Kiser Lake Nutrient Assessment and Management Recommendations

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Prepared for

U.S. Environmental Protection Agency, Region 5

and

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Contents

1. Introduction

USEPA is providing technical assistance to Ohio to advance the State's nutrient reduction efforts, specifically focusing on reducing the occurrence and impact of harmful algal blooms (HABs) in inland lakes, with a priority for lakes that are sources of drinking water. This conceptual lake management plan has been developed as a part of that effort for Kiser Lake, in west central Ohio (Figure 1). The lake management plan includes the following:

- Evaluation of the available water quality data for the lake and its tributaries;
- Assessment of current data gaps and monitoring recommendations for filling those gaps;
- Evaluation of available data relative to the potential for HABs;
- Recommendations for managing internal lake nutrient loading and nutrient loading from the watershed to maintain and improve water quality and limit the occurrence of HABs.

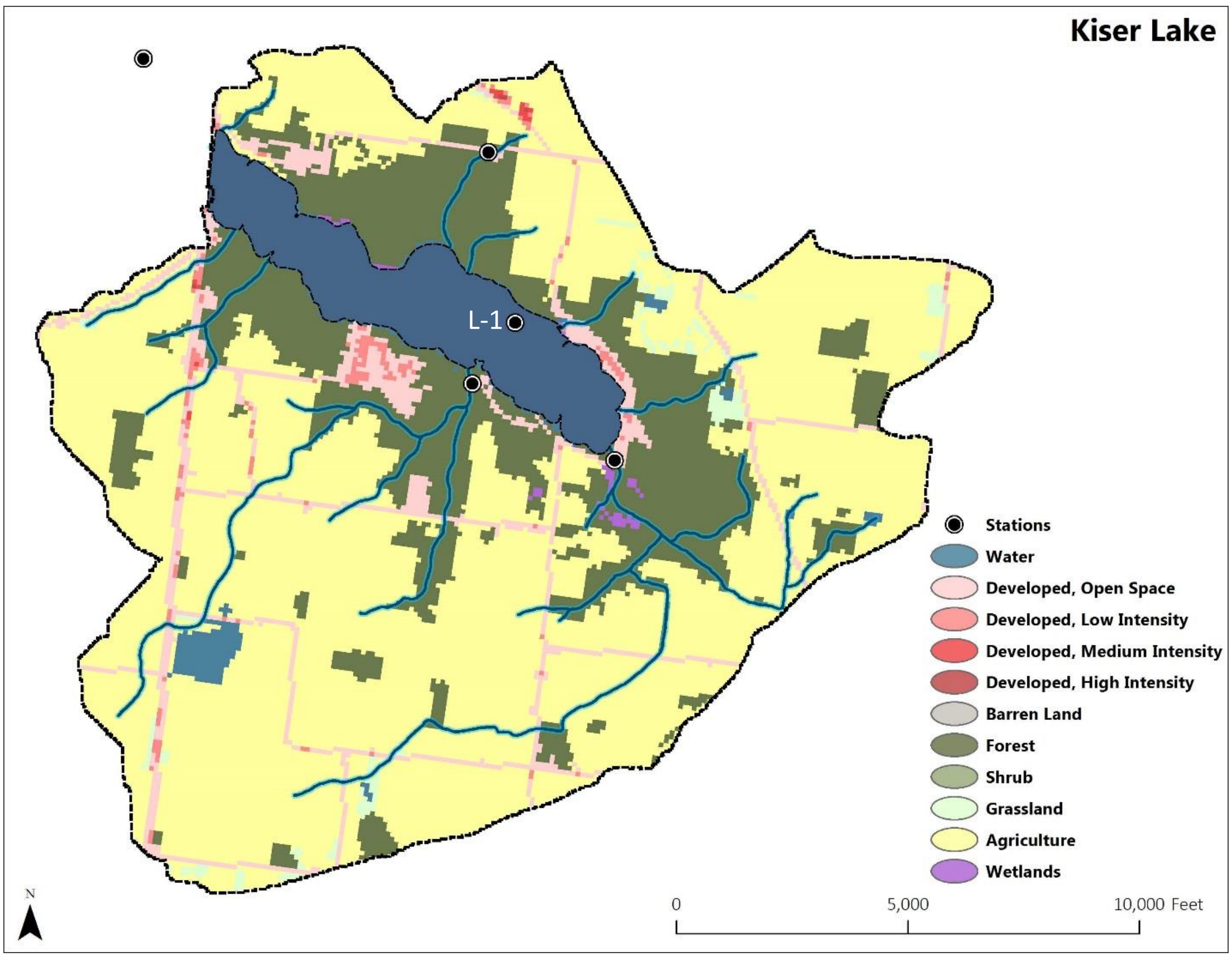

Figure 1. Kiser Lake Watershed.

2. Background

Kiser Lake is located in Champaign County approximately 60 miles northwest of Columbus, and 35 miles north of Dayton, Ohio and is managed by the Ohio Department of Natural Resources (ODNR) as part of Kiser Lake State Park. The lake has a surface area of 394 acres (160 ha), a mean depth of approximately 6.2 feet (1.9 meters (m)), with a maximum of depth of 12 feet (3.7 m) and 5.5 miles (8.9 km) of shoreline (Figure 2). The lake is relatively shallow with dense vegetation, including large areas of lily pads. Boat motors are not permitted within the lake. The hydraulic residence time of the lake is 0.45 to 0.58 years according to two sources (Fulmer and Cooke 1990; Ohio EPA 2009). Although this translates to a flushing rate of about twice a year, it is enough time to allow for retention of nutrients from the watershed that could increase the potential for nutrient recycling within the lake and for algal blooms to potentially develop.

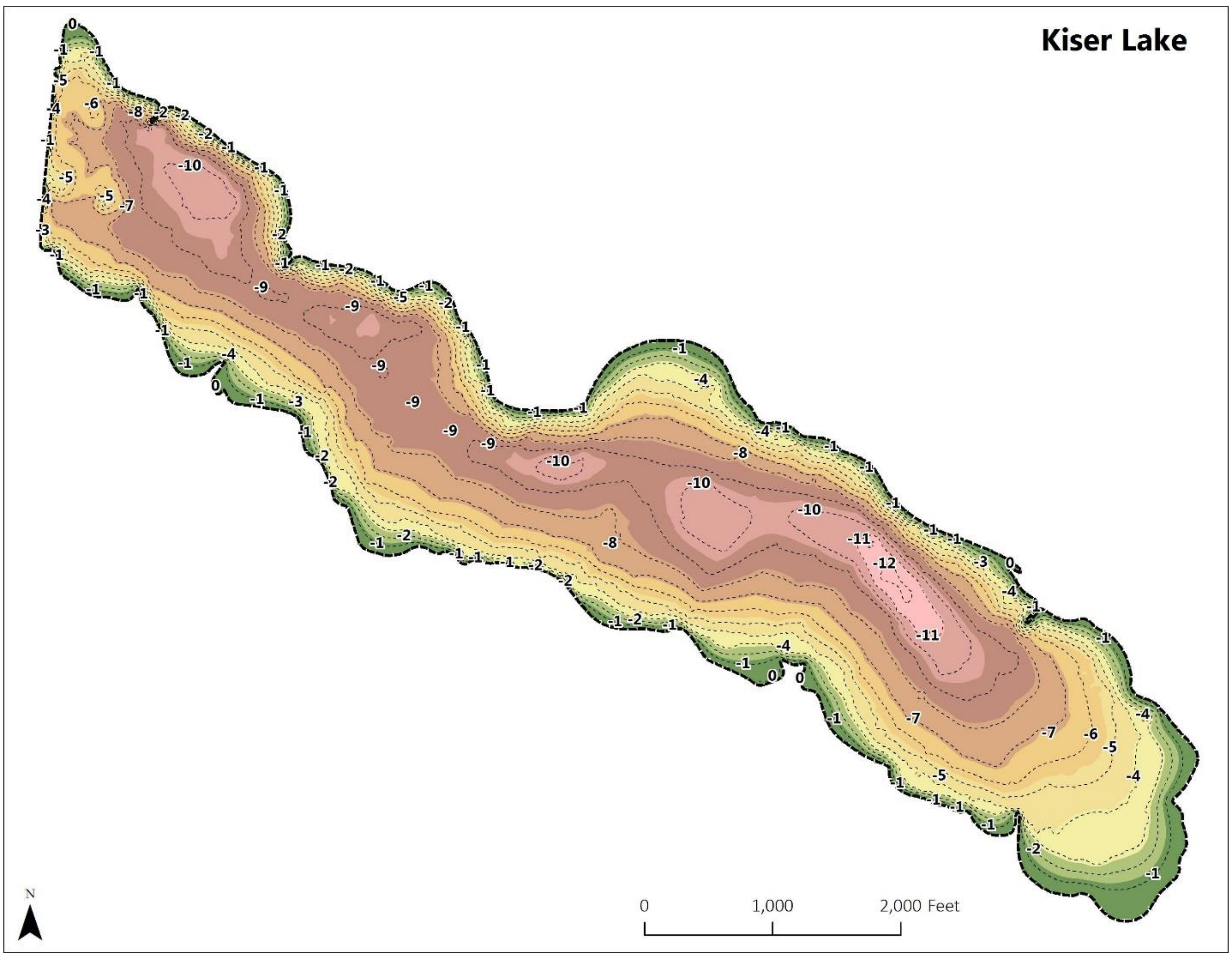

Figure 2. Kiser Lake Bathymetric Map.

In 1840, a dam was erected on Mosquito Creek to furnish power for a grist and saw mill. When power was no longer needed for this operation, the dam was neglected and most of the lake was lost. The Kiser family expressed interest in rebuilding the lake in 1932 and offered several hundred acres of the Mosquito Creek Valley to the state of Ohio. Construction of the new dam began in 1938 and in 1940 all work on the spillway, dam, and bridges was completed and the valve was closed for the first time (ODNR 2016).

Kiser Lake is surrounded by gently rolling, wooded hills created by glacial deposits in the form of end moraines resulting from the ice margin remaining "stationary for a period of time, creating a linear ridge along the ice front. One such moraine (called the Farmersville) surrounds the lake on three sides creating a hummocky[1] elevation through the area. Moraine deposits containing boulders, some weighing many tons, were carried from as far away as Canada. These boulders, called erratics, are a familiar sight at Kiser Lake. Another geologic feature at Kiser Lake State Park is the kame field at the southeastern end of the lake. Kames are mounds of sand and gravel that are formed by meltwater flowing across glacial ice. The water deposits sediment into holes along the ice margin leaving behind hummocky mounds" (ODNR 2016).

"The wetlands at Kiser Lake are in the form of fen and wet meadow habitat. These areas were formed when blocks of ice broke away from the glacier and became covered by sand and gravel. As the climate warmed, the ice melted and left a depression filled with water surrounded by glacial deposits. These areas are filled with many intriguing plants including pitcher plant, sundew, tamarack and spruce" (ODNR 2016).

The Kiser Lake watershed is approximately 5,332 acres (2160 ha). The watershed to lake surface area yields a 13.5:1 surface area ratio, which is an average ratio for a lake with flushing rate of approximately twice per year. This is a typical ratio for a lake that has a flushing rate of approximately twice per year. The watershed land-use primarily consists of cultivated cropland (54%), with remaining land use of forest (21%), hay/pasture (8%), and developed land (7%) (Figure 1). There is one larger sized community within the watershed, the Village of Grandview Heights, which is on the south side of the lake. This community has around 70 homes and uses on-site sewage systems. There are approximately 100 additional homes within the watershed. Near the northern edge of the watershed there is an animal feeding operation, a dairy with approximately 400 cows.

3. Evaluation of Existing Water Quality

Tetra Tech reviewed and evaluated all available water quality monitoring data for Kiser Lake, both recent (2015) and historical, as well as existing study plans and trophic state analyses. All information provided by Ohio EPA and/or gathered by Tetra Tech was used to further understand and assess the nutrient loading dynamics to Kiser Lake as well as to identify where more information needs to be collected to refine potential management strategies.

3.1. Assessment of Existing Water Quality and Nutrient Dynamics

Water quality monitoring efforts at Kiser Lake by Ohio EPA were most recently conducted in September and October 2015. Historical monitoring efforts at Kiser Lake by Ohio EPA include those conducted in 1977, 1989, 2009, and 2010. Kiser Lake was briefly studied by Dennis Cooke and Donald Fulmer from Kent State University in 1989 and was also part of the National Lakes Assessment in 2007. During all

[1] Hummocky cross-stratification is a type of sedimentary structure found in sandstones. It is a form of cross-bedding usually formed by the action of large storms, such as hurricanes. It takes the form of a series of "smile"-like shapes, crosscutting each other.

monitoring activities at Kiser Lake samples were collected at one main lake station (L-1). Tributary sampling was conducted in 2010 and 2015 by Ohio EPA on two main inflows (Mosquito Creek at Kiser Lake Road and a tributary to Mosquito Creek near mouth). In 2015, Ohio EPA also collected a sample on an unnamed tributary near Airport Road just south of Snapp Road in the northern part of the watershed. Samples were collected by Ohio EPA in Mosquito Creek downstream of Kiser Lake (outflow from the lake) in 2009, 2010 and 2015. These monitoring locations are shown in Figure 1 and indicated by black dots.

3.1.1. Kiser Lake Water Quality

Kiser Lake is a shallow, hyper-eutrophic lake as indicated by high concentrations of total phosphorus (TP) and chlorophyll (chl) and low water transparency (Secchi disk depth) (Table 1). Nuisance algal blooms caused by excess nutrient concentrations have started to become more common at Kiser Lake and in some cases have produced toxins (i.e., microcystin). In July 2015, microcystin was detected in samples collected at the Kiser Lake State Park Beach above both the Recreational Public Health Advisory (6 µg/L) and the Recreational No Contact Advisory (20 µg/L) concentrations (Ohio EPA 2016). Microcystin concentrations at the Kiser Lake State Park Beach were measured at 42, 7, 63, and 79 µg/L (July 10, 11, 13, 20, respectively). Although concentrations of microcystin were detected at levels above the Recreational No Contact Advisory at Kiser Lake in July 2015 the state of Ohio issued only a public-health advisory because there were no reported probable cases of human illness or pet deaths as a result of the bloom. This was the first bloom at Kiser Lake to prompt a health advisory (Columbus Dispatch, July 14th, 2015).

The occurrence of cyanobacteria that generate toxins above public health advisory limits is directly related to the supply of nutrients, particularly phosphorus. Phosphorus is most often the limiting nutrient for phytoplankton production in freshwater systems, especially when the nitrogen:phosphorus ratio consistently exceeds 7:1 (Smith, 1979). Total phosphorus (TP) concentrations measured at the surface (0.5 m) and bottom (3 m) in Kiser Lake in September and October 2015 are summarized in Table 1, as are historical TP concentrations. Summer (June through September) averages of TP, chl, and Secchi disk depth were calculated for 1989, 2009, and 2010 (Table 2) as these were the years with the most complete summer datasets.

Recent TP concentrations are much lower than those observed historically and there is some concern that the recent TP data may be an underestimate of actual phosphorus concentrations in the lake. The confidence in the recent TP data is low given the difference between recent and historical data, as well as the magnitude of recent TP concentrations with respect to other water quality variables. For example, the chl:TP ratios for the recent (2015) Kiser Lake samples are 1.4 and 2.1, which are much higher than one would expect, even in a hyper-eutrophic system. The average chl:TP ratio for lakes, globally, is 0.25 to 0.35. A highly productive (eutrophic to hyper-eutrophic) lake/reservoir could have chl:TP ratios as high as or near 1.0. Nevertheless, it is apparent from the historical TP data as well as recent chl and Secchi disk depth data that Kiser Lake is hyper-eutrophic and suffers from excess nutrients.

There does not appear to be a significant difference between surface and bottom TP concentrations in Kiser Lake, although the number of bottom samples collected is low (n = 5). This is not surprising given the shallowness of the lake (mean depth of 1.9 m) and the recent temperature profiles showing an unstratified water column (Figure 3). Dissolved oxygen (DO) concentrations in Kiser Lake in September and October 2015 are shown in Figure 4. Dissolved oxygen concentrations in September were slightly lower than saturation (64 to 77%) while concentrations in October were above saturation (105 to 113%) in the top 1.5 m and below saturation (45 to 79%) in the bottom 2 m. Given the high concentration of chl measured in September and October 2015, it is likely that DO was being driven by photosynthetic activity in the epilimnion.

Table 1. Historical and Recent Water Quality Data for Kiser Lake

Date	Depth (m)	Total Phosphorus (µg/L)	Ortho-Phosphorus (µg/L)	TKN (µg/L)	NO2+NO3 (µg/L)	NH4 (µg/L)	Chl (µg/L)	Secchi (m)	Chl:TP	Data Source
4/22/1977	surface	70	--	--	--	--	39	0.64	0.56	1
8/19/1977	surface	120	--	--	--	--	149	0.37	1.2	1
4/20/1989	0.3	36	0	800	1,380	50	--	0.31	--	1
4/20/1989	3	40	0	1,100	1,360	50	--	--	--	1
6/14/1989	surface	106	--	--	--	--	20.6	0.56	0.19	2
8/8/1989	surface	128	--	--	--	--	109	0.51	0.85	2
8/17/1989	0.3	60	10	1,200	--	--	79.1	0.33	1.3	1
8/17/1989	2.7	100	--	1000	--	--				1
7/31/2007	1.16 (integrated)	108	--	1,166 (TN)	5	30	34.8	0.61	0.32	3
6/16/2009	surface	65	ND	1,230	ND[5]	ND[5]	48.6		0.75	1
7/1/2009	surface	80	ND	770	ND[5]	ND[5]	69.3	0.99	0.87	1
7/9/2009	surface	81	ND	960	ND[5]	ND[5]	47.6	1.02	0.59	1
8/6/2009	surface	107	ND	1,040	ND[5]	ND[5]	54.6	0.56	0.51	1
9/22/2009	surface	121	ND	1,370	ND[5]	ND[5]	124	0.46	1.0	1
6/16/2010	surface	ND[4]	10	1,210	ND[5]	ND[5]	123	1.10	24.6[4]	1
6/16/2010	bottom	92	ND	1,250	180	ND[5]	--	--	--	1
7/21/2010	surface	72	ND	1,130	ND[5]	ND[5]	93.3	0.53	1.3	1
8/4/2010	surface	77	ND	940	ND[5]	ND[5]	66.7	0.38	0.87	1
8/18/2010	surface	110	ND	1,270	ND[5]	ND[5]	84.8	0.33	0.77	1
9/23/2010	surface	44	ND	1,250	ND[5]	ND[5]	65.3	0.35	1.5	1
9/21/2015	surface	33	13.8	810	ND[5]	ND[5]	46.2	0.57	1.4	1
9/21/2015	bottom	37	17.6	810	ND[5]	ND[5]	--	--	--	1
10/6/2015	surface	17	9.8	580	120	ND[5]	35.5	0.69	2.1	1
10/6/2015	bottom	10	10	1,120	ND[5]	ND[5]	--	--	--	1

[1]Ohio EPA; [2]Fulmer and Cooke 1990; [3]National Lakes Assessment 2007; [4]TP sample data suspect and was qualified as UJ, PT (analyzed outside of the holding time); [5]Reported NO2+NO3 and NH4 values from 2009 to 2015 are suspect given that the tributary inlets were as high as 3.7 and 23.5 mg/L; refer to Table 3.

Table 2. Summer Mean TP, Chl and Secchi Disk Depth for Kiser Lake.

Year	Summer (June - September) Mean		
	TP (µg/L)	Chl (µg/L)	Secchi Disk Depth (m)
1989	99	69.7	0.47
2009	91	68.8	0.76
2010	79	86.6	0.54

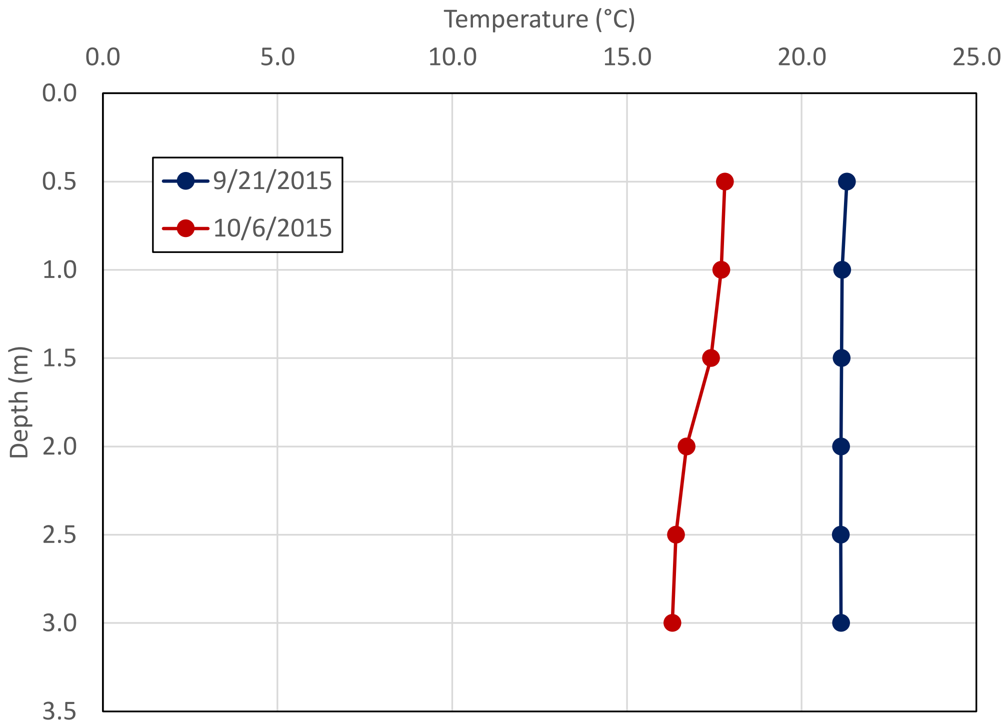

Figure 3. Temperature Profiles in Kiser Lake, September and October, 2015.

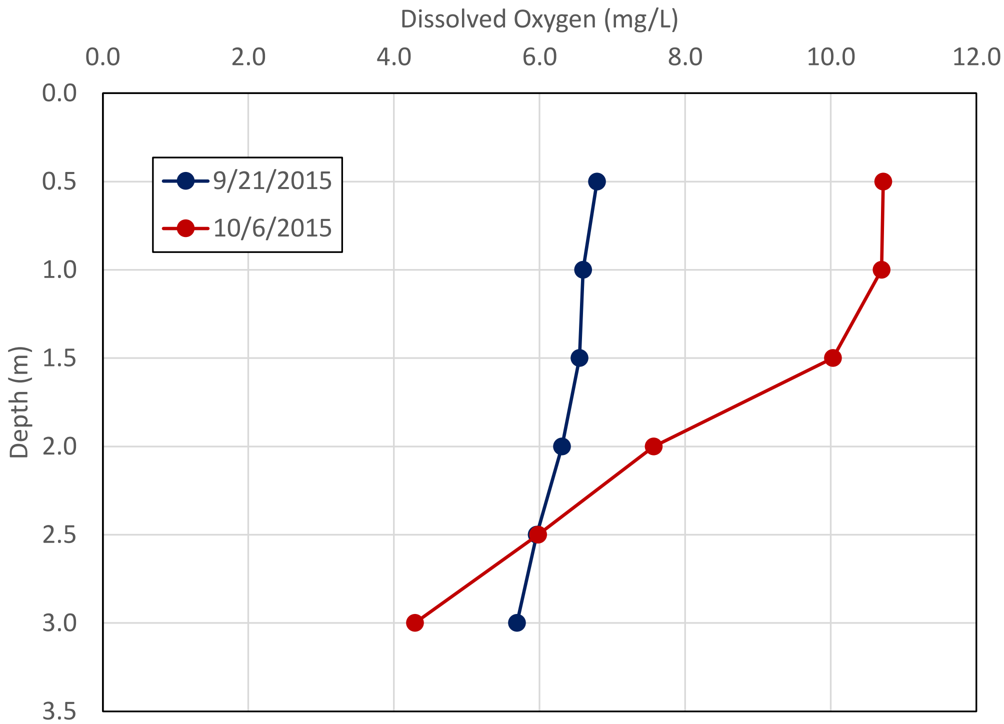

Figure 4. Dissolved Oxygen Profiles in Kiser Lake, September and October, 2015.

3.1.2. Kiser Lake Tributary Water Quality

Kiser Lake has multiple tributaries, many of which are minor. The largest tributary (inflow) is Mosquito Creek which enters the lake on the eastern shore (Figure 1). There is a limited amount of water quality data for the tributaries entering Kiser Lake. In 2010, Ohio EPA collected three samples on two of the larger tributaries: Mosquito Creek (the main inflow) and a smaller tributary that enters the lake on the southeast side (Figure 1). One of those samples (August 4th), was collected following a minor runoff event. In October 2015, during a storm event, Ohio EPA collected samples at these two locations, plus an additional small tributary below a dairy operation in the northern part of the watershed. Table 3 summarizes the water quality data for tributaries entering Kiser Lake during 2010 and 2015.

TP concentrations in the tributaries were much higher in 2015 than in 2010 even when comparing only storm event concentrations (10/29/2015 and 8/4/2010). The TP concentrations in 2010 seem exceptionally low given that the watershed consists mostly of agricultural lands. Nitrogen concentrations (all species) also varied between the two years, with higher concentrations of TKN and Nitrite+Nitrate (NO2+NO3) occurring in 2015 and ammonia (NH4) being higher in 2010. Overall, phosphorus (TP and Ortho-P) were higher in the smaller tributaries than in Mosquito Creek. The sample collected in the small tributary downstream of the dairy operation had the highest TP, Ortho-P, TKN, and NO2+NO3 concentrations of all the tributary samples in either 2010 or 2015. Ammonia concentrations in this tributary were also high during the 2015 sampling event and were similar to those measured in 2010 in Mosquito Creek.

Comparing 2010 tributary TP concentrations to TP concentrations in Kiser Lake, the tributary concentrations of TP in 2010 are much lower than those measured in the lake. This indicates that there is an internal source of phosphorus contributing to the TP concentration within the lake, which could be a driving factor of nuisance algal blooms (assuming the 2010 tributary TP concentrations are reliable and representative of the lake).

A comparison of 2015 TP concentrations between the tributaries and lake is not feasible given that the tributary samples were collected after the lake samples. In order to confirm whether an internal source of phosphorus is contributing to the TP concentration of Kiser Lake, more routine (monthly to twice monthly) tributary and lake sampling is necessary. Without this data, the possible internal loading indicated by the 2010 data cannot be confirmed.

Table 3 indicates that there were very high NO2+NO3 concentrations and very low NH4 concentrations in several of the storm event samples. This suggests a source of newly generated nitrogen directly entering the streams.

Table 3. Water quality data for tributaries entering Kiser Lake. Samples collected right after or during a storm event are indicated with an asterisk.

MOSQUITO CREEK @ KISER LAKE RD. (CO. RD. 19)

Year	Date	Total Phosphorus (µg/L)	Ortho-Phosphorus (µg/L)	TKN (µg/L)	NO2+NO3 (µg/L)	NH4 (µg/L)	Chl (µg/L)	FLOW (cfs)
2010	7/21/2010	ND	ND	240	2,320	90	0	1.782
	8/4/2010*	20	ND	470	1,810	116	0.7	2.15
	8/18/2010	ND	ND	340	2,110	100	0.3	1.111
2015	10/29/2015*	70	45	500	3,700	ND	--	--

TRIB. TO MOSQUITO CREEK (9.50) NEAR MOUTH (Southeast shore)

Year	Date	Total Phosphorus (µg/L)	Ortho-Phosphorus (µg/L)	TKN (µg/L)	NO2+NO3 (µg/L)	NH4 (µg/L)	Chl (µg/L)	FLOW (cfs)
2010	7/21/2010	ND	ND	ND	120	ND	0	0.124
	8/4/2010*	29	ND	ND	170	ND	1.2	0.141
	8/18/2010	18	ND	240	ND	ND	0.6	0.108
2015	10/29/2015*	171	109	640	1,410	ND	--	--

KISER TRIB. @ SNAPP ROAD (below Dairy Operation in northern part of watershed)

Year	Date	Total Phosphorus (µg/L)	Ortho-Phosphorus (µg/L)	TKN (µg/L)	NO2+NO3 (µg/L)	NH4 (µg/L)	Chl (µg/L)	FLOW (cfs)
2015	10/29/2015*	597	497	1,100	23,500	91	--	--

*Storm event

3.1.3. Kiser Lake Nutrient Dynamics

To understand the magnitude and timing of external and internal phosphorus loading to Kiser Lake, a phosphorus mass balance model should be developed. A mass balance model is a valuable tool for understanding the dynamics, timing, fate, and transport of phosphorus into and within a lake which then allows one to determine the driving factor of nuisance and harmful algal blooms. Once the mass balance model is calibrated for sedimentation and internal loading, the model can then be used to run restoration scenarios to evaluate the effectiveness of potential lake management alternatives, both watershed and in-lake activities.

Due to the limited amount of water quality and hydrology data for Kiser Lake and its main inflows, a phosphorus mass balance model could not be developed. However, a general understanding of phosphorus loading is possible based on the available water quality data and the characteristics of the watershed and the lake.

3.1.3.1. Watershed Nutrient Loading

Land use within the Kiser Lake watershed is dominated by agriculture, predominately cultivated crops with some hay and pasture lands (Figure 1 and Table 4). Since tributary inflow data is limited for the Kiser Lake watershed, U.S. EPA's Spreadsheet Tool for Estimating Pollutant Load (STEPL) was used to estimate nutrient loads by land uses within the watershed. STEPL employs simple algorithms to calculate annual nutrient and sediment loads based on soil characteristics, land use data, and precipitation records.

Results from the STEPL model for the Kiser Lake Watershed are shown in Table 5. As expected based on the land use composition of the watershed, cropland was estimated as the land use that contributes the largest external load of phosphorus to Kiser Lake. The high TP concentrations in tributaries to Kiser Lake measured in October 2015 also support the conclusion that agricultural land uses contribute a large portion of the external phosphorus load to Kiser Lake. Additional water quality, as well as flow data, are required for the major tributaries to Kiser Lake to accurately assess the watershed nutrient loading.

Table 4. Land Uses within the Kiser Lake Watershed (Source: 2011 National Land Cover Database or NLCD)

NLCD Land Use	STEPL Land Use	Percentage	Acres
Open Water	Omitted	8.4	448.6
Dev. Open Space	Urban	6.2	331.8
Developed Low Intensity	Urban	0.8	44
Developed Medium Intensity	Urban	< 0.1	3.8
Developed High Intensity	Urban	< 0.1	0.9
Deciduous Forest	Forest	20.8	1107.7
Evergreen Forest	Forest	0.2	13.1
Mixed Forest	Forest	< 0.1	2.7
Grassland/Herbaceous	Pasture	1.3	68.7
Pasture/Hay	Pasture	8.2	436.1
Cultivated Crops	Cropland	53.7	2861.5
Emergent Herbaceous Wetlands	Omitted	0.2	13.1

Table 5. STEPL Total Phosphorus Loading Estimates for Kiser Lake Watershed

STEPL Land Use	Total Phosphorus Load (lb/yr)	Total Phosphorus Load (kg/yr)	Percent
Urban	383	174	7.4
Cropland	4297	1949	83.3
Pastureland[1]	322	146	6.3
Forest	154	70	3.0
Total	5156	2339	100.0

[1]Note that the loads from pasture land are based on STEPL's default loading rate for this land use category and do not account for the specific number of cattle in the watershed.

3.1.3.2. In-Lake Nutrient Dynamics

The Mosquito Valley was historically a low marshy area, dotted with numerous springs (ODNR 2016). Given this, as well as Kiser Lake's historical hyper-eutrophic water quality conditions (Table 1), the lake morphometry, and the abundant aquatic vegetation, internal loading of phosphorus is most likely occurring and has been for some time. Shallow lakes with enriched sediments from a history of high external loading, which is probably the case at Kiser Lake, typically have extensive phosphorus recycling (Cooke et al. 2005). Internal phosphorus mechanisms in a shallow lake, like Kiser Lake, include the classic sediment release through iron-redox reactions, wind resuspension, cyanobacteria uptake and migration, bacteria mineralization of sediment phosphorus, and bioturbation. However, without additional lake phosphorus samples as well as a phosphorus mass balance model, the magnitude and timing of the internal loading cannot be determined.

3.2. Data Gaps Assessment

While reviewing recent and historical data for Kiser Lake and its main tributaries it became evident that there are some fairly substantial data gaps associated with both hydrology and water quality. The largest data gap is the limited amount of reliable lake water quality data. While there are two years (2009 and 2010) where samples were collected for an extended period of time, May through September, they were mostly collected at just one depth in the lake and mostly just once per month. There is also some concern with the quality of the phosphorus data, and possibly the chl data, given the unusually large chl:TP ratios and differences between more recent data and historical data. Given this, the lake water quality data that is available is not sufficient to develop a phosphorus mass balance model nor to assess nutrient dynamics within the lake or how phosphorus dynamics impact lake productivity. Without additional data and understanding of lake water quality and internal phosphorus loading, recommendations for in-lake management strategies cannot be specified.

There are only a few data points associated with the main inflows into Kiser Lake in terms of both water quality and flow. The lack of flow data and general understanding of the hydrology/hydraulics of the lake and its watershed make it challenging to determine external phosphorus loading and to evaluate potential watershed best management practices (BMPs). General assumptions can be made based on land use categories and simple loading estimates; however, watershed BMPs should not be recommended without a greater understanding of external nutrient loading magnitude, timing, and location especially during storm water events.

Relative to understanding phosphorus dynamics in Kiser Lake there is also a need for additional data on the type and aerial coverage of both submersed and emergent rooted aquatic plants. With this additional data, the phosphorus observed within the water column in combination with the additional phytoplankton data will enable identification of the drivers for primary production. This will allow for a more comprehensive understanding of the phosphorus cycling within the lake and the timing and drivers for potential HAB production.

4. Evaluation of Potential Management Actions

This section provides a summary of recommended future monitoring activities and nutrient management strategies.

4.1. Recommended Future Monitoring Activities

After a review of the existing water quality data available for Kiser Lake and its tributaries, Tetra Tech recommends that a monitoring program be implemented which includes the following elements.

1. Tetra Tech strongly encourages Ohio EPA to collect monthly to twice monthly samples in Kiser Lake from March through October. Twice monthly samples would be most beneficial during the critical growing season months of May through September. Water samples should be collected at Station L-1 at both 0.5 m from the surface and 0.5 m from the bottom. The sampling at 0.5 m from the bottom of the lake will provide an understanding of the sediment water nutrient cycling dynamics; it might also provide insight into the cyanobacterial vertical transport of phosphorus to the upper water column during or prior to bloom events. *In-situ* measurements of temperature, DO, pH, specific conductivity should be recorded at 0.5 m increments throughout the water column at the same time water samples are being collected. During the same monitoring event, Secchi disk depth should also be measured and recorded. Water samples collected at Station L-1 should be analyzed for, at a minimum, TP, soluble reactive phosphorus-phosphate (SRP), total nitrogen (TN), nitrate+nitrite, ammonia, and chl. Tetra Tech also recommends that Ohio EPA collect monthly samples for phytoplankton analysis. There currently is no consistent information on the phytoplankton community composition and abundance within Kiser Lake. Ohio EPA should continue to test for cyanotoxins (Microcystin, etc.) if there are blooms of cyanobacteria blooms, scums appear on the lake surface, or chlorophyll concentrations exceed 10 μg/l within Kiser Lake.

2. Tetra Tech recommends that Ohio DNR/Ohio EPA install and operate level loggers on the dam of Kiser Lake as well as in the outlet structure to obtain accurate records of both lake level and outflow. There is currently no lake level information available and no information on how much water leaves the lake. Understanding the water budget of the lake and its hydraulic flushing rate are very important to determining the most effective ways to manage excess nutrient and improve water quality.

3. Tetra Tech recommends that Ohio EPA collect monthly water quality samples in the major tributaries to Kiser Lake, including the three tributaries that were sampled in October 2015 (Table 3). These monthly samples should be collected during baseflow conditions and be analyzed for the same water quality parameters as lake samples with the exception of chl. Tetra Tech recommends that Ohio EPA also collect two to three water quality samples during storm events to capture runoff conditions within these tributaries. At the time of any water quality sample, flow measurements should also be recorded within the tributaries.

4. Tetra Tech strongly encourages Ohio EPA to install the necessary equipment to obtain continuous flow data for the largest inflow into Kiser Lake, Mosquito Creek. There is a significant lack of information concerning the hydrology of the watershed and water budget of Kiser Lake. Having at least one continuous flow data logger in the watershed will allow for more accurate estimates of other tributary flow into the lake. Truly understanding how much water enters Kiser Lake will help refine the external loading of phosphorus from the watershed which will allow a more targeted approach for reducing that load.

5. Tetra Tech recommends that at least 20 percent of phosphorus and chl samples be split so they can be analyzed by an independent laboratory in addition to the Ohio EPA laboratory.

6. It is recommended that an aquatic plant survey be conducted in August to map the relative community structure, density and coverage of the macrophytes within the lake to better understand the nutrient utilization and cycling within the lake.

4.2. Potential Nutrient Management Strategies

This section presents potential nutrient management strategies for the watershed as well as Kiser Lake.

4.2.1. Watershed Nutrient Reduction Strategies

Nutrient reduction strategies that should be promoted within the Kiser Lake watershed are identified in the following section and have been identified based primarily on the characteristics of the watershed (i.e., primarily agricultural land uses with limited development around the lake). Priority locations for these practices should be identified based on the results of the recommended tributary monitoring, as well as site reconnaissance. For example, site reconnaissance should identify animal operation areas; tile outlet areas; agricultural areas with no or limited riparian buffers; and areas of rill, gully, or streambank erosion. Specific locations for these strategies cannot be identified without more data, although several of these strategies (e.g., manure management, constructed wetlands) should be targeted toward the unnamed tributary near Airport Road because of the upstream animal operation.

- Improve nutrient management, particularly by implementing 4R practices (Right source, Right rate, Right time, Right place). Improved nutrient management will maximize crop uptake of phosphorus and minimize the loss of nutrients from crop land.
- Evaluate the operation and maintenance of the on-site sewage systems in the Village of Grandview Heights, and ensure there are no systems discharging directly to the lake.
- Increase acreage using cover crops. Benefits of cover crops include reduced soil erosion, increased soil organic matter, increased soil porosity which promotes matrix flow in the soil profile; improved infiltration and reduced compaction; and improved nutrient use and water efficiency.
- Expand use of water quantity management (to the degree that agricultural land in the watershed is tiled). In addition to controlled drainage, this measure includes practices such as grassed waterways, saturated buffers, and blind inlets.
- Increase acreage under no-till and/or reduced tillage. Benefits of no-till and reduced tillage are similar to those realized from using cover crops (e.g., reduced erosion, increased soil organic matter, improved infiltration).

- Increase the use of riparian buffers and filter strips along critical streams.
- Treatment trains with alum at mouths of tributaries. Phosphorus interception by inactivation with alum could be used in tributaries before discharge to Kiser Lake. The alum injection system consists of an alum storage tank, an alum metering pump, and an injection delivery line with or without air injection for flash mixing enhancement.
- Constructed wetlands. Constructed wetlands used to treat animal wastes are typically surface flowing systems composed of cattails, bulrush, and reed plants. Before treating animal waste in a constructed wetland, storage in a lagoon or pond is required to protect the wetland from high pollutant loads that might kill the vegetation or clog pore spaces. After treatment in the wetland, the effluent is typically held in another storage lagoon and then land-applied.

4.2.2. In-Lake Nutrient Reduction Strategies

In-lake nutrient reduction strategies may be necessary in Kiser Lake if it is determined that internal loading of phosphorus is contributing to the excess nutrient load and subsequent degraded water quality. As mentioned previously, internal loading is suspected but cannot be confirmed based on the available data.

Dredging

Many shallow, eutrophic lakes do not stratify thermally making them susceptible to continual or periodic nutrient inputs from the sediment. Removal of the phosphorus-enriched layer of sediment through dredging is probably the most effective long-term solution to reducing internal phosphorus loading. The depth of sediment that would need to be removed in Kiser Lake via dredging is unknown at this time. Sediment cores should be collected from Kiser Lake in at least three different locations to determine the profile and speciation of sediment phosphorus.

Sediment re-suspension and nutrient liberation during and after dredging is the primary in-lake concern with this management strategy. The sediment interstitial waters of eutrophic lakes can have high concentrations of phosphorus and dredge agitation and wind action can move these nutrient-laden sediments into the euphotic zone of a lake, creating the potential for increased algal blooms (Cooke et al. 2005).

Unfortunately, dredging is one of the most expensive lake restoration techniques. An assessment of ten lake dredging projects averaged $17,894/hectare (ha) (in 2002 dollars) (Cooke et al. 2005). This cost includes the dredging itself plus disposal and other related costs, but not any engineering or permitting related costs. Challenges may also occur with the disposal of lake sediment if elevated concentrations of heavy metals and other toxic substances are found. Another concern with dredging is that there is a potential to impact geological conditions that allows the stored lake water to remain on the surface of the sediment and not infiltrate into the groundwater at a rate that would result in a significant lowering of the water storage capacity. As with phosphorus sediment analysis, the soil layer acting as the seal of the lake would need to be determined through analysis of sediment cores to ensure dredging activities would not result in water loss.

Nutrient Inactivation

Phosphorus inactivation is the most common and successful technique to control sediment phosphorus in lakes and provides long-term control over internal phosphorus loading. The strategy centers on chemically inactivating sediment phosphorus and thus decreasing its release from the sediments under both anoxic and oxic conditions. The formation of aluminum-bound phosphate (inactivation) effectively controls internal phosphorus loading until external phosphorus loading increases the sediment phosphorus concentration to the point where it exhausts the available aluminum supplied by the treatment. Phosphorus inactivation by aluminum sulfate (alum) also strips the water column of phosphorus, leading to an immediate increase in water clarity and reduction in algal biomass and productivity.

Internal loading of phosphorus (i.e., recycling of sediment phosphorus) can be the major source of phosphorus-causing algal blooms in both thermally stratified and un-stratified lakes (Welch and Cooke 1995). Alum has been shown to be highly effective at reducing internal loading in both shallow (un-stratified) and deep (stratified) lakes (Welch and Cooke 1999; Cooke et al. 2005). However, the effectiveness at reducing algae is often greater in shallow lakes, like Kiser Lake, because the phosphorus released from the sediment is immediately available in the lighted zone. In contrast, internally loaded phosphorus is often locked in the hypolimnion (bottom) of stratified lakes and is unavailable until fall mixing of the water column, so phosphorus inactivation might not have an immediate effect in deeper lakes.

When alum is applied to the lake surface, it instantaneously forms an aluminum hydroxide floc that settles out of the water column within 2 minutes to 2 hours. The floc travels through the water column sorbing phosphorus and other particulates (i.e. algal cells) providing an immediate increase in transparency. Once the aluminum-phosphorus complex is formed, phosphorus is biologically inactivated and wind- or fish-induced mixing back into the water column will not result in breaking that bond without a dramatic change in pH to either less than 4 or greater than 9. The aluminum-phosphorus complex will simply resettle to the bottom of the lake when the wind energy drops below a mixing threshold for the lake.

Nutrient inactivation is appropriate when internal loading is a significant phosphorus source and driving excess algal growth and degraded water quality. Effectiveness of alum treatments at reducing whole-lake total phosphorus and sediment phosphorus release rates averaged 51 and 73 percent in six un-stratified lakes, and effectiveness was maintained near that level for 5 to 11 years (Cooke et al. 2005). A properly dosed shallow lake is expected to maintain effectiveness for approximately 10 years. However, an alum treatment's effectiveness can be shortened if external loading of phosphorus from the watershed is not controlled. Additionally, many historic alum treatments that provided only short-term effectiveness were under-dosed. Dosing procedures developed in the late 1990s and refined in recent years have resulted in larger doses on the basis of measured mobile phosphorus and biogenic phosphorus in sediments (Rydin and Welch 1998, 1999).

For nutrient inactivation to be considered for Kiser Lake, at least one year's worth of monthly to twice monthly water quality data needs to be collected for both the lake and main tributaries. This data will provide a better understanding of the nutrient dynamics within the lake as well as the source of phosphorus loading. Ideally, an alum treatment would only be considered for Kiser Lake after the development of a phosphorus mass balance model; however, if internal loading is evident from an increase in lake TP concentration through the summer, without an increase in tributary TP, it could be assumed that internal loading is a factor and needs to be controlled. In lake TP not onlyincludes the phosphorus taken-up by phytoplankton but also includes TP that is brought into the column by cyanobacteria from the sediment-water interface, which is a component of internal phosphorus loading.

Aeration/Circulation

Aeration/artificial circulation has been the most often used technique in lake water quality management. Devices include pumps, jets, and diffused air. Successful aeration or water column circulation increases the oxygenation of the water column and does not induce a significant pH change or increase in turbidity. Water column DO concentrations are increased with aeration/circulation largely because water under-saturated with oxygen is brought into contact with the air.

Complete circulation has been used to reduce algal abundance through light limitation if the lake is deep enough. However, this is not the case for Kiser Lake which has a mean depth of only 1.9 m. Aeration/circulation of shallow lakes may also increase nutrient availability from the sediment with undesirable effects, such as an increase in productivity (algal biomass) (Cooke et al. 2005). Specifically, given the shallow depth (mean of 1.9 m) of Kiser Lake, aeration would possibly increase nutrient availability, as well as increase the photic zone to the entire water column resulting in an increase in productivity (algal biomass). It is unknown if Kiser Lake suffers from low DO conditions which adversely impact habitat as well as potentially increase internal loading of phosphorus. In order to assess if aeration/circulation would be beneficial to Kiser Lake a more complete set of temperature, DO, and water quality data (specifically sediment and water column iron and iron to phosphorus ratios are needed.

Shoreline Maintenance

Healthy shorelines are simply lake edges planted with shrubs, trees or perennials instead of lawn or grass to the water's edge. Reducing erosion of the lakeshore areas would help to reduce phosphorus and sediment loading to Kiser Lake and potentially improve temperature and DO conditions by allowing for re-established native vegetation. Shorelines and banks that are showing moderate to high erosion rates (indicated by poorly vegetated reaches, exposed tree roots, steep banks, etc.) can be stabilized by engineering controls, vegetation, and restoration of riparian areas.

Almost all of the shoreline of Kiser Lake is within Kiser Lake State Park making shoreline maintenance an easier management strategy to implement than if multiple private residences were along the lake.

Waterfowl Management

Waterfowl can be a major component to the nutrient loading of a lake. For example, on average the daily phosphorus load from waterfowl waste is one third of a human waste generation. This means that the direct phosphorus input into a lake from three waterfowl is equal to one human without sanitary disposal. Therefore, if there are 300 waterfowl utilizing the lake that is the same as 100 humans without sanitary waste adding phosphorus to the lake. If a large enough population utilizes the lake, phosphorus loading, mostly all in soluble form, can be a significant source contributing to the lake's eutrophication. The diet of most waterfowl consists of weeds, grass, and other vegetation, leading to a high phosphorus content in their excrement.

There are a variety of management strategies to reduce nutrient loading from waterfowl, resident and non-resident. Strategies typically recommended for resident populations include aggressive harassment using radio controlled boats and/or planes, specifically trained dogs, and noise makers, trapping and relocation, and egg addling. Other management strategies that have been effective at reducing waterfowl use of a lake include increasing riparian vegetation around the lake shoreline, using artificial swans or other artificial predatory birds as deterrents, and implementing a program prohibiting feeding of waterfowl.

A survey of resident and non-resident bird species that utilize Kiser Lake should be conducted to estimate their potential nutrient loading to the lake. Appropriate management strategies can be selected based on the number of waterfowl utilizing the lake, species of waterfowl and their potential impact to the nutrient dynamics of Kiser Lake.

Aquatic Plant Control

Aquatic vegetation in lakes provide numerous benefits to fish, waterfowl, ecological structure, and is associated with clear water quality. For most rooted aquatic plants, nutrient sources (e.g., phosphorus, nitrogen) for growth are obtained from the sediment while dissolved minerals (e.g., calcium, potassium, etc.) are commonly obtained from the water column. Rooted aquatic plants play an important role in phosphorus cycling in lakes, particularly upon decomposition. Alternatively, very dense masses of aquatic macrophytes can have deleterious effects on lake water quality as well as fish, invertebrates, and waterfowl. Specifically, water quality impacts often include disrupting DO and temperature patterns as well as increasing the internal phosphorus loading from the sediment. Methods to control nuisance aquatic vegetation include chemical (i.e., herbicides), mechanical, and physical removal options.

Aquatic herbicides approved by the USEPA are routinely applied to control nuisance growth of aquatic vegetation. Dredging and deepening of the near-shore area can affect macrophyte density by manually removing vegetation, reducing their primary nutrient source, and increasing the depth to which they can obtain light for growth. Substantial reductions of macrophytes along the shoreline could result in deleterious effects on desirable warm-water fish species that rely on submersed vegetation for cover. Dredging is very costly and disposal of dredge spoils can be problematic, particularly if toxic substances are found in the spoils. Therefore, other more cost effective management options are often prioritized over dredging for reducing aquatic vegetation. Harvesting plants is an option and is an alternative to herbicides, but there is no solid evidence that harvested and removed rooted plants reduce lake nutrient content. In fact, removal of macrophyte cover could expose bottom sediment to wind-caused resuspension and possibly exacerbate the lake nutrient problem. On the other hand, leaving plants to senesce (annual decline and decay) in the lake releases (recycles) nutrients into the water that are taken up by plant roots from bottom sediment. Nevertheless, harvesting has not been shown to effectively reduce lake nutrient content.

An aquatic plant survey should be conducted at Kiser Lake to determine the existing macrophyte community in terms of number of species as well as density and coverage. If control or reduction in the current aquatic plant community is warranted management decisions should be based on improving habitat, recreation, and overall health of the lake, not on the removal of plant material for nutrient reduction.

4.3. Refinement of Nutrient Management Strategies

Aggressive watershed nutrient management, given the available data for Kiser Lake, is warranted due to historical HAB occurrence and poor water quality conditions. This would include an education and awareness program to all watershed residents and business to inform them about their role in Kiser Lake’s environmental health and to encourage active steps they can take to reduce nutrient loading to the lake. In addition, specific nonpoint sources of nutrients need to be identified and targeted for sustainable BMP implementation. Long-term water quality and aquatic habitat conditions in Kiser Lake will not be sustainable without a reduction in external load of nutrients, especially phosphorus. The degree of reduction necessary cannot be effectively determined until more data and a phosphorus mass balance is developed. Similarly the appropriate approach to in-lake nutrient management would not be cost–effective without the development of a phosphorus mass balance and understanding of the drivers and timing of phosphorus loading to the lake.

5. Conclusions

Based upon the available data, it is apparent that Kiser Lake has water quality problems that include toxic algal blooms, degraded water quality, and reduced aquatic habitat that place restrictions of the recreational beneficial uses of the lake. The current lake conditions are due to legacy nutrients within the lake sediments and on-going loading from the watershed. Additional data are needed to refine and predict the level of management activity needed in both the watershed and lake to meet the management goals for water quality and safe recreational uses. Nevertheless, watershed management through enhanced public awareness and BMP development for nutrient controls should start immediately. Intermediate phosphorus inactivation and water column stripping can also be undertaken to reduce the occurrence and intensity of HABs, with the understanding that the final intensity of inactivation and possibility for other in-lake activities will most likely have to follow once a phosphorus mass balance is developed.

6. References

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7. Glossary of Terms

The following definitions describe keywords used in this plan.

Term	Definition
Abundance	An ecological concept referring to the relative representation of a species in a particular ecosystem. It is usually measured as the large number of individuals found per sample.
Algae[1]	Small aquatic plants that occur as single cells, colonies, or filaments. They contain chlorophyll, but lack special water-carrying tissues. Through the process of photosynthesis, algae produce most of the food and oxygen in water environments.
Algal bloom	Rapid growth of algae populations in response to eutrophic conditions.
Alum[2]	Aluminum sulfate, an aluminum salt, that is used to lower lake P content by removing phosphorus in the water column (through chemical precipitation) and by retarding release of mobile P from lake sediments (P inactivation). Alum (aluminum sulfate) is added to the water column to form aluminum phosphate and a colloidal aluminum hydroxide floc to which certain phosphorus fractions are bound. The aluminum hydroxide floc settles to the sediment and continues to sorb and retain phosphorus.
Anoxic	Characterized by very low concentrations of dissolved oxygen (< 2 mg/L DO).
Bathymetric survey[1]	A survey of the bottom contours of a lake; can be used to calculate lake volume.
Benthic[3]	Associated with the lake bottom.
Biomass[1]	The weight of biological matter. Standing crop is the amount of biomass (e.g., fish or algae) in a body of water at a given time. Often measured in terms of grams per square meter of surface.
Bioturbation	Increase in water turbidity by aquatic organisms activates, such as mixing sediments into the water column
Chlorophyll[1]	A green pigment in algae and other green plants that is essential for the conversion of sunlight, carbon dioxide, and water to sugar.
Chlorophyll a[1]	A type of chlorophyll present in all types of algae, sometimes in direct proportion to the biomass of algae.
Decomposition[1]	The transformation of organic molecules (e.g., sugar) to inorganic molecules (e.g., carbon dioxide and water) through biological and non-biological processes.
Dissolved Oxygen (DO) Demand[4]	A volumetric measure of the net whole-lake oxygen demand. Measured in terms of mg of oxygen consumed per square meter per day.
Ecosystem	A system formed by the interaction of a community of organisms with each other and the environment.
Epilimnion[3, 4]	The upper, warm, lighter, homogeneous layer of a lake.
Euphotic zone[3]	The lighted and usually well-mixed portion of a lake.

Term	Definition
Eutrophic[2]	A eutrophic lake is rich in nutrients and organic materials. Excessive loading of plant nutrients, organic matter, and silt cause increased primary producer biomass, reduced water clarity, good growing conditions for nuisance species, and usually decreased lake volumes.
Eutrophication[1, 2]	The process of physical, chemical, and biological changes associated with nutrient, organic matter and silt enrichment and sedimentation of a lake that cause a water body to age and become eutrophic. Symptoms include dissolved oxygen depletions and fish kills.
External loading[1]	The total amount of material (sediment, nutrients, oxygen-demanding material) brought into the lake by inflowing streams, runoff, direct discharge through pipes, groundwater, the air, and other sources over a specific period of time.
Flushing rate[1]	The rate at which water enters and leaves a lake relative to lake volume, usually expressed as the time needed to replace the lake volume with inflowing water.
Habitat	An area where a plant or animal species lives, grows, and reproduces, and the environment that satisfies their life requirements.
Hyper-eutrophic	Characterized by severely eutrophic conditions and excessive primary production.
Hypolimnion[4]	The lower, fairly homogeneous cold layer of a lake.
In-situ	On site, within the water.
Internal nutrient cycling[1]	Transformation of nutrient such as nitrogen or phosphorus from biological to inorganic forms through decomposition, occurring within the lake itself.
Internal nutrient loading	The total amount of nutrients released into the water column over a specific period of time as a result of nutrient recycling from sediments, wind resuspension, mineralization of nutrients, macrophyte senescence, and decomposition of organic material.
Interstitial	Within the spaces between solid particles in sediments.
Loading	*See external loading and internal nutrient loading.*
Macrophyte[2]	Rooted emergent, floating, and submersed vascular plants.
Mesotrophic[1]	The medium range of eutrophication.
Natural resources	Landforms, soils, waters, and their associated flora and fauna.
Nonpoint source[1]	Pollution that cannot be traced to specific origin or starting point, but seems to flow from many different sources. Non-point source pollutants are generally carried off the land by stormwater runoff.
Nutrient[1]	An element or chemical essential to life, such as carbon, oxygen, nitrogen, and phosphorus. Nutrients promote growth and repair the natural destruction of organic life.
Organic matter[1]	Molecules manufactured by plants and animals and containing linked carbon atoms and elements such as hydrogen, oxygen, nitrogen, sulfur, and phosphorus.

Term	Definition
pH[1, 3]	A measure of the concentration of hydrogen ions in a substance (the negative log of the hydrogen-ion concentration), which ranges from very acid (pH = 1) to very alkaline (pH = 14). pH 7 is neutral and most lake waters range between 6 and 9. pH values less than 6 are considered acidic, and most life forms cannot survive at pH of 4.0 or lower.
Photic zone[1]	The lighted region of a lake where photosynthesis takes place. Extends down to a depth where plant growth and respiration are balanced by the amount of light available.
Photosynthesis[1]	A chemical reaction that occurs only in plants. Plants use a green pigment called chlorophyll to convert water and carbon dioxide into cellular material and oxygen in the presence of light. Hence, photosynthesis occurs only during daylight hours.
Phytoplankton[1]	Microscopic algae and microbes that float freely in open water of lakes. In some lakes, they provide the primary base of the food chain for all animals. They also produce oxygen by a process called photosynthesis.
Point source[1]	Pollution discharged into water bodies from specific, identifiable pipes or points, such as an industrial facility or municipal sewage treatment plant.
Primary productivity[1]	The rate at which algae and macrophytes fix or convert light, water, and carbon dioxide to sugar in plant cells.
Residence time[1]	The amount of time required to completely replace the lake's current volume of water with and equal volume of "new" water.
Respiration[1]	Process by which organic matter is oxidized by organisms, including plants, animals, and bacteria. The process releases energy, carbon dioxide, and water. Respiration occurs at all depths in a lake and is not dependent on light.
Riparian areas	Areas closely related to or bordering rivers, streams, lakes, arroyos, playas, ravine bottoms, etc.
Runoff[1]	That portion of precipitation that flows over the land carrying with it such substances as soil, oil, trash, and other particulate and dissolved materials until it ultimately reaches streams, rivers, lakes, or other water bodies.
Secchi depth[1]	A measure of transparency of water (the ability of light to penetrate water) obtained by lowering a black and white disk (Secchi disk, 20 cm in diameter) into water until it is no longer visible. Measure in units of meters or feet.
Sediment[1]	Bottom material in a lake that has been deposited after the formation of a lake basin. It originates from remains of aquatic organisms, chemical precipitation of dissolved minerals, and erosion of surrounding lands.
Senescence	The deterioration of plant cells with age.
Soluble	Able to be dissolved in water.
Specific conductance[7]	Specific conductance is a measure of the ability of water to conduct an electrical current. It is highly dependent on the amount of dissolved solids (such as salt) in the water.

Term	Definition
Stratification[1]	Process in which several horizontal water layers of difference density may form in some lakes. During stratification, the bottom pass (hypolimnion) is cool, high in nutrients, low in light, low in productivity, and low in dissolved oxygen. The top mass (epilimnion) is warm, higher in dissolved oxygen, light, and production, but lower (normally) in nutrients. The sharp boundary between the two masses is called a thermocline.
Thermocline[3]	A transitional layer between the epilimnion and the hypolimnion, the rate of temperature change with depth is greatest in this layer.
Trophic state[1]	The degree of eutrophication of a lake. Transparency, chlorophyll a levels, phosphorus concentrations, amount of macrophytes, and quantity of dissolved oxygen in the lake can be used to assess trophic state.
Trophic state index[1]	A number used to categorize lakes as oligo-, meso-, or eutrophic on a scale generally from 1 to 100: the higher the number, the more eutrophic. It can be calculated a variety of ways, using chlorophyll (a measure of algae abundance), Secchi depth (an indirect measure of algae abundance by measuring water clarity), or nutrients.
Turbid[1]	Thick or cloudy with sediment or other suspended material, such as algae.
Turbidity[7, 8]	A measurement of the degree to which the transmission of light through water is restricted due to scattering and absorption. The higher the intensity of scattered light, the higher the turbidity. Turbidity is influenced by concentrations of suspended sediment as well as concentrations of algae and colloidal matter.
Water column[1]	Water in the lake between the interface with the atmosphere at the surface and the interface with the sediment layer at the bottom.
Watershed[1]	A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.
Wetlands	Areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas.

Note: Sources for definitions:

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