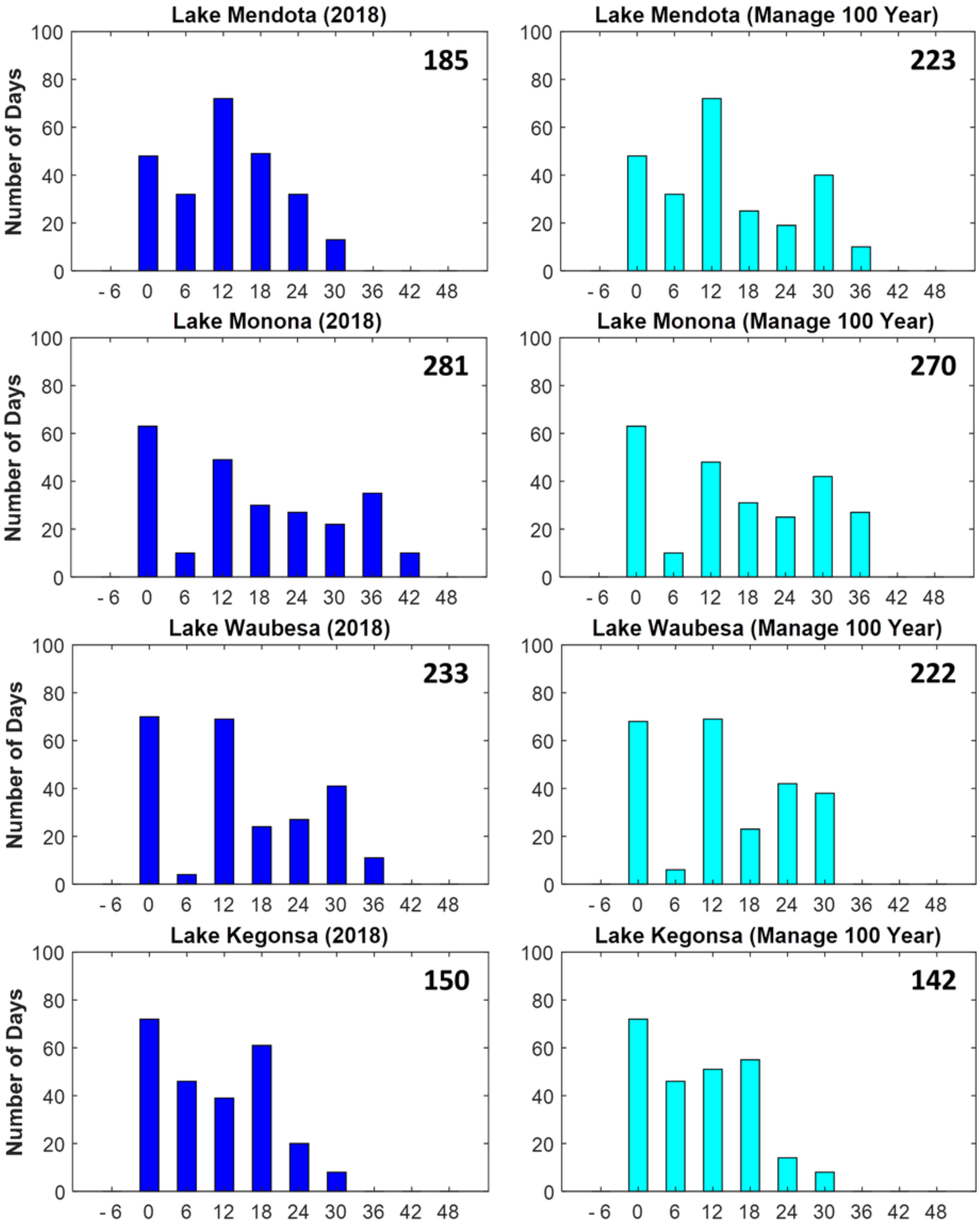


Figure 19: Number of days within water level ranges comparing 2018 levels on the left (blue bars) to safely managing Lake Mendota to the 100 year on the right (cyan bars). The x-axis shows the summer minimum/maximum water level range as denoted by 0 and each six inch increment above or below the summer range (x-axis).

4.2-c Remove all dams from the Yahara Lakes

The adaptation scenario of removing all dams is assessed. Specifically, the dams removed are Tenney Lock and Dam (Lake Mendota), Babcock Lock and Dam (Lake Waubesa), Lafollette Lock and Dam (Lake Kegonsa), and Stoughton Dam. The modeling assumes prior to 2018 there are no dams in place and uses antecedent water conditions for 1 year prior to initiate the modeling. Analysis was not conducted on how this alternative would be achieved (i.e. lowering Lake Mendota approximately 4 feet) but rather on impacts to flooding. Figure 20 shows 2018 levels (blue line) compared to modeling results of removing all dams for the Yahara Lakes (dark red line). The modeling results show that the three lower lakes would result in increased water levels mainly attributed to the removal of Tenney Dam which is not in place to regulate and buffer flow delivered downstream. Changes to peak water levels in comparison to 2018 were +2”, +1”, and +3” for Lakes Monona, Waubesa, and Kegonsa, respectively. In Figure 21, a histogram plot shows 2018 levels (blue bars) and the scenario of removing all dams (dark red bars) is presented. The histogram plot shows the number of days (y-axis) within the summer minimum/maximum range as donated by 0 and each six inch increment above or below the range (x-axis). The histogram plot shows Lakes Monona, Waubesa, and Kegonsa would experience more days above the summer maximum target than occurred with the dams present primarily attributed to removal of Tenney Dam.

Under this adaptation scenario, the following considerations have been identified:

- Removal of Tenney Dam is likely to require a phase in period to lower the lake approximately 4 feet (for 2018) as it is unlikely to be accomplished over one year. Timing of drawdown is likely contingent upon expected wet and dry weather years and further study would be needed to determine lowering Lake Mendota.
- Removal of the dams eliminates the ability to retain water during dry periods.
- Removal would require permitting from the DNR as well as consideration for biological impacts.

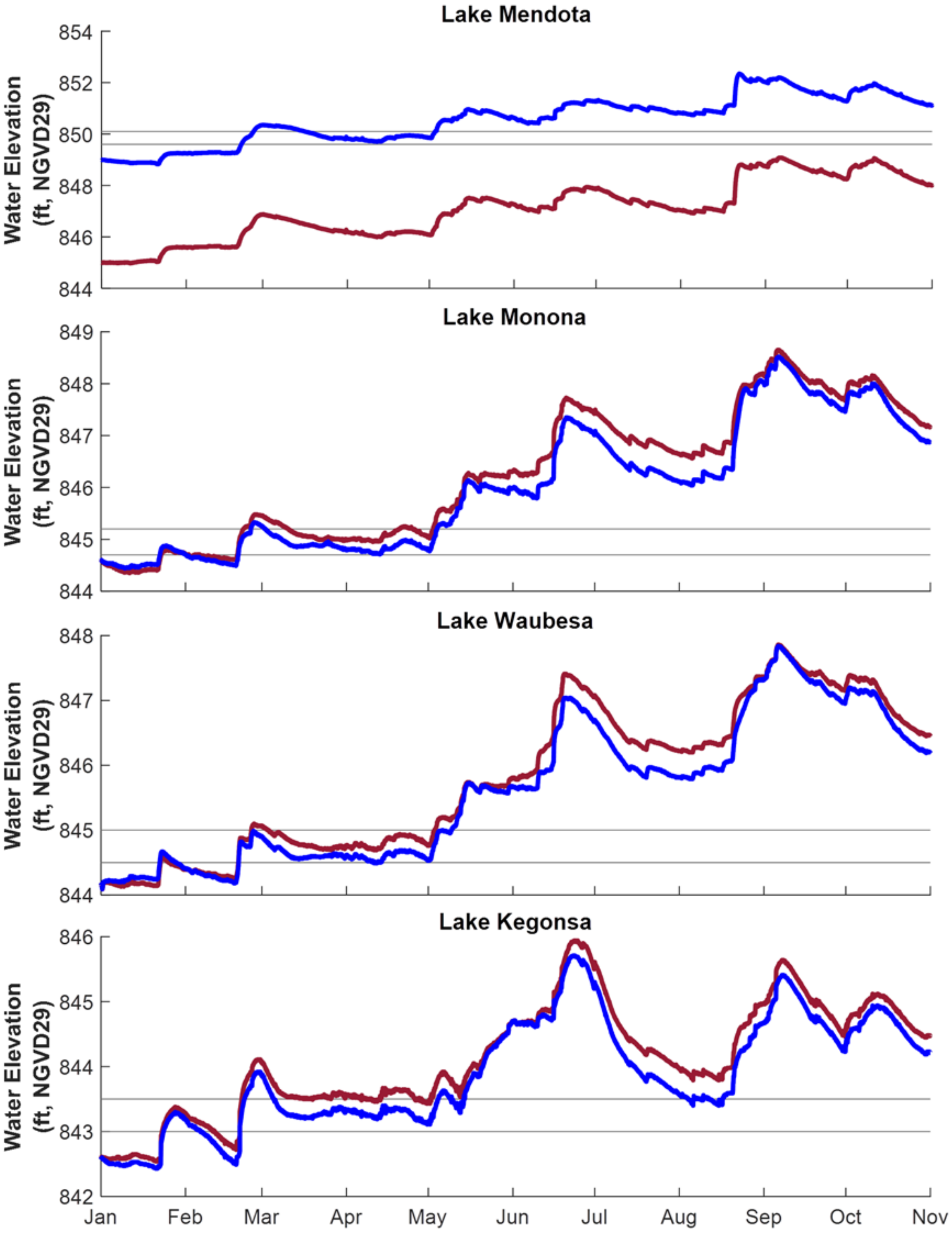


Figure 20: Water levels showing 2018 (blue line) compared to removal of all dams (dark red line). The two parallel gray lines represent summer minimum and maximum target levels.

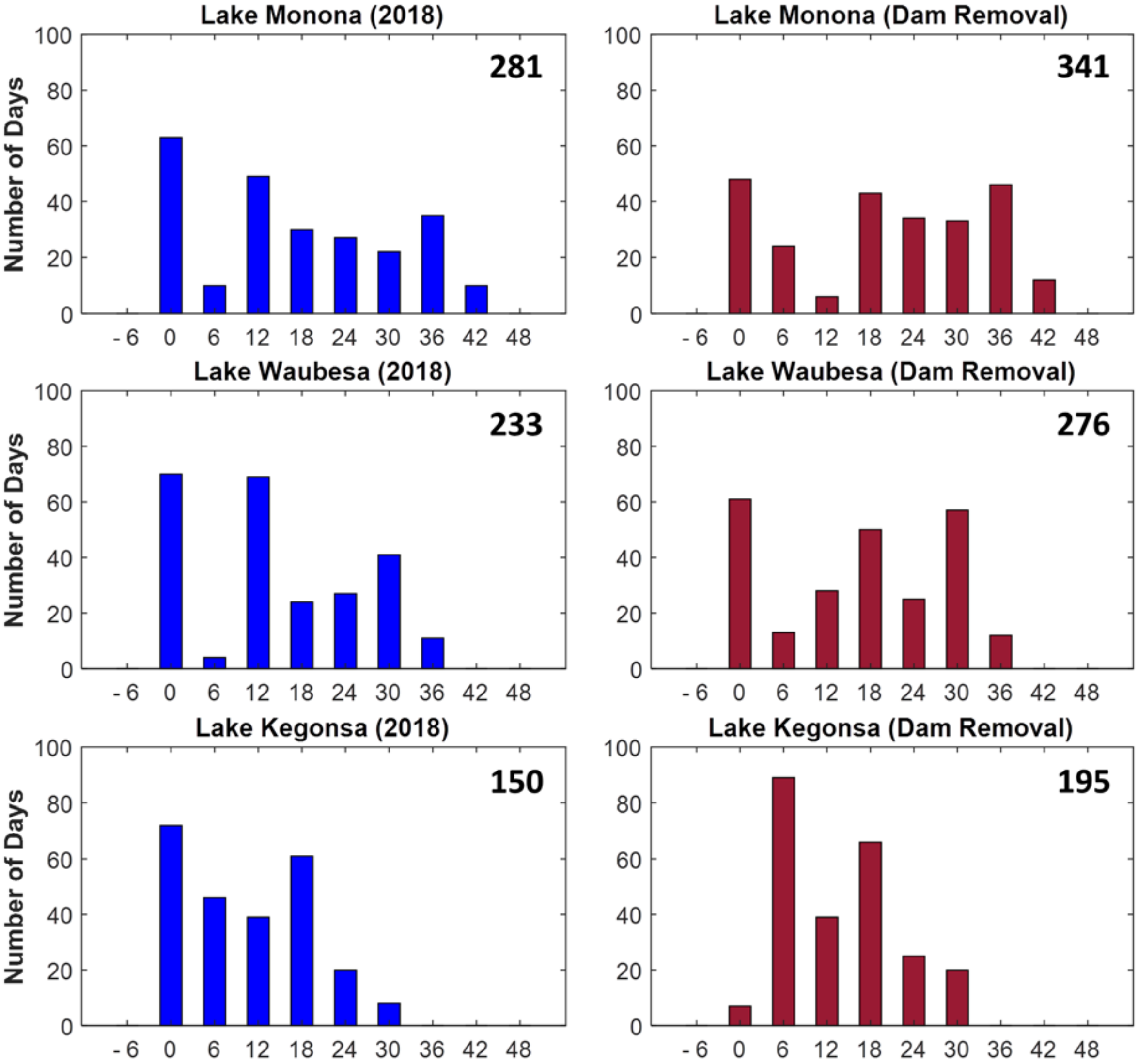


Figure 21: Number of days within water level ranges comparing 2018 levels on the left (blue bars) to removal of all dams (dark red line). The x-axis shows the summer minimum/maximum water level range as denoted by 0 and each six inch increment above or below the summer range (x-axis).

4.3 Mitigation Scenarios

4.3-a Bridge Modifications

In this scenario, human made structures such as automobile bridges and railroad bridges are widened and assumed to free span with no pier supporting structures. In total there are 14 bridges widened which include all bridges from Lake Monona to Stoughton Dam. Also, no changes were made to deepen the river beyond its current water depth. Figure 22 shows a schematic of changes made at Exchange Street Bridge with the existing cross section in brown and widened to the new cross section in red.

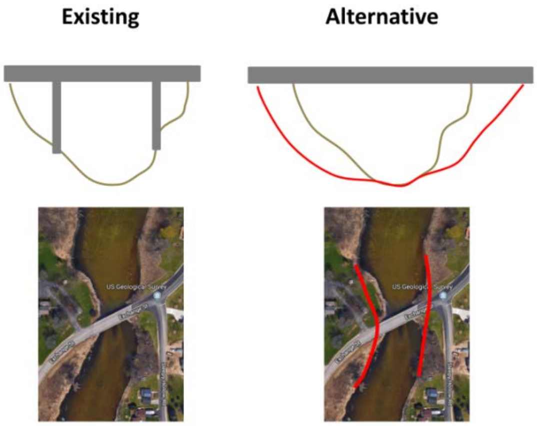


Figure 22: Existing (brown line) and after cross section in brown and widened to the new cross section in red.

Figure 23 shows 2018 levels (blue line) compared to modeling results of increasing bridge capacity (red line). The modeling results show that minimal changes in water levels are achieved by expanding the bridges which confirms previous research conducted on the hydraulics of the Yahara Lakes (Reimer and Wu, 2016). These bridges can constrict and limit flow, causing choking. To overcome choking, more energy is needed to move water. One way to increase energy or improve the movement of water is to increase water depth. For the majority of 2018, water depths in the river were deep enough to provide adequate energy needed to overcome choking conditions, therefore the results show minimal overall improvements. Changes to peak water levels in comparison to 2018 were -1.5”, -2”, -2”, and -0.25” for Lakes Mendota, Monona, Waubesa, and Kegonsa, respectively. In Figure 24, a histogram plot shows 2018 levels (blue bars) and the scenario of increasing bridge capacity (red bars) is presented. The histogram plot shows minor improvement with fewer days above the summer maximum target than occurred with the narrow bridges present.

Under this mitigation scenario, the following considerations have been identified:

- Bridge modifications would require coordination among several parties (State, Local, and Federal).
- Bridge modifications would require replacement of those that are not on current schedules to be replaced within the next 10 years due to their age and current funding obligations (except County Highway AB which is being replaced in 2019).

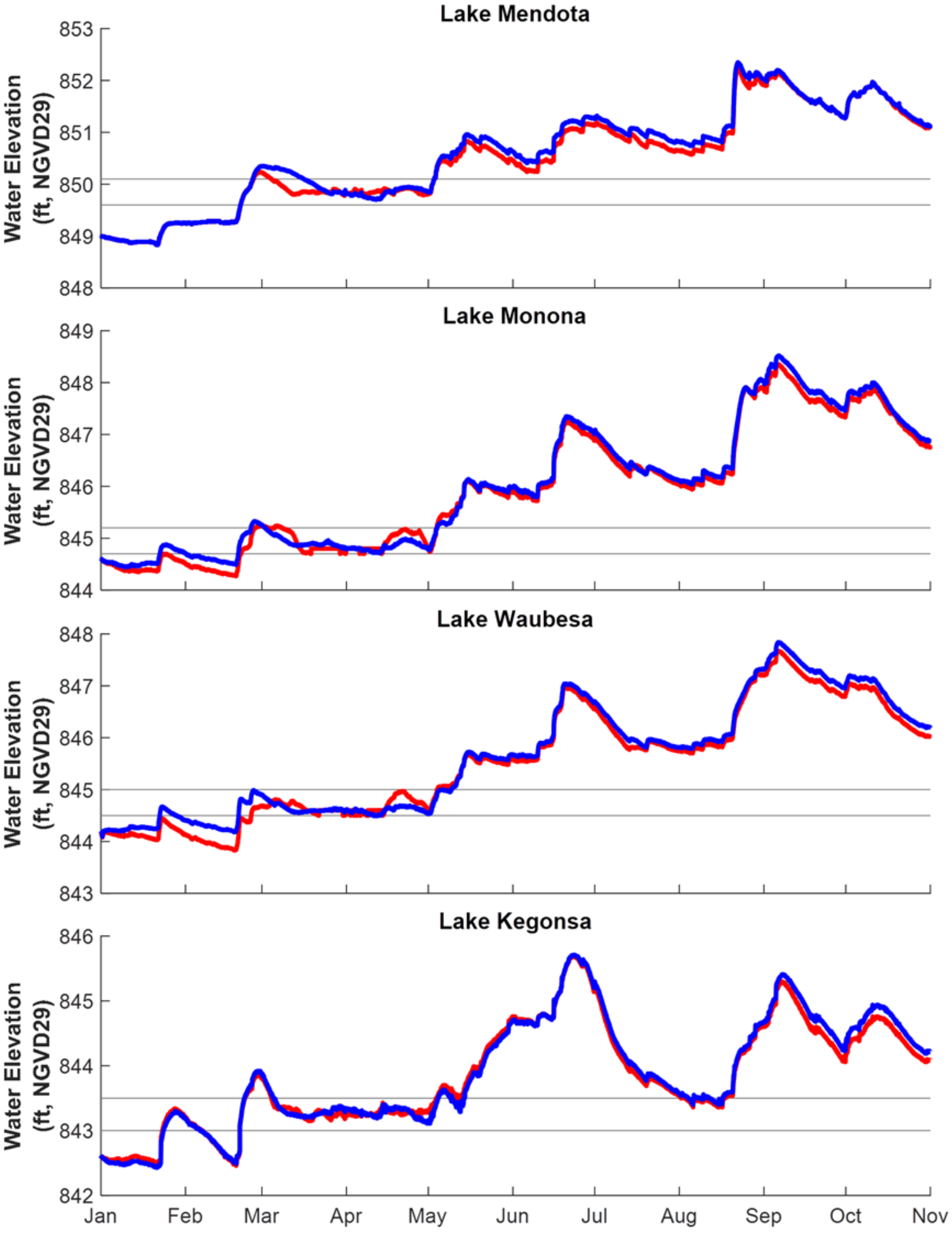


Figure 23: Water levels showing 2018 (blue line) compared to bridge modifications (red line). The two parallel gray lines represent summer minimum and maximum target levels.

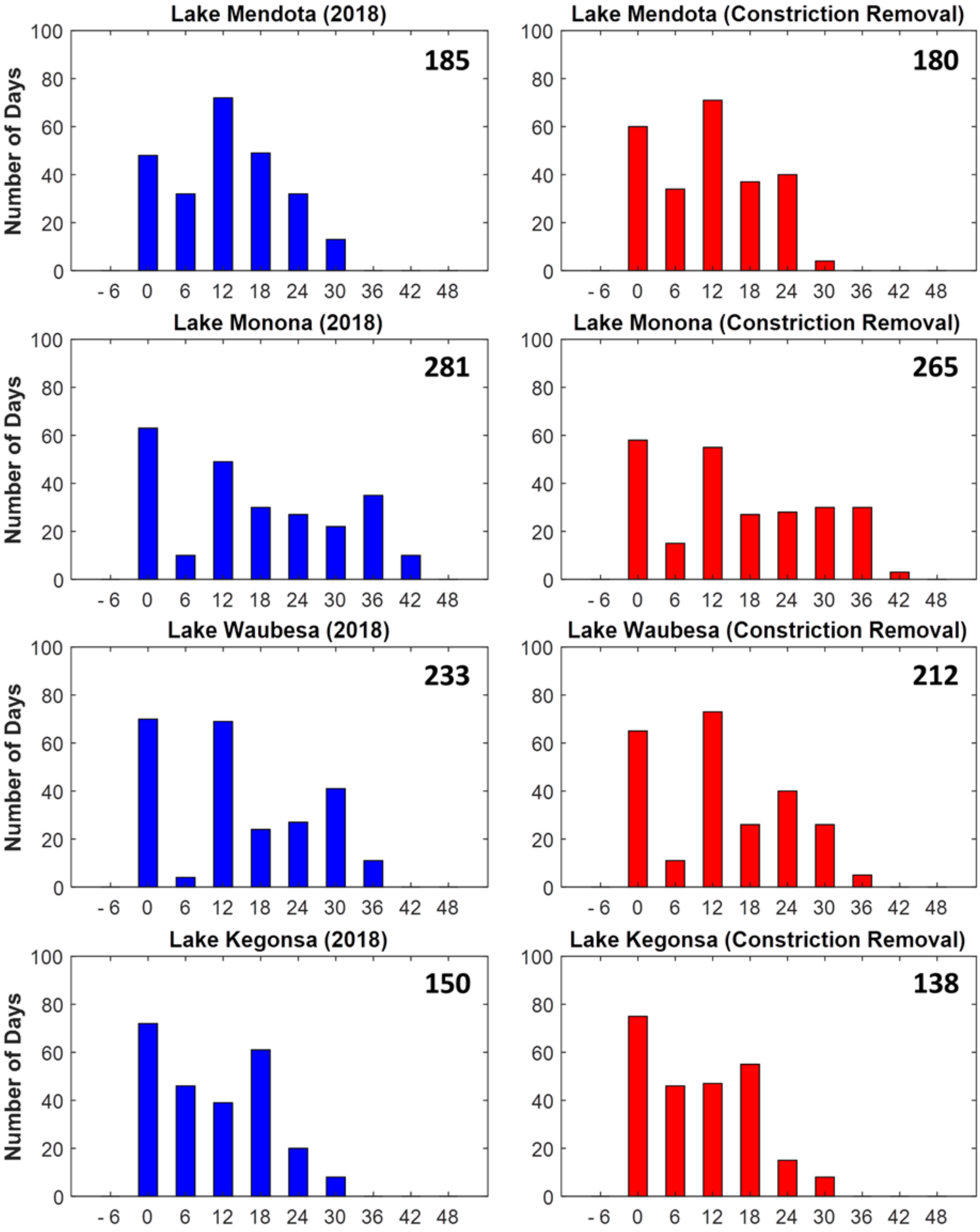


Figure 24: Number of days within water level ranges comparing 2018 levels on the left (blue bars) to bridge modifications (red bars). The x-axis shows the summer minimum/maximum water level range as denoted by 0 and each six inch increment above or below the summer range (x-axis).

4.3-b Yahara River Dredging

To evaluate this scenario, preliminary simulations were employed to optimize dredging efforts. Dredging the Yahara River was conducted from Lake Monona to the Stoughton Dam. The modeling assumed the Yahara River was dredged 50 feet wide ranging in depths of 2-3 feet. The total cubic yards of material removed from each of the Yahara River areas are approximately 50,000 cubic yards between Monona and Waubesa, 75,000 cubic yards between Waubesa and Kegonsa, and 150,000 cubic yards between Kegonsa and Stoughton.

Figure 25 shows 2018 levels (blue line) compared to modeling results of dredging the Yahara River (purple line). The modeling results show that a large benefit in reducing water levels could be achieved from dredging. Changes to peak water levels in comparison to 2018 were -6”, -12”, -11”, and -7” for Lakes Mendota, Monona, Waubesa, and Kegonsa, respectively. In Figure 26, a histogram plot shows 2018 levels (blue bars) and the scenario of dredging the Yahara River (purple bars). The histogram plot shows significant improvement in more days within the summer range target than occurred in 2018. Specifically, the histogram plot shows Monona previously had many days above summer maximum in the 36” and 42” categories versus the dredging scenario has no days within those two categories and only a few days within the 30” over summer maximum category.

Under this mitigation scenario, the following considerations have been identified:

- Dredging deeper than design may be considered to provide a longer life expectancy.
- Dredging in subsequent years may be required to maintain depth due to continued sedimentation that would limit flow capacity.
- Dredging the Yahara River could also benefit aquatic plant harvesting operations due to deeper water depths helpful for navigation and draft.
- Dredging the Yahara River would impact historical artifacts such as the Native American Fish Weir.
- Dredging may require bridge replacements if abutments or piers do not have proper support from sediment
- Dredging may require the purchase of land and/or easements for dewatering locations and hydraulic pipelines and sediment disposal. The acquisition of land may consider additional land to support future maintenance dredging.
- Dredging would require a permitting and approval process from DNR, including compliance with NR 150 and Chapter 30.
- Sediment sampling for contaminants would need to be completed to determine impacts to water quality and proper disposal methods of sediment which would impact project costs
- Further study is suggested to evaluate the feasibility of the project such as costs, dewatering locations, biological impacts, and construction techniques.

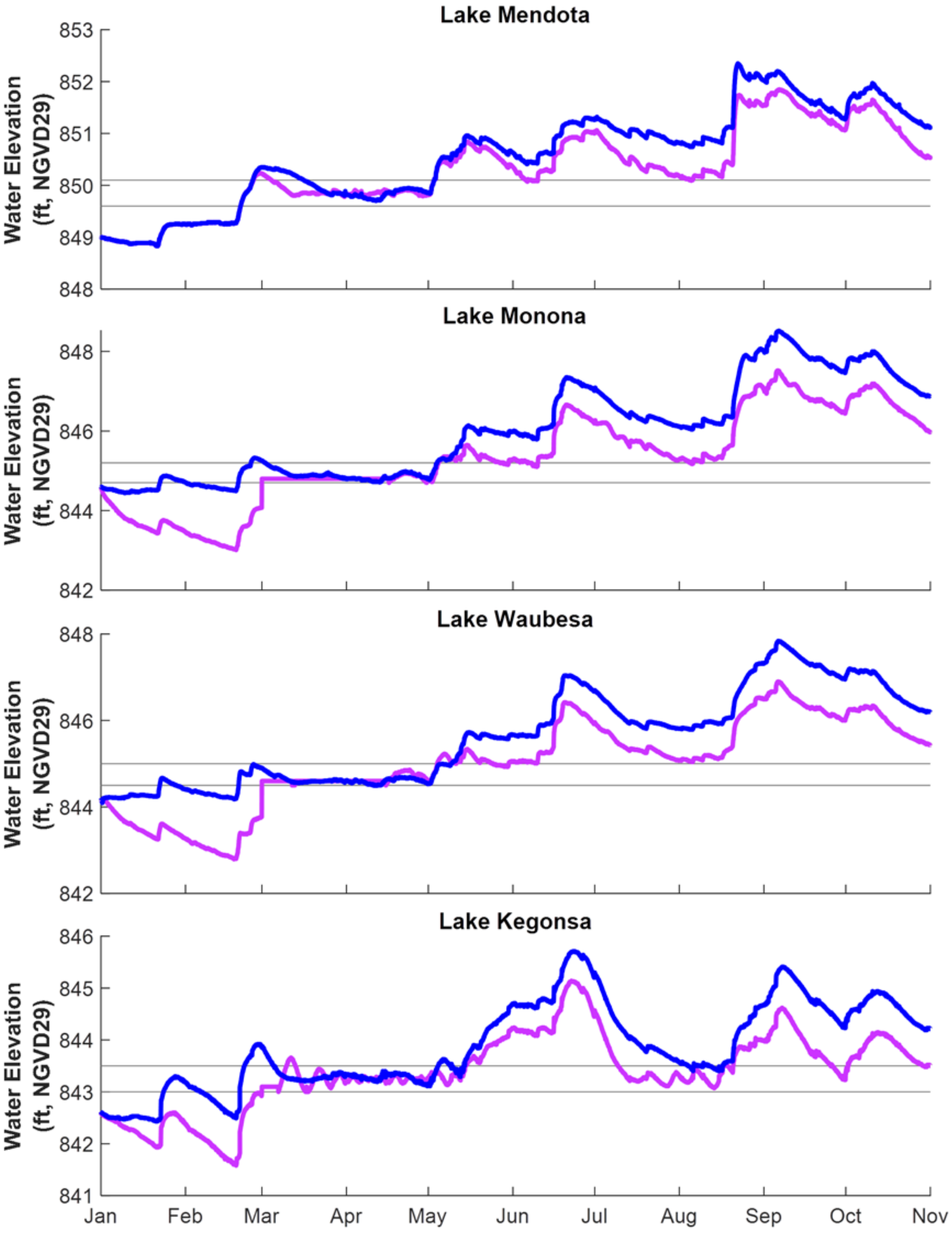


Figure 25: Water levels showing 2018 (blue line) compared to dredging the Yahara River (purple line). The two parallel gray lines represent summer minimum and maximum target levels.

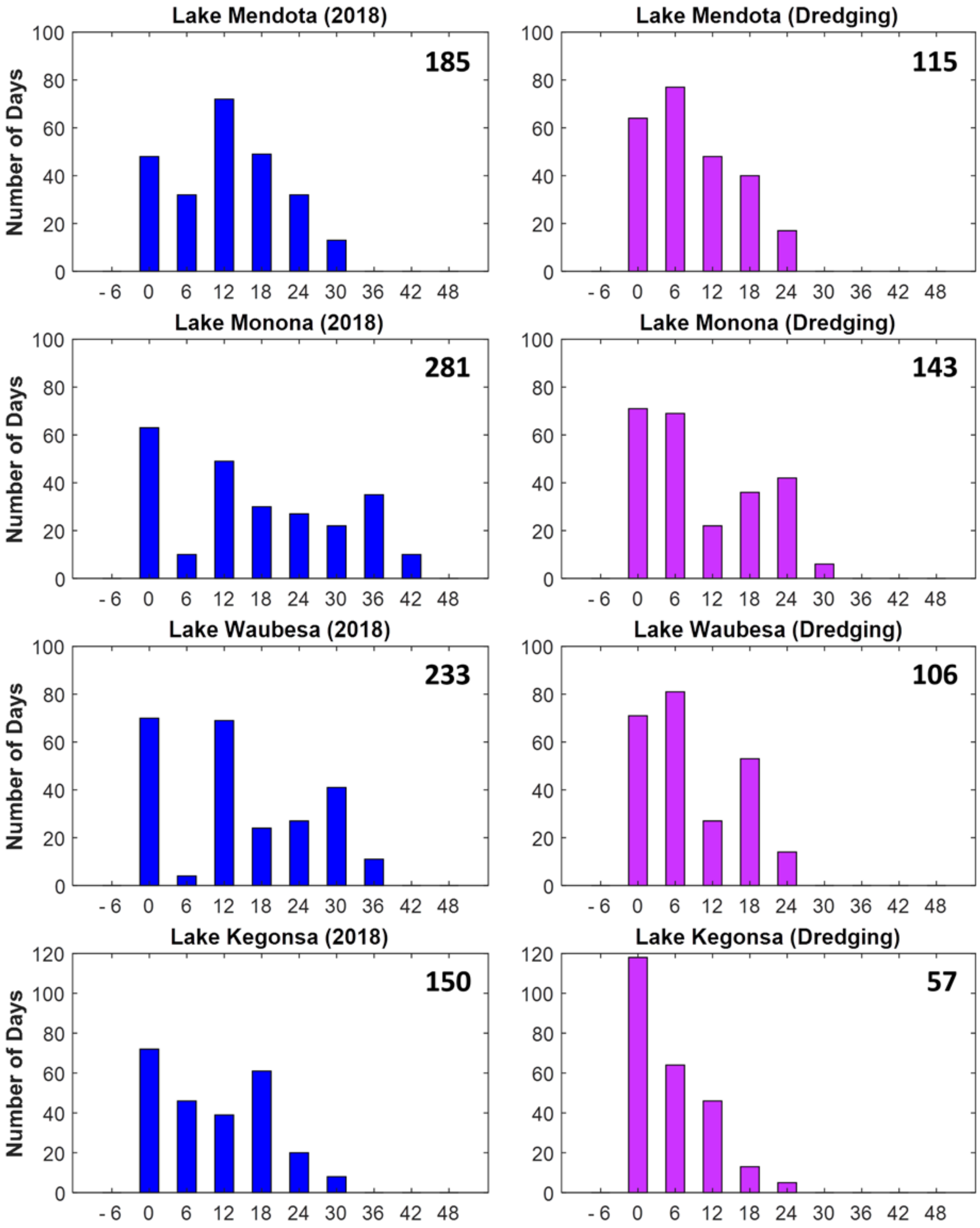


Figure 26: Number of days within water level ranges comparing 2018 levels on the left (blue bars) to dredging the Yahara River (purple bars). The x-axis shows the summer minimum/maximum water level range as denoted by 0 and each six inch increment above or below the summer range (x-axis).

4.3-c Flow Reroute and Pumping

The technical work group identified two possible options of flow reroute and pumping. One option is to create a pipeline from Lake Waubesa to Lake Kegonsa and bypass Lower Mud Lake. A second option is deliver water out of the Yahara Lakes from Lake Waubesa to Badfish Creek as shown in Figure 27. Analysis presented here investigates delivering water through approximately 1.5 mile pipeline to Badfish Creek.

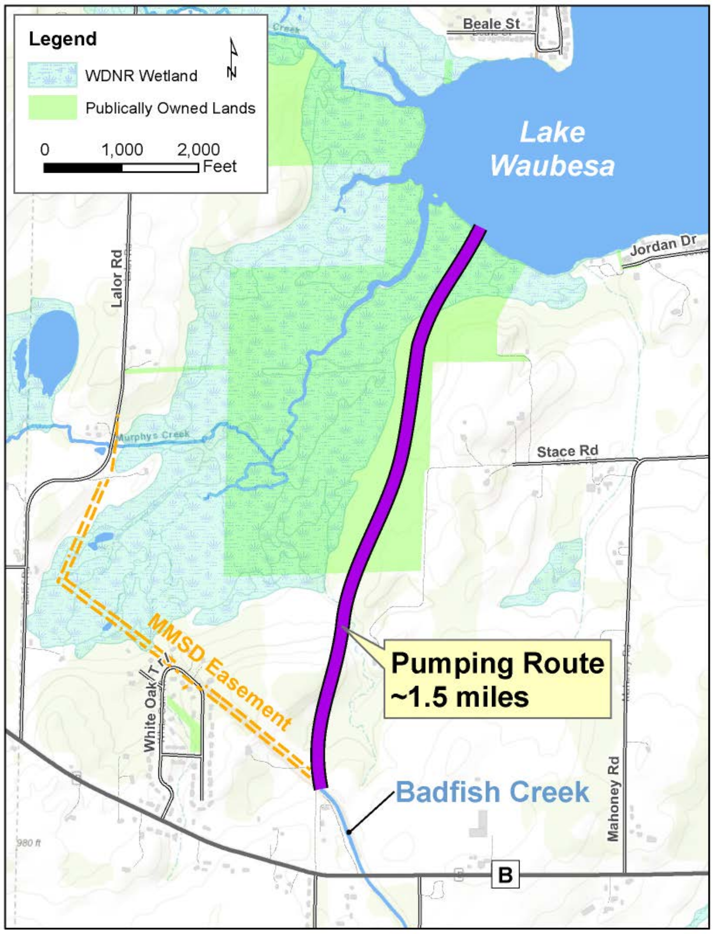


Figure 27: Flow reroute and pumping out of the Yahara Lakes from Lake Waubesa to Badfish Creek.

A preliminary assessment of discharges and flow capacity of Badfish Creek was conducted. From the USGS monitoring station of Badfish Creek near Cooksville, WI (Figure 28), the discharges appear to be flashy from runoff ranging from a peak near 2,000 cfs to approximately 100 cfs during baseflow. In the analysis, a flow of 400 cfs was assumed in delivery of water from Lake Waubesa to Badfish Creek. The assumed flow rate is within the reported range of flows observed by USGS monitoring; however, further hydraulic analysis on Badfish Creek is suggested to confirm appropriate flow rates and stream capacities.

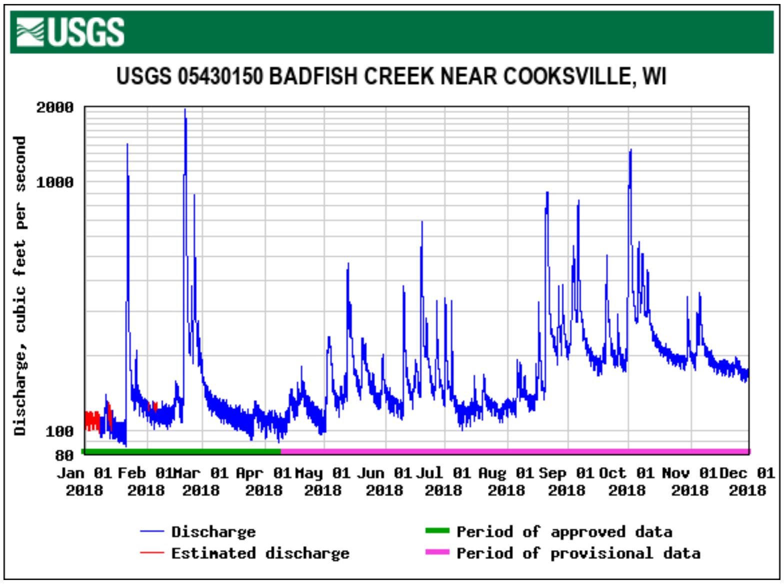


Figure 28: Badfish Creek flow rates

Figure 29 shows 2018 levels (blue line) compared to modeling results of flow reroute (magenta line). The modeling results show that a large benefit in reducing water levels could be achieved from rerouting flow by pumping. Changes to peak water levels in comparison to 2018 were -12”, -10”, -21”, and -10” for Lakes Mendota, Monona, Waubesa, and Kegonsa, respectively. In Figure 30, a histogram plot shows 2018 levels (blue bars) and the scenario of flow reroute by pumping (magenta bars). The histogram plot shows significant improvement in more days within the summer range target than occurred in 2018. The results show that Lake Monona does not show the greatest benefit as the remainder of the lakes mainly attributed to no improvements made in the connecting river from Lake Monona to Lake Waubesa.

Under this mitigation scenario, the following considerations have been identified:

- Flow reroute and pumping would require a permitting and approval process from DNR.
- Flow reroute and pumping would require the purchase of land and/or permanent easements for pipelines and pump buildings.
- Flow reroute and pumping should be equipped with a Supervisory control and data acquisition (SCADA) system to record and regulate flow based on upstream lake levels and downstream levels (e.g. Badfish) to minimize flooding.
- Flow reroute could be designed for low water levels to discharge using gravity and during high water levels a pump would be utilized. Further study is suggested to optimize operational costs versus flooding.
- Further analysis and assessment is necessary for impacts to downstream flooding (i.e. flow from pump station may be limited based on water levels downstream).
- Further study is suggested to evaluate the feasibility of the project such as capital and operating costs, pump station siting, piping configuration, etc.

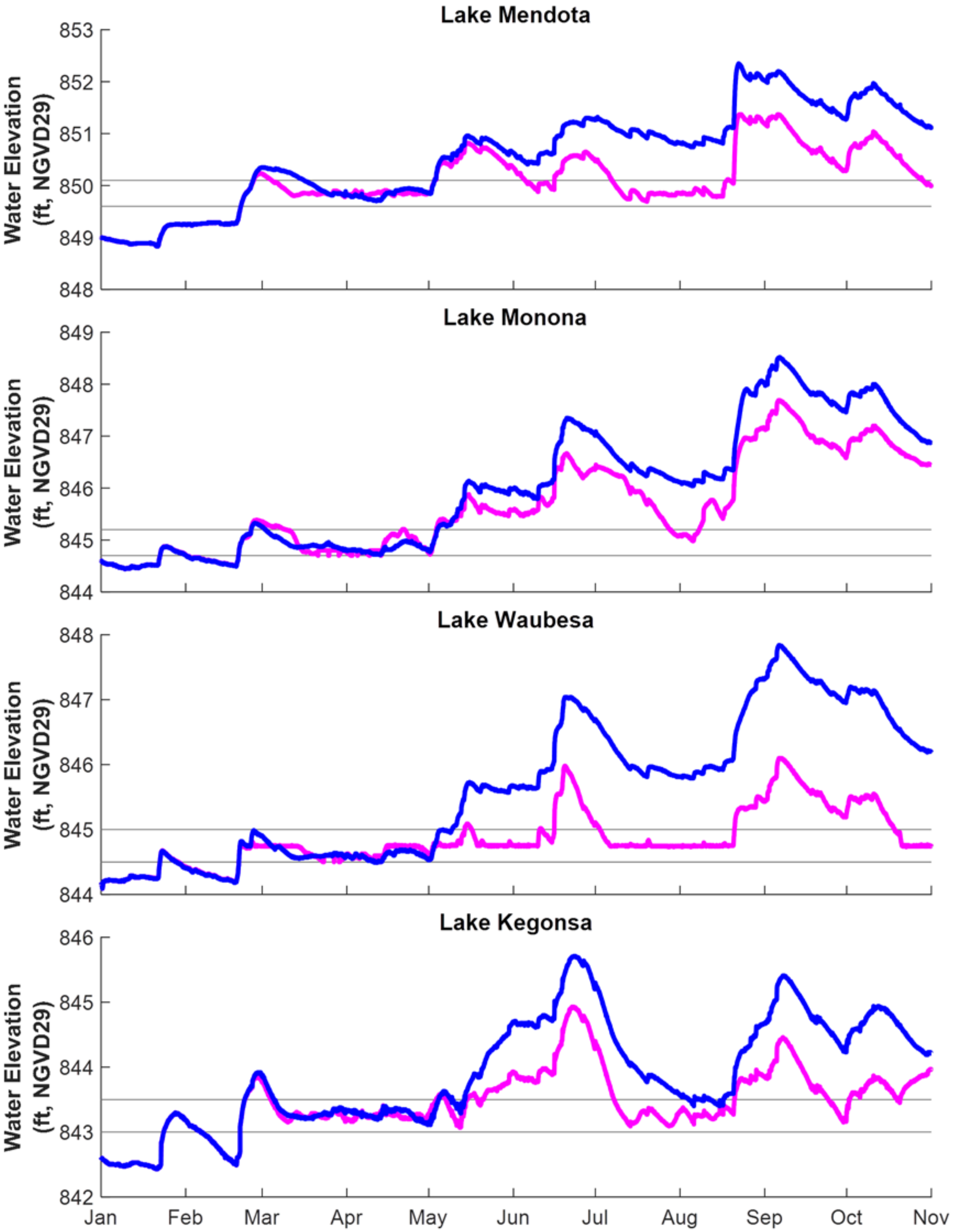


Figure 29: Water levels showing 2018 (blue line) compared to reroute of flow by pumping (magenta line). The two parallel gray lines represent summer minimum and maximum target levels.

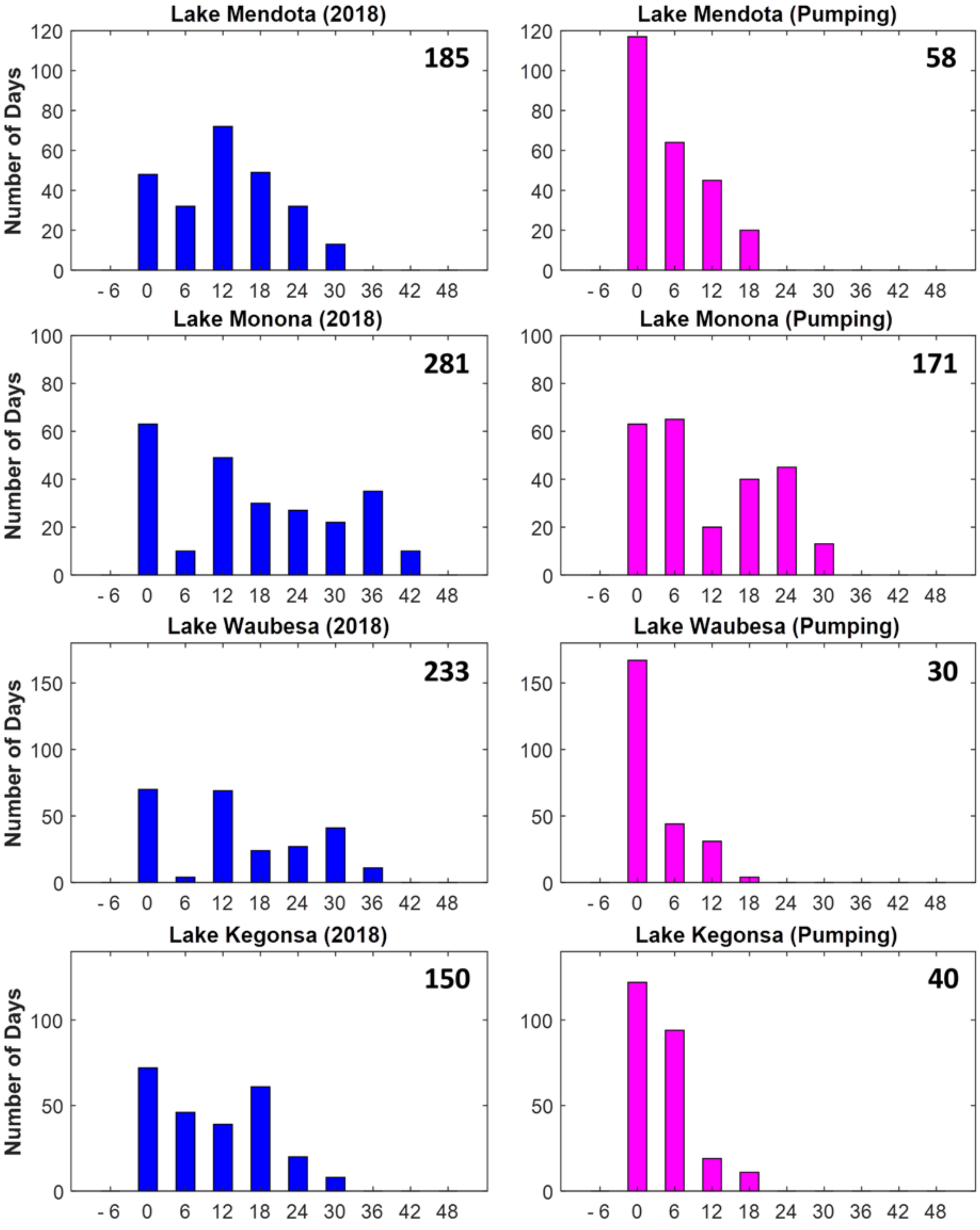


Figure 30: Number of days within water level ranges comparing 2018 levels on the left (blue bars) to reroute of flow by pumping (magenta bars). The x-axis shows the summer minimum/maximum water level range as denoted by 0 and each six inch increment above or below the summer range (x-axis).

4.3-d Combined dredging and flow rerouting

While the previous results show individual benefits from each scenario, it is recognized that final solutions may be a combination of solutions. As an example, the top two benefits of dredging and pumping were selected to be used in combination. Specifically pumping was utilized as previously stated in section 3.7 and dredging was employed only between Lakes Monona and Waubesa.

Figure 31 shows 2018 levels (blue line) compared to combination of dredging and flow reroute (dark gray line). The modeling results show that a large benefit in reducing water levels could be achieved using a combination of scenarios. Changes to peak water levels in comparison to 2018 were -12”, -20”, -25”, and -13” for Lakes Mendota, Monona, Waubesa, and Kegonsa, respectively. In Figure 32, a histogram plot shows 2018 levels (blue bars) and the combination of dredging and flow reroute (dark gray bars). The histogram plot shows significant improvement in more days within the summer range target than occurred in 2018.

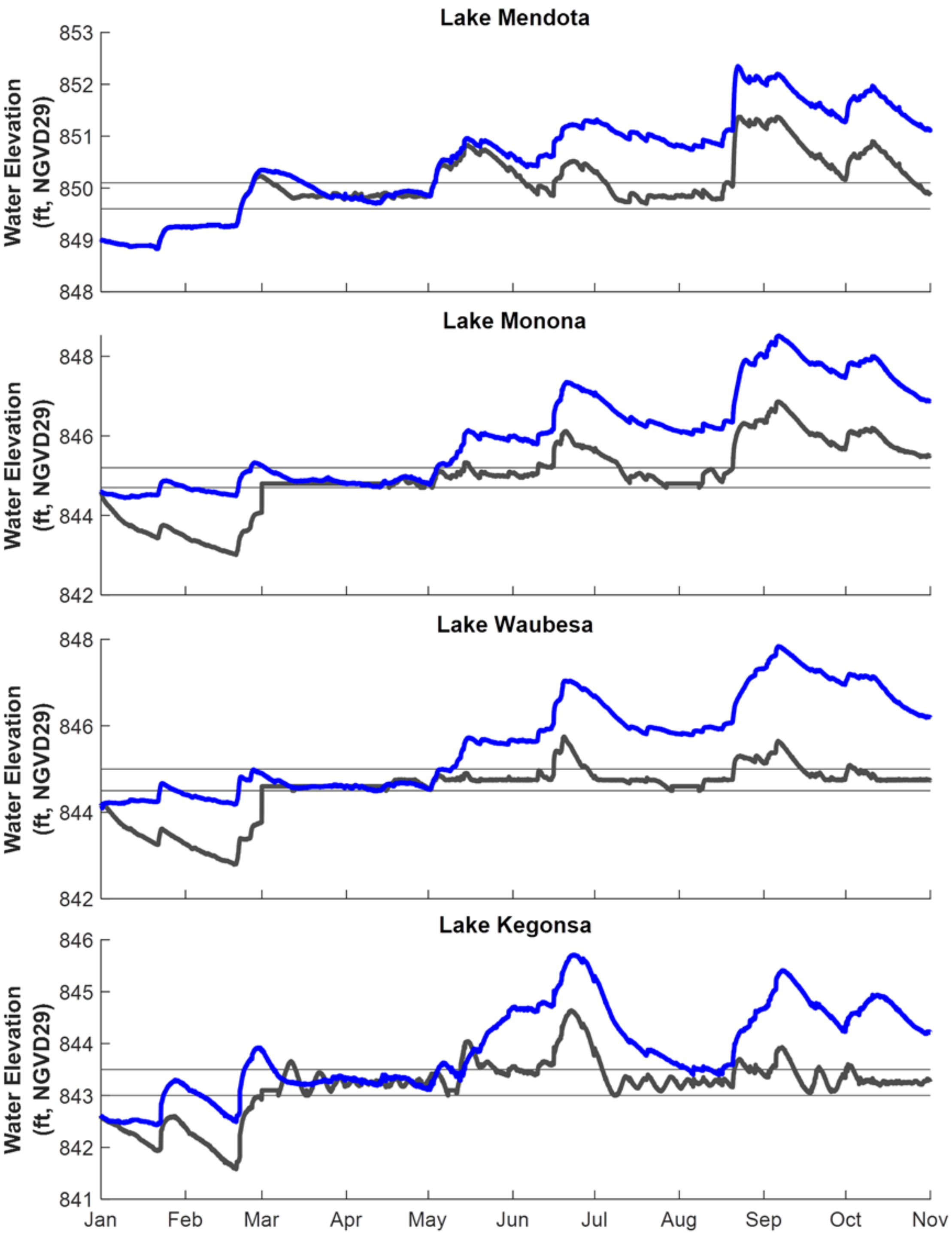
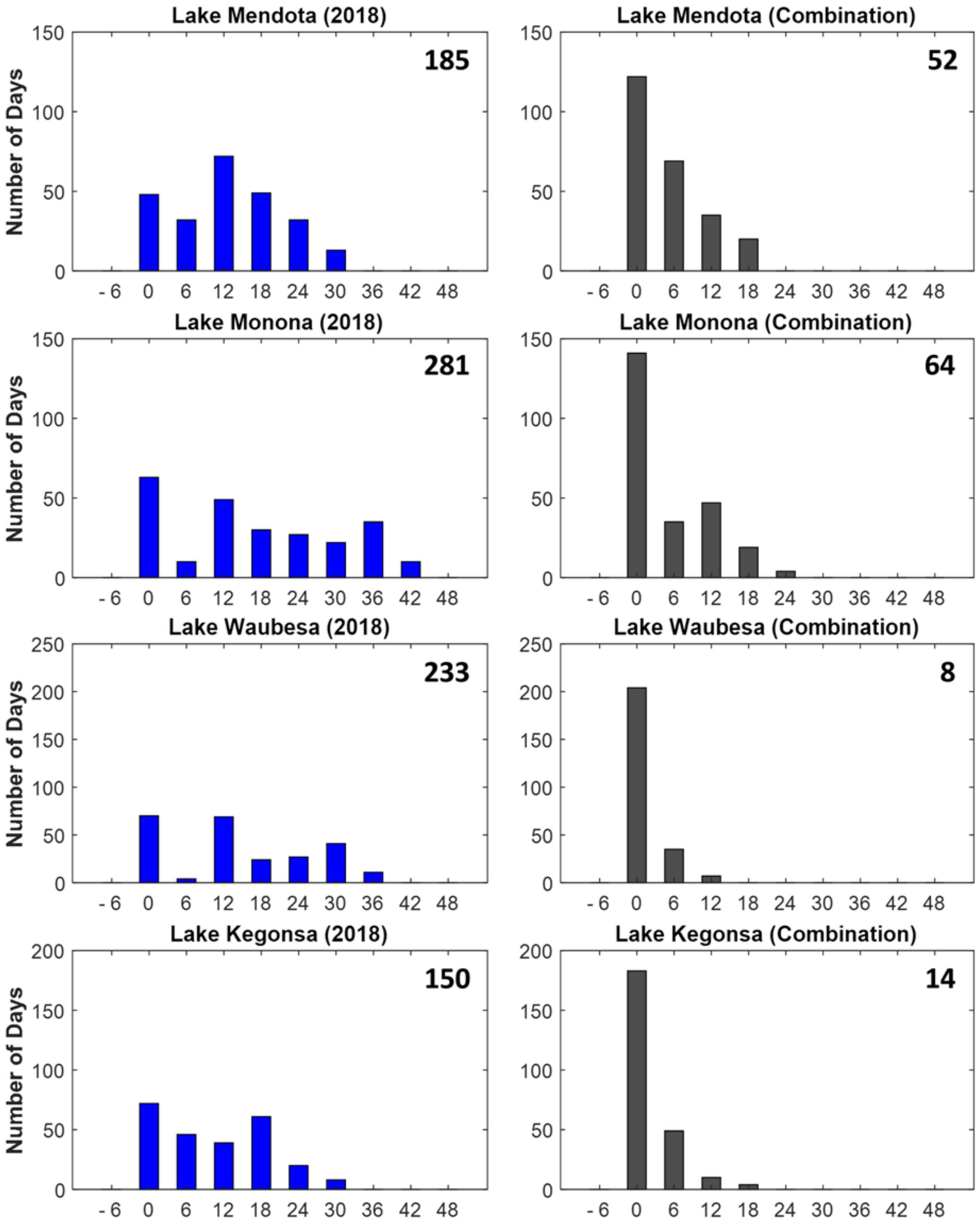


Figure 31: Water levels showing 2018 (blue line) compared to combination of dredging and pumping (dark gray line). The two parallel gray lines represent summer minimum and maximum target levels.



Lake Mendota (2018)

Lake Mendota (Combination)

Lake Monona (2018)

Lake Monona (Combination)

Lake Waubesa (2018)

Lake Waubesa (Combination)

Lake Kegonsa (2018)

Lake Kegonsa (Combination)

Figure 32: Number of days within water level ranges comparing 2018 levels on the left (blue bars) to combination of dredging and pumping (dark gray bars). The x-axis shows the summer minimum/maximum water level range as denoted by 0 and each six inch increment above or below the summer range (x-axis).

5.0 Summary and Discussion

- Based on modeling the lakes for the period January through October, 2018, the adaptation scenarios of lowering Lake Mendota and removing the dams provided little benefit to flooding. In both of these scenarios, the flows through the lower lakes are limiting efficient release of water and are still prone to flooding.
- The adaptation strategy of safely managing Lake Mendota to 100 year levels provides relief to the lower lakes but at the risk of using available capacity for storage from future rainfalls.
- The mitigation scenario of removing constriction points provided little benefit overall to flooding as most improvements are gained during low water conditions.
- The mitigation scenarios of dredging and pumping produced the best results overall.
- The combination of dredging and pumping provided the largest benefit. This combination of mitigation scenarios delivered approximately 95,000 ac-feet per year by pumping water. The watershed area for the Yahara Lakes (subtracting out lake water surface area) is approximately 230,000 acres. As a result, the combination scenario would equate to storing approximately 5 inches spread evenly across the watershed. In other words, all land types such as roads, parking lots, rooftops, agriculture fields, wetlands, grasses would need to store and prevent runoff of 5 inches more water than in 2018 to equate to the mitigation scenario. For example, a ¼ acre lot would need to store approximately 34,000 gallons of rain water. Figure 33 below provides a graphical representation to relate the increased delivery of water to the same amount water stored on land.

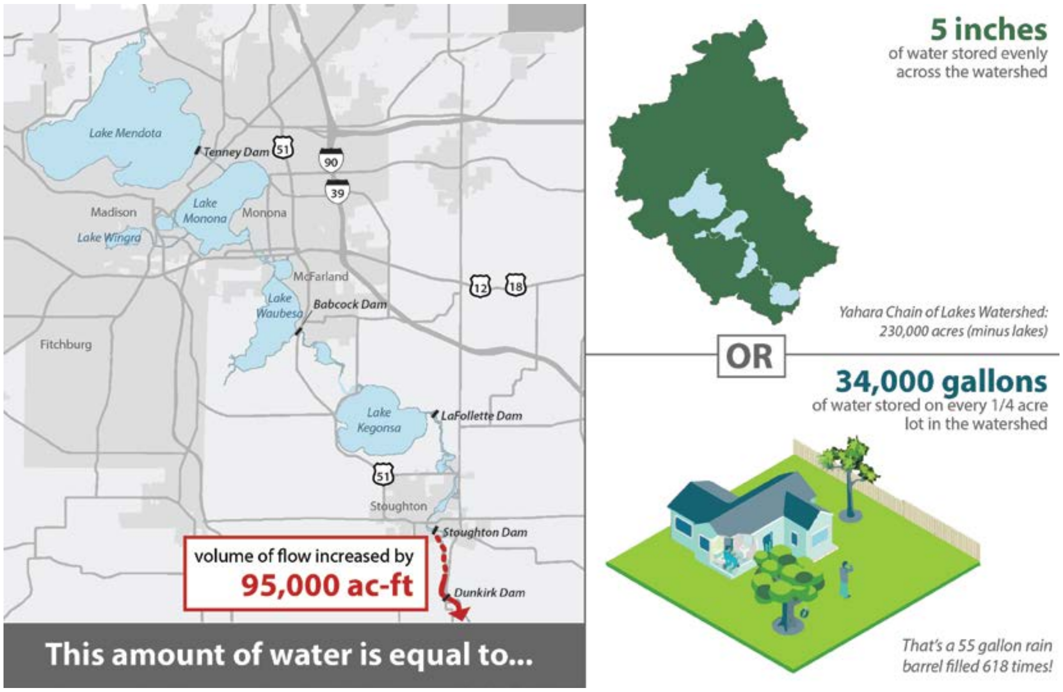


Figure 33: The increased delivery of water from pumping and dredging (left) is related to the equivalent amount of water that would be stored on land (right).

- A summary of changes to peak water levels for each scenario is presented below. In the table below, increases to peak water level are represented with a + sign and a decrease is a – sign.

Table 5: Summary of changes to peak water levels from each scenario

	Lake Mendota	Lake Monona	Lake Waubesa	Lake Kegonsa
Adaptation				
(a) Lower Lake Mendota one foot – Flood Storage	-2”	-2”	-2”	-0.5”
Lower Lake Mendota one foot – Maintain Lower	-24”	+6”	-3”	+3”
(b) Safely manage Lake Mendota at 100 year level	+6”	-6”	-6”	0”
(c) Remove all dams from the Yahara Lakes	-39”	+2”	+1”	+3”
Mitigation				
(a) Bridge Modfications	-1.5”	-2”	-2”	-0.25”
(b) Yahara River Dredging	-6”	-12”	-11”	-7”
(c) Flow Reroute and Pumping	-12”	-10”	-21”	-10”
(d) Combined (b) and (c)	-12”	-20”	-25”	-13”

6.0 Continuing Efforts

While focus in this report has been attributed to increasing river flow capacity, it is important that storm water management efforts continue for improving runoff volumes entering the Yahara Lakes. Most recently a Stormwater Technical Advisory Committee (TAC) was convened between July 2016 and April 2017. The TAC held a series of technical discussions and received stakeholder input, resulting in the following recommendations:

1. Require county-wide that new development not increase stormwater runoff volumes above pre-development levels (100% volume control).
2. Require 50% volume control for redevelopment in existing urban areas.
3. Require 100% volume control of runoff for internally drained areas (i.e. greater than 20,000 ft² of one foot or deeper ponded area); require storage volume within internally drained areas for back-to-back 100-yr, 24-hr storms; require development of emergency drawdown (pumping) plans for internally drained areas.
4. Establish a county-wide volume-trading (fee-in-lieu) program as an alternative when onsite control would be costly, inefficient, or prohibited.
5. Consider capital projects and/or grant funding for implementing volume control practices in developed areas, and in rural areas not subject to volume control regulations.
6. Develop policies and procedures to facilitate the standardization of the design and installation of infiltration practices. Currently, these TAC recommendations are more stringent than state standards and thus are only implemented on voluntary basis. Further efforts by the TAC are underway to continue expanding the work and develop innovative solutions for implementing recommendations.

In 2019 the county budget includes new initiatives to improve stormwater impacts and reduce runoff. A study will be conducted to assess restoration of the Door Creek wetlands that were inundated with water through the summer, preventing worsening flood conditions for homes in the Towns of Dunn and Pleasant Springs. Door Creek is identified as a potential “Suck the Muck” location, and the study goals are intended to identify restoration of the Door Creek system that improves water quality, adds flood storage, and improves fish habitat. Also, a new Dane County Conservation Reserve (CRP) Program will be created to convert lands at greater risk of runoff to prairies and grasses, which are more able to hold soil and reduce water runoff. This Dane County CRP program ($750,000) will provide funding to farmers and property owners to convert lands to permanent cover for projects that reduce runoff and erosion. Furthermore, $8 million was added to the budget for conservation acquisitions with a goal of permanently securing properties that improve the county’s ability to reduce stormwater runoff and improve water quality. Lastly, Dane County supports an urban water quality grant program ($1 million added funding) offered to municipalities that apply for funding. New in 2019, the grant program will fund projects that provide stormwater volume control.

Also, the 2019 Dane County budget invests in strategies to improve flow in the Yahara River system. A new $2 million initiative is created to analyze and restore potential locations in the river where water flow may be constricted. Also, two new aquatic plant harvesters and a hydraulic crane that will mount to an existing barge will be added to the county’s fleet to improve removal of aquatic plants, trees and other large items of debris that restrict flow in the Yahara River. Currently, construction is underway to replace the Highway AB Bridge that crosses the Yahara River. As part of the construction, the pier depths are being modified to accommodate potential future dredging efforts in the river to improve water flow.

Lastly, the 2019 Dane County budget includes enhancing its emergency response capabilities. County government issued over 400,000 sandbags and deployed two sand-bagging machines during the August rains and subsequent flooding. The budget includes dollars to acquire three additional fast-fill sand bagging machines, another 250,000 sandbags, large pumps to move volumes of water off roads and other critical infrastructure, and portable generators that can keep services needed in an emergency situation when power is out. Also, a new airboat will be purchased to help with high water rescues. To ensure a seamless public safety response, a new web-based phone communication system will be acquired to assist the 911 Center. The budget also includes funds to provide emergency housing for those with special needs who are displaced or need to be moved from harm's way in a short time frame.

Flood risk in Dane County has been increasing and will likely continue to increase unless vital actions are taken. The 2019 Dane County budget recognizes the need and proposes a total of over $18 million for investing in strategies that reduce risk and improve preparedness in the event of future flooding. As a community it is essential that all units of government including state, cities, villages, towns, and the county work together and invest in strategies that reduce risk and improve preparedness to future flooding. This goal of this report is to increase our awareness, improve our understanding, and provide possible scenarios to be resilient for future flooding for the Yahara River Chain of Lakes.

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Appendix I – Dane County Board Resolution 2018 RES-227

2018 RES-227

ESTABLISHING A TECHNICAL WORK GROUP TO ADDRESS RECENT FLOODING
IN THE YAHARA CHAIN OF LAKES

Climate change is increasing the frequency of wetter conditions, more severe storms and threats to public health, safety and public and private property. This summer storms have caused dramatic and unprecedented flooding damage across the County including historic high water levels on the Yahara Chain of Lakes and severe flooding in Madison's Isthmus, resulting in financial damages exceeding $78,287,645 to residents and $37,114,219 to businesses with approximately only 2% of those damages insured.

Lake levels for the Yahara Chain of Lakes (Mendota, Monona, Waubesa, Kegonsa) are managed by Dane County in accordance with Wisconsin Department of Natural Resources lake level orders developed in 1979.

Similar to flood events of 1993, 2000, and 2008, the events of 2018 call the questions of:

1. How to manage our lakes and reduce flooding with ever increasing volumes of water, mostly attributed to climate change and urban development;
2. How to improve the volume of water leaving the Yahara River system, a chain of impounded lakes connected by low gradient (relatively flat) river with obstructions by 31 bridges and railroad crossings, aquatic plants and sediment deposits; and
3. How to reduce stormwater runoff volumes through increased stormwater infiltration and better management of stormwater on impervious surfaces.

These questions must be asked within the larger context of the powers of the Wisconsin Department of Natural Resources (WI DNR) "to promote safety, and to protect life, health, property, property values, and economic values" and to "regulate and control the level and flow of water in all navigable waters…" (Chapter 31.02 Wis Stats).

NOW, THEREFORE BE IT RESOLVED, that the Land & Water Resources Department shall immediately convene a technical work group that may include representation from the University of Wisconsin and other experts to evaluate lake level conditions, model various scenarios that include predicted climate changes, identify short- and long-term approaches to improve resiliency for future events by February 1, 2019.

BE IT FUTHER RESOLVED, that the Lakes and Watershed Commission in cooperation with the Environment Agriculture and Natural Resources Committee shall convene a task force to review the findings of the technical work group and make policy recommendations prior to March 31, 2019.

BE IT FURTHER RESOLVED, that the task force shall comply with the meeting requirements set forth in Chapter 7 of the Dane County Code of Ordinances.

BE IT FURTHER RESOLVED, that Dane County will continue to prioritize the aggressive harvesting of aquatic plants, including native species, in the Yahara River to improve water flow through the system.

BE IT FURTHER RESOLVED, that, consistent with the Lake Level Management Guide that calls for attaining minimums in the fall and winter, Dane County will continue to implement any tools that may be available to lower lake levels to DNR designated minimum levels as soon as possible and work to maintain lakes at that level until the County Board acts on recommendations from the task force.

Appendix II – Technical Work Group Members

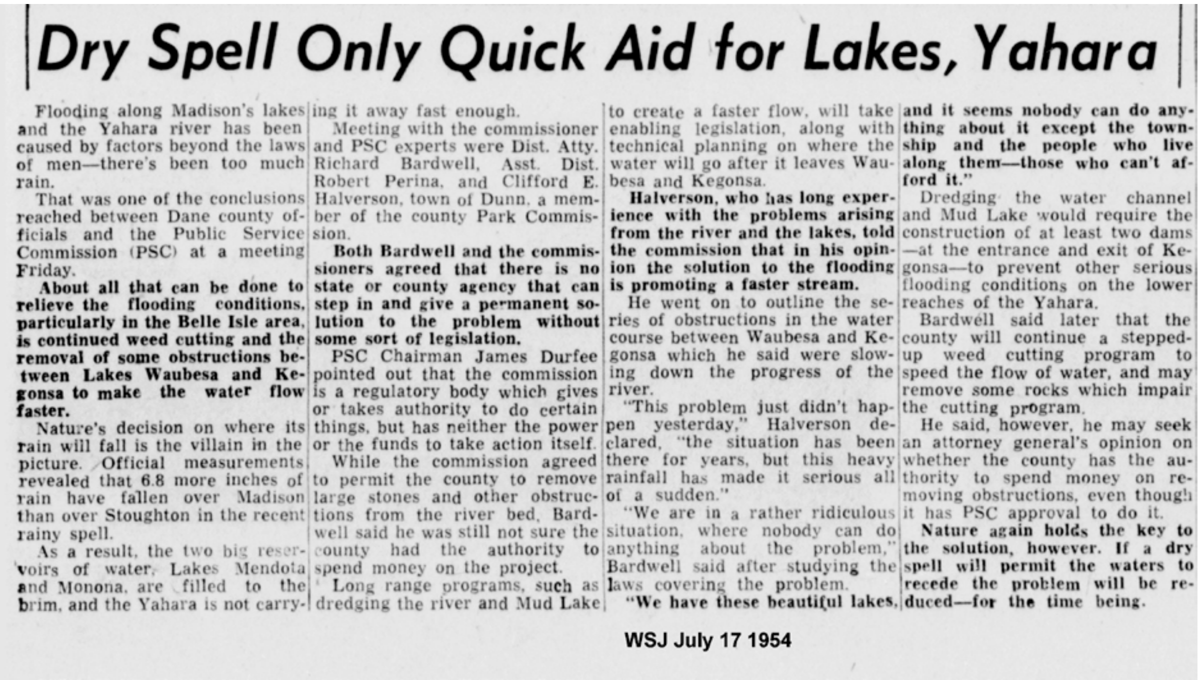
Technical Work Group Members:

Shelly Allness – WDNR, Policy Advisor
Jeremy Balousek – Dane County Land & Water Resources Department
Rob Davis – WDNR, Dam Safety
Greg Fries – City of Madison Engineering
Josh Harder – Dane County Land & Water Resources Department
Dick Lathrop – University of Wisconsin Madison, Limnology
Ken Potter – University of Wisconsin Madison, Civil & Environmental Engineering
John Reimer – Dane County Land & Water Resources Department
Chin Wu – University of Wisconsin Madison, Civil & Environmental Engineering

Other Participants from WDNR:

Dan Oele (Fisheries Biologist)
Dave Rowe (Fishery Team Supervisor)
Travis Schroeder (Waterway and Wetland Supervisor)
Wendy Peich (Waterway Regulation)
Eric Rortvedt (Stormwater Engineer)
Laura Bub (Runoff Management Field Supervisor)
Jim Amrhein (Water Quality Biologist)
Susan Graham (Aquatic Plant Management)
Mike Sorge (Water Resources Field Supervisor)
Jake Donar (Conservation Warden)
Andy Barta (DOT Liaison)

Appendix III– 1954 Flooding Article



Dry Spell Only Quick Aid for Lakes, Yahara

Flooding along Madison's lakes and the Yahara river has been caused by factors beyond the laws of men—there's been too much rain.

That was one of the conclusions reached between Dane county officials and the Public Service Commission (PSC) at a meeting Friday.

About all that can be done to relieve the flooding conditions, particularly in the Belle Isle area, is continued weed cutting and the removal of some obstructions between Lakes Waubesa and Kegonsa to make the water flow faster.

Nature's decision on where its rain will fall is the villain in the picture. Official measurements revealed that 6.8 more inches of rain have fallen over Madison than over Stoughton in the recent rainy spell.

As a result, the two big reservoirs of water, Lakes Mendota and Monona, are filled to the brim, and the Yahara is not carrying it away fast enough.

Meeting with the commissioner and PSC experts were Dist. Atty. Richard Bardwell, Asst. Dist. Robert Perina, and Clifford E. Halverson, town of Dunn, a member of the county Park Commission.

Both Bardwell and the commissioners agreed that there is no state or county agency that can step in and give a permanent solution to the problem without some sort of legislation.

PSC Chairman James Durfee pointed out that the commission is a regulatory body which gives or takes authority to do certain things, but has neither the power or the funds to take action itself.

While the commission agreed to permit the county to remove large stones and other obstructions from the river bed, Bardwell said he was still not sure the county had the authority to spend money on the project.

Long range programs, such as dredging the river and Mud Lake to create a faster flow, will take enabling legislation, along with technical planning on where the water will go after it leaves Waubesa and Kegonsa.

Halverson, who has long experience with the problems arising from the river and the lakes, told the commission that in his opinion the solution to the flooding is promoting a faster stream.

He went on to outline the series of obstructions in the water course between Waubesa and Kegonsa which he said were slowing down the progress of the river.

"This problem just didn't happen yesterday," Halverson declared, "the situation has been there for years, but this heavy rainfall has made it serious all of a sudden."

"We are in a rather ridiculous situation, where nobody can do anything about the problem," Bardwell said after studying the laws covering the problem.

"We have these beautiful lakes, and it seems nobody can do anything about it except the township and the people who live along them—those who can't afford it."

Dredging the water channel and Mud Lake would require the construction of at least two dams—at the entrance and exit of Kegonsa—to prevent other serious flooding conditions on the lower reaches of the Yahara.

Bardwell said later that the county will continue a stepped-up weed cutting program to speed the flow of water, and may remove some rocks which impair the cutting program.

He said, however, he may seek an attorney general's opinion on whether the county has the authority to spend money on removing obstructions, even though it has PSC approval to do it.

Nature again holds the key to the solution, however. If a dry spell will permit the waters to recede the problem will be reduced—for the time being.

WSJ July 17 1954

Appendix IV– INFOS Details

In this report, the Integrated Nowcast Forecast Operation System (INFOS) to evaluate how alternative strategies for managing the lakes would have performed in 2018. INFOS incorporates a suite of integrated models that feature hydrologic process for runoff and hydraulic river flows and water levels (Figure 5). The hydrologic model is used to predict runoff discharge from tributaries into the Yahara Lakes. The Soil and Water Assessment Tool (SWAT) is employed which considers topography, land use, soils, and climate (rainfall, snow, temperature). The model is constructed with DEM data of 10 feet horizontal spacing. Land use and cover data provide model parameters such as overland flow friction (roughness). Soil data from the Soil Survey Geographic Database was obtained from the USDA Natural Resources Conservation Service (NRCS). SWAT simulations were conducted with the Green and Ampt infiltration equation using hourly rainfall data (Arnold, 1998). A total of 201 subwatersheds were created ranging from 0.5 to 15 square miles (see Figure 5). Output results from the SWAT hydrologic model serves to provide water inputs to the hydraulic model. Specifically, hydraulic modeling is performed with the Finite Volume Coastal Ocean Model (FVCOM), developed by Chen et al. (2003) and has been successfully utilized for modeling the Yahara Lakes (Reimer and Wu, 2016). The hydraulic model solves the continuity equation, momentum equation, and temperature equation under hydrostatic pressure assumption on horizontal unstructured meshes with a vertical sigma coordinate system. For additional model details and application for the Yahara Lakes, readers are referred to Reimer and Wu, 2016.

The hydraulic model domain is constructed with what is referred to as unstructured mesh. In particular, the mesh defines flood extents and lake volumes constructed from DEM topography and bathymetry data. The 500 year floodplain was mapped to define extents of the model domain as shown by the cyan grid in Figure 5. The unstructured meshes characterize different sizes of lakes and rivers. The meshes are designed to have smaller sizes (~ 1 foot) in rivers and larger sizes (~350 feet) in lakes, allowing for accurate representation of the river hydraulics and reliable characterization of lake water storage. As shown in Figure 5, the meshes overlay the water surface (shown in blue) and land surfaces (cyan) for the 500 year floodplain. The multi-scale of meshes, for the rivers to lakes, maintains optimal number of meshes, to reduce model computational time.

Model simulations are executed using a high performance computing (HPC) server. The modeling server is equipped with parallel computing to provide timely results. In the modeling configuration, the time ratio of run time to modeled time is 1:72. In other words, to simulate the 2018 year requires about 4 days of computing.