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Spatial and Temporal Variability of Nutrients and Algae in the Republican River and Milford Lake, Kansas, June through November 2017 and May through November 2018

Scientific Investigations Report 2020–5135

U.S. Department of the Interior
U.S. Geological Survey

Cover. Wildflowers in bloom along the South causeway, Milford Lake, Kansas, September 10, 2017. Photograph by Lindsey King.

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Contents

Figures

Tables

Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square kilometer (km^2)	0.3861	square mile (mi^2)
square kilometer (km^2)	247.1	acre
	Volume	
milliliter (mL)	0.0338	ounce, fluid (oz)
cubic hectometer (hm^3)	810.7	acre-foot (acre-ft)
	Flow rate	
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
	Mass	
milligram (mg)	0.00003527	ounce, avoirdupois, (oz)
microgram (µg)	0.00000003527	ounce, avoirdupois, (oz)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F = (1.8 × °C) + 32.

Datum

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Supplemental Information

Concentrations of chemical constituents in water are given in either milligrams per liter (mg/L) or micrograms per liter (µg/L).

Concentrations of nitrogen species in water are given in milligrams per liter as nitrogen (mg/L-N). Concentrations of phosphorus species in water are given in milligrams per liter as phosphorus (mg/L-P).

Total nitrogen is the sum of total Kjeldahl nitrogen (U.S. Geological Survey parameter code 00625, also known as ammonia plus organic nitrogen) and dissolved nitrate plus nitrite (U.S. Geological Survey parameter code 00631).

Abbreviations

AVLD	absolute value logarithmic difference
DIW	deionized water
HAB	harmful algal bloom
KDHE	Kansas Department of Health and Environment
NWIS	National Water Information System
NWQL	National Water Quality Laboratory
RFU	relative fluorescence units
RPD	relative percentage difference
RSD	relative standard deviation
TKN	total Kjeldahl nitrogen
USGS	U.S. Geological Survey
YSI	Yellow Springs Instruments

Spatial and Temporal Variability of Nutrients and Algae in the Republican River and Milford Lake, Kansas, June through November 2017 and May through November 2018

By Brianna M. Leiker,[1] Justin R. Abel,[1] Jennifer L. Graham,[1] Guy M. Foster,[1] Lindsey R. King,[2] Tom C. Stiles,[3] and Riley P. Buley[4]

Abstract

Milford Lake has been listed as impaired and designated hypereutrophic because of excessive nutrient loading, specifically biologically available orthophosphate. It is the largest lake by surface area in Kansas and is a reservoir built for purposes including water supply and recreation. In 2015, the Kansas Department of Health and Environment (KDHE) divided the lake into three zones (Zones A, B, and C) for recreational monitoring of harmful algal blooms (HABs). Upstream Zone C has historically been more affected by HABs than Zones B and A, and Zone C has historically had the highest phosphorus concentrations.

The U.S. Geological Survey, in cooperation with the KDHE, completed a study in 2017–18 to assess the spatial and temporal variability of nutrients and algae in the Republican River (the primary inflow to Milford Lake) and Milford Lake using spatially and temporally dense data. During the study period, discrete water-quality samples were collected at 36 lake sites, 21 river sites, and 1 pond. All samples were analyzed for nutrients; some samples were also analyzed for chlorophyll, phycocyanin, microcystin, and (or) phytoplankton community composition and abundance. Results from this study provide perspective for understanding the potential role nutrient and algal conditions have in facilitating the formation of HABs and may inform future actions to prevent and mitigate HABs and their potential effects on human and environmental health.

In 2017, one low-flow floating synoptic on the Republican River into Zone C of Milford Lake and one 24-hour synoptic in Zone C of Milford Lake were completed. Results from the low-flow floating synoptic on July 17, 2017, at 21 river sites, 8 lake sites, and 1 pond site indicated that the Republican River was not contributing dissolved orthophosphate or total phosphorus concentrations higher than those in the main body of Milford Lake.

No patterns in nutrient or total microcystin concentrations were evident from the 24-hour synoptic at two sites on August 24–25, 2017. Total nitrogen was dominated by total Kjeldahl nitrogen (TKN) at both sites. Different oscillation activity in algal biomass and chlorophyll at the two sites demonstrated the variable nature of algal accumulations and their effects on nutrient and dissolved oxygen concentrations. Different patterns in chlorophyll and microcystin concentrations indicate that the relation between algal biomass and cyanotoxin concentrations were different at the two sites, possibly because of differences among algal communities present at each site.

Three whole-lake synoptics through Zones A, B, and C in Milford Lake were completed on July 10, August 9, and October 16–17, 2018, at 30 lake sites. Orthophosphate was consistently at least 77 percent of total phosphorus at all sites except the two most uplake sites. At the two most uplake sites, orthophosphate was between 52 and 72 percent of the total phosphorus present at the site.

Concentrations of TKN were not consistently increasing or decreasing during 2018. Total nitrogen was dominated by TKN in July and August. Very low concentrations of dissolved nitrate plus nitrite indicate that the nutrient was likely tied up in algal biomass. By October, total nitrogen was approximately one-half TKN and one-half dissolved nitrate plus nitrite. Higher concentrations of dissolved orthophosphate and dissolved nitrate plus nitrite in October than in July and August were likely caused by reduced biological activity (less uptake of nutrients) and lower air and water temperatures. Multiple inflow events (streamflow greater than median daily value) between August and October also may have moved nutrients through the lake.

Chlorophyll, phycocyanin, microcystin, and phytoplankton samples were collected at eight sites in 2018. Most sites had their highest chlorophyll concentrations in August. The three most uplake sites had their highest phycocyanin concentrations in July, whereas the other five sites had their highest phycocyanin concentrations in August. Two

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of 23 samples had detections of total microcystin (0.11 and 0.12 microgram per liter). Phytoplankton community composition mainly consisted of Bacillariophyta, Chlorophyta, Cryptophyta, and Cyanobacteria. Phytoplankton community composition and abundance data described broad seasonal patterns and did not capture the full range of possible conditions at each site.

Introduction

Algae and other green plants convert phosphorus, nitrogen, and carbon dioxide into biomass through photosynthesis, which forms the bottom of a food web in a lake. When excessive nutrients are present, eutrophication may contribute to the impairment of aquatic life. Potential consequences of eutrophication include increased productivity, excess algal biomass, and reductions in water clarity and dissolved oxygen. Harmful algal blooms (HABs) are another potential consequence of eutrophication and cause ecological, economic, and public health concerns (Graham and others, 2009; Kansas Department of Health and Environment, 2014a).

Milford Lake has been listed as impaired and designated hypereutrophic because of excessive nutrient loading, specifically biologically available orthophosphate (Kansas Department of Health and Environment, 2014a; U.S. Army Corps of Engineers, [n.d.]b). According to the U.S. Army Corps of Engineers, phosphorus levels in Milford Lake are “nearly five times higher than average” compared to the Kansas City District’s 17 other lakes (U.S. Army Corps of Engineers [n.d.]b). The Kansas Department of Health and Environment (2014a) assigned a total maximum daily load to the lake to reduce phosphorus and nitrogen loads into the lake. The lake is also listed as impaired because of low (less than [<] 5 milligrams per liter [mg/L]) dissolved oxygen (Kansas Department of Health and Environment, 2014a). Microbial respiratory activities in the water column and (or) sediment may contribute to the dissolved oxygen violations in the lake (Kansas Department of Health and Environment, 2014a).

The spatial and temporal variability of HABs in Milford Lake was previously assessed by Foster and others (2017, 2019). Foster and others (2017) investigated the spatial variability of cyanobacteria and microcystin in Milford Lake in 2015. Cyanobacteria and microcystin concentrations varied by orders of magnitude through the lake but generally decreased in the downlake (towards the outlet) direction in July and August 2015. Foster and others (2019) characterized the spatial and temporal variability of cyanobacterial abundance, chlorophyll, and microcystin concentrations in the upstream one-third of Milford Lake in 2016. On single sample days in July and September 2016, algal communities in Milford Lake were generally either dominated by cyanobacteria, dominated by diatoms, or codominated by cyanobacteria and diatoms (Foster and others, 2019). Daily maxima for chlorophyll were as much as 400 times higher than daily minima, and daily maxima for microcystin were up to several orders of magnitude higher than daily minima (Foster and others, 2019).

In 2017 and 2018, the U.S. Geological Survey (USGS), in cooperation with the Kansas Department of Health and Environment (KDHE), completed a study to assess the spatial and temporal variability of nutrients and algae in the Republican River (the primary inflow to Milford Lake) and Milford Lake. The objective of this study was to characterize algal and nutrient dynamics in the upper reaches of Milford Lake, including the Republican River headwaters and the upper reaches of the lake where it is believed that HABs typically develop (Foster and others, 2019). Results from this study may inform future actions to prevent and mitigate HABs and their potential effects on human and environmental health.

Purpose and Scope

The purpose of this report is to present the results of a USGS study to assess the spatial and temporal variability of nutrients (dissolved orthophosphate, total phosphorus, total Kjeldahl nitrogen [TKN], and dissolved nitrate plus nitrite) and algae (chlorophyll, phycocyanin, the cyanotoxin microcystin, and phytoplankton community composition and abundance) in the Republican River and Milford Lake using spatially and temporally dense data collected from June through November 2017 and May through November 2018. Nationally, the methods and results presented in this report provide perspective for understanding the potential role nutrient and algal conditions have in facilitating the formation of HABs.

Discrete water-quality samples were collected at 36 lake sites, 21 river sites, and 1 pond. All samples were analyzed for nutrients; some samples were also analyzed for chlorophyll, phycocyanin, microcystin, and (or) phytoplankton community composition and abundance. Phycocyanin is an accessory pigment in cyanobacteria (Hambrook Berkman and Canova, 2007) and microcystin is a cyanotoxin. Continuous water-quality data (water temperature, specific conductance, pH, dissolved oxygen, chlorophyll fluorescence, and phycocyanin fluorescence) were collected at one lake site to characterize variability during the recreation season.

Description of Study Area

Milford Lake is the largest lake by surface area in Kansas. It is a reservoir that was completed by the U.S. Army Corps of Engineers in 1967 with the primary purpose of flood control and secondary purposes including water supply, recreation, and wildlife habitat (U.S. Army Corps of Engineers, [n.d.]a, [n.d.]b; Kansas Department of Health and Environment, 2014a). At the conservation pool/multipurpose elevation, Milford Lake has a surface area of about 63 square kilometers (km^2), a maximum depth of 18.0 meters (m), a mean depth of 7.4 m, and a volume of about 460 cubic hectometers (Kansas Department of Health and Environment, 2014a). The long-term (1981 through 2010) mean high temperatures near Wakefield, Kansas, for months May through September ranged from 76 to 91 degrees Fahrenheit (PRISM Climate Group, 2020).

The primary inflow to Milford Lake is the Republican River, which drains areas of Kansas, Nebraska, and Colorado. The drainage area of the lake is 64,400 km^2. Land use in the drainage basin is predominantly agricultural: 53 percent planted/cultivated and 42 percent herbaceous (Yang and others, 2018).

In 2015, the KDHE divided the lake into three zones (Zones A, B, and C) for recreational monitoring of harmful algal blooms (Foster and others, 2017; fig. 1). Historically, Zone C has been more affected by HABs than Zones B and A and has had the highest phosphorus concentrations, according to data collected by the U.S. Army Corps of Engineers (fig. 2; Marvin Boyer, U.S. Army Corps of Engineers, written commun., 2020). In 2015 and 2016, HAB advisories in Zone C lasted longer than those in Zones B and A (Kansas Department of Health and Environment, 2020b). In 2017, Zone C was the only zone that was assigned a HAB advisory (Kansas Department of Health and Environment, 2020b). No HAB advisories were assigned to Milford Lake in 2018 (Kansas Department of Health and Environment, 2020b). Data collections in 2017 focused on the Republican River and Zone C of Milford Lake. Data collections in 2018 focused on the whole lake to compare Zone C to Zones B and A. More information on the general limnology, water quality, and KDHE zone system at Milford Lake can be found in Foster and others (2017).

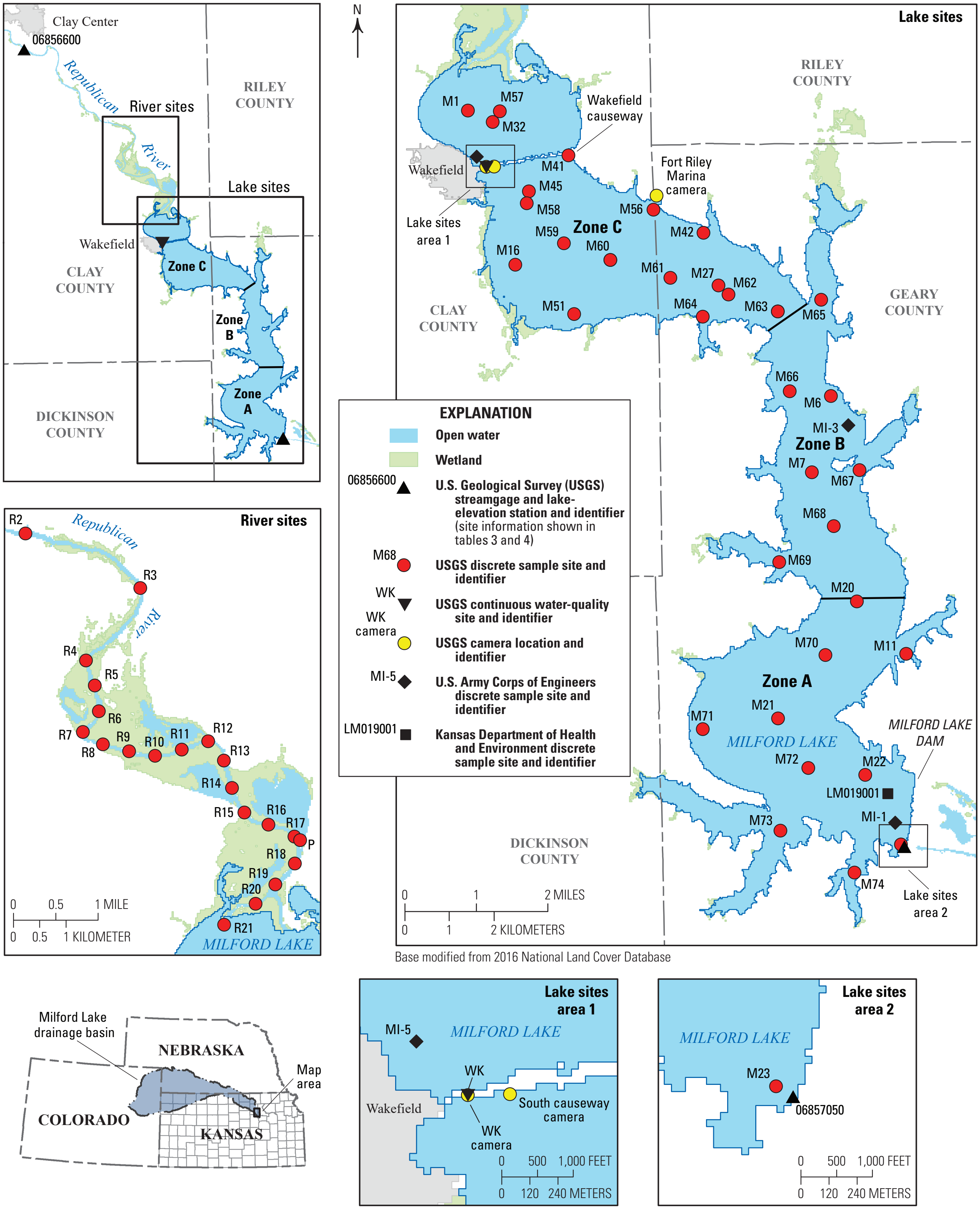


Figure 1. Zone designations; the locations of the discrete sampling, inflow, lake elevation, and continuous water-quality sites; and the camera locations within Milford Lake, Kansas.

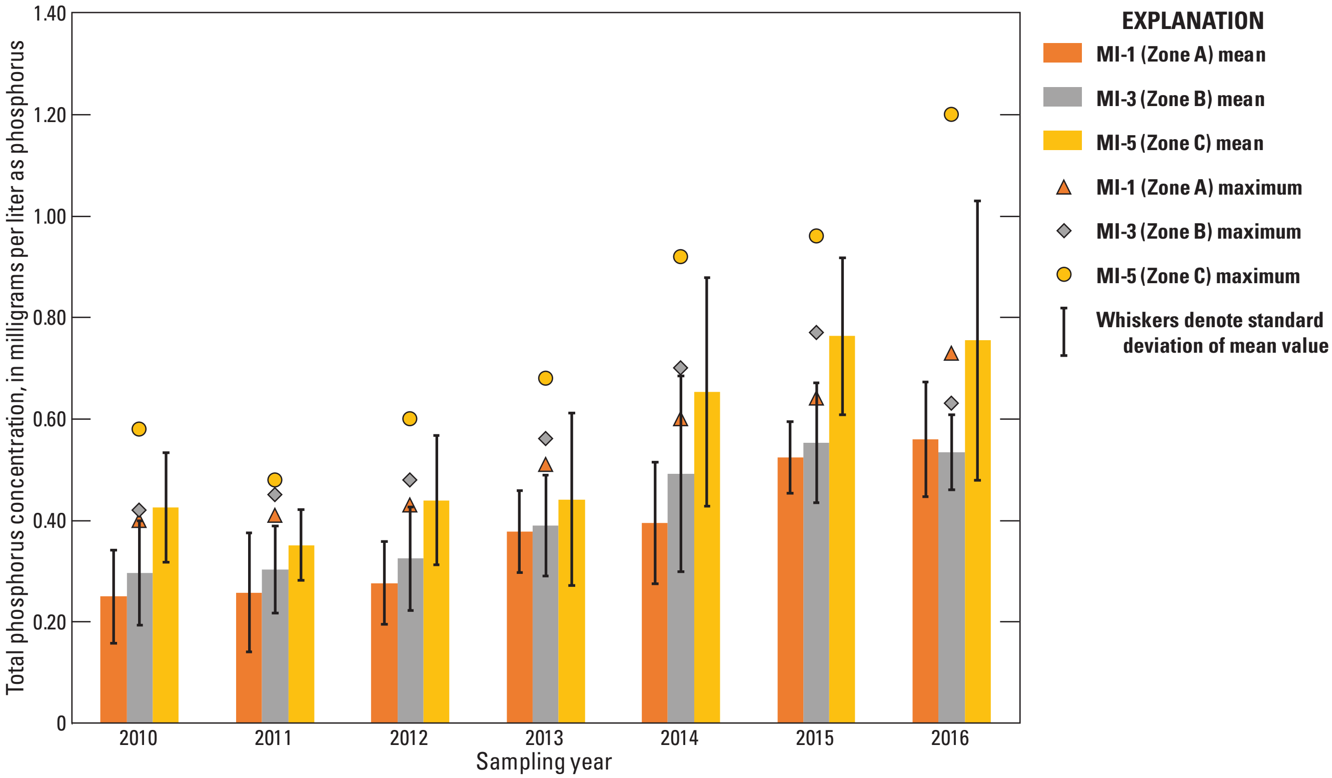


Figure 2. Historical (2010–16) mean and annual maximum (April–September) phosphorus concentrations at three locations in Milford Lake [data courtesy of Marvin Boyer, U.S. Army Corps of Engineers, written commun., 2020].

Methods

Continuous water quality and the spatial and temporal variability of nutrient and algal concentrations were assessed June 8 through November 1, 2017, and May 16 through November 22, 2018. In 2017, one low-flow floating synoptic on the Republican River into Zone C of Milford Lake (fig. 1) and one 24-hour synoptic in Zone C of Milford Lake were completed with sensor-based water-quality measurements and the collection of discrete nutrient samples. At a subset of sites, discrete chlorophyll and microcystin samples were also collected. In 2018, three whole-lake synoptics through Zones A, B, and C in Milford Lake were completed with sensor-based water-quality measurements and discrete nutrient and chlorophyll samples. At a subset of sites, phycocyanin, microcystin, and phytoplankton samples were also collected. During the study periods, discrete water-quality samples were collected at 35 lake sites, 21 river sites, and 1 pond (fig. 1). Continuous water-quality data were collected at one site in Zone C (fig. 1).

Sampling techniques were used in combination with time-lapse photography and continuous water-quality monitoring to characterize variability of total and dissolved nutrients, chlorophyll, phycocyanin, and microcystin concentrations and phytoplankton community composition in the Republican River and Milford Lake in 2017 and 2018. All data except time-lapse photography, phytoplankton community and composition, vertical profile data, and extracted phycocyanin data are available through the USGS National Water Information System (NWIS) (U.S. Geological Survey, 2019). Phytoplankton community composition and abundance data are available in a USGS data release (Leiker, 2020a). Time-lapse photos are available in another USGS data release (Leiker, 2020b). Vertical profile data are available in another USGS data release (Leiker, 2020c). Extracted phycocyanin data are provided in appendix 1.

Discrete Sample Collection

Discrete samples were collected in accordance with standard USGS methods (U.S. Geological Survey, variously dated). Three sampling schemes were utilized to characterize nutrient and algal dynamics in Milford Lake in 2017 and 2018: a low-flow floating synoptic (2017), a 24-hour synoptic (2017), and three whole-lake synoptics (2018). The goal of the low-flow floating synoptic was to identify nutrient hotspots in the Republican River between Clay Center, Kans., and Milford Lake. The goal of the 24-hour synoptic was to investigate diel patterns in nutrient release from lakebed sediments. The goal of the three whole-lake synoptics was to characterize the distribution of nutrients, algal biomass as chlorophyll (hereafter referred to as "chlorophyll"), and phytoplankton community abundance and composition.

For all sampling schemes except for July 20, 2017, samples were processed in the field for dissolved and total nutrient analysis in accordance with Wilde and others (2004) and kept chilled and in the dark until shipment to the analyzing laboratory listed in table 1. For the July 20, 2017, samples, samples and capsule filters were not kept continuously chilled and filtration was delayed as much as 36 hours after collection because of field logistics. Value qualifiers were added to affected results from the July 20, 2017, samples. All samples were analyzed for nutrients by the USGS National Water Quality Laboratory (NWQL), in Lakewood, Colorado, in accordance with standard methods (table 1). Some samples were also analyzed for chlorophyll, phycocyanin, microcystin, and (or) phytoplankton community composition and abundance (table 1). The analysis method for microcystin was modified from Foster and others (2017) to use a different ELISA kit (IMNT2 instead of IMNT), so data collected in the current study may have different cross-reactivity to toxin variants than data collected by Foster and others (2017) (Graham and others, 2010).

Low-Flow Floating Synoptic

The low-flow floating synoptic was completed on July 20, 2017. During the low-flow synoptic the lake elevation was within 1.5 feet of the multipurpose pool, and streamflow at the Republican River at Clay Center (USGS station 06856600, fig. 1; hereinafter referred to as “site 06856600”) was low compared to the median daily value at the site (table 2). Thirty sites were sampled starting at site 06856600 and ending at the boundary between Zones C and B (fig. 1, table 3).

Table 1. Laboratory method information for constituents analyzed in the Republican River and Milford Lake, Kansas, 2017–18.

[mg/L, milligram per liter; NWQL, U.S. Geological Survey National Water Quality Laboratory; µg/L, microgram per liter; KSWSC, U.S. Geological Survey Kansas Water Science Center; Wilson Lab, Alan Wilson’s laboratory at Auburn University; OGRL, U.S. Geological Survey Organic Geochemistry Research Laboratory; BSA, BSA Environmental Services, Inc.]

Constituent	Method	Reporting limit	Laboratory
Dissolved orthophosphate, as phosphorus	Fishman, 1993	0.004 mg/L	NWQL
Total phosphorus, as phosphorus	Patton and Truitt, 1992	0.02 mg/L	NWQL
Total Kjeldahl nitrogen, as nitrogen	Patton and Truitt, 2000	0.07 mg/L	NWQL
Dissolved nitrate plus nitrite, as nitrogen	Patton and Kryskalla, 2011	0.01 mg/L	NWQL
Chlorophyll	Foster and others, 2017	1 µg/L	KSWSC
Phycocyanin	Kasinak and others, 2015	0.5 µg/L	Wilson Lab
Total microcystin	Foster and others, 2017	0.10 µg/L	OGRL
Phytoplankton community composition and abundance	Graham and others, 2017	1 cell	BSA

Table 2. Inflow and lake elevation data during discrete sampling events, Milford Lake, Kansas, 2017 and 2018.

[ft^3/s, cubic feet per second; ft, feet; MPP, multipurpose pool; USGS, U.S. Geological Survey]

Discrete sample date	Inflow (ft^3/s)[a]	Median inflow (ft^3/s)[b]	Lake elevation (ft)[c]	Difference from MPP (ft)[d]
July 20, 2017	355	518	1,143.12	−1.28
August 24, 2017	198	436	1,144.82	+0.42
August 25, 2017	187	453	1,144.82	+0.42
July 10, 2018	231	694	1,145.28	+0.88
August 9, 2018	140	474	1,143.17	−1.23
October 16, 2018	1,550	219	1,153.18	+8.78
October 17, 2018	1,360	234	1,153.32	+8.92

[a]Daily streamflow at the inflow site Republican River near Clay Center, Kansas (USGS station number 06856600; U.S. Geological Survey, 2019).

[b]Median value for the day of the year, based on 102 years of approved record at Republican River near Clay Center, Kansas (U.S. Geological Survey, 2019).

[c]Lake elevation at site Milford Lake near Junction City, Kansas (USGS station number 06857050; U.S. Geological Survey, 2019).

[d]Difference from MPP elevation of 1,144.40 ft (U.S. Army Corps of Engineers, 2020).

Table 3. Site list for 2017 data collections with date(s) sampled and sample analyses.

[Data for sites can be accessed in U.S. Geological Survey (2019) using the station numbers provided in this table. M, month; DD, day; YYYY, year; PO_4, dissolved orthophosphate; TP, total phosphorus; TKN, total Kjeldahl nitrogen; NO_3+NO_2, nitrate plus nitrite; Chl, chlorophyll; MC, total microcystin]

Site identifier	Site name	U.S. Geological Survey station number	Sample analyses	Date(s) sampled (M/DD/YYYY)
06856600	Republican River at Clay Center, Kansas	06856600	PO_4, TP, TKN, and NO_3+NO_2	7/20/2017
R2	Republican River at Redwood Road near Clay Center, Kansas	391809097031100	PO_4, TP, TKN, and NO_3+NO_2	7/20/2017
R3	Republican River near Thunder Road near Union, Kansas	391734097014100	PO_4, TP, TKN, and NO_3+NO_2	7/20/2017
R4	Republican River near Unnamed Road, Clay County, Kansas	391650097022500	PO_4, TP, TKN, and NO_3+NO_2	7/20/2017
R5	Republican River in Clay County, Kansas	391635097021800	PO_4, TP, TKN, and NO_3+NO_2	7/20/2017
R6	Republican River near 11th Road, Clay County, Kansas	391619097021600	PO_4, TP, TKN, and NO_3+NO_2	7/20/2017
R7	Republican River near Union, Kansas	391606097022900	PO_4, TP, TKN, and NO_3+NO_2	7/20/2017
R8	Republican River near Sunflower Road, Clay County, Kansas	391559097021300	PO_4, TP, TKN, and NO_3+NO_2	7/20/2017
R9	Republican River near Cane Creek, Clay County, Kansas	391554097015200	PO_4, TP, TKN, and NO_3+NO_2	7/20/2017
R10	Republican River near 9th Road, Clay County, Kansas	391551097013100	PO_4, TP, TKN, and NO_3+NO_2	7/20/2017
R11	Republican River near 10th Rd, Clay County, Kansas	391554097011100	PO_4, TP, TKN, and NO_3+NO_2	7/20/2017
R12	Republican River near Unnamed Road, Clay Center, Kansas	391559097004900	PO_4, TP, TKN, and NO_3+NO_2	7/20/2017
R13	Republican River near Mall Creek, Clay County, Kansas	391547097003700	PO_4, TP, TKN, and NO_3+NO_2	7/20/2017
R14	Republican River near Pasture Road. Clay County, Kansas	391530097003100	PO_4, TP, TKN, and NO_3+NO_2	7/20/2017
R15	Republican River near Tinder Road, Clay County, Kansas	391515097002200	PO_4, TP, TKN, and NO_3+NO_2	7/20/2017
R16	Republican River near County Road 859, Clay County, Kansas	391507097000300	PO_4, TP, TKN, and NO_3+NO_2	7/20/2017
R17	Republican River near Valleyview Road, Clay County, Kansas	391459096594300	PO_4, TP, TKN, and NO_3+NO_2	7/20/2017
P	Pond near Republican River, Clay County, Kansas	391457096593800	PO_4, TP, TKN, and NO_3+NO_2	7/20/2017
R18	Republican River near Timber Creek, Clay County, Kansas	391442096594300	PO_4, TP, TKN, and NO_3+NO_2	7/20/2017
R19	Republican River near County Line Road, Clay County, Kansas	391430096595900	PO_4, TP, TKN, and NO_3+NO_2	7/20/2017
R20	Republican River near County Road 837, Clay County, Kansas	391418097001500	PO_4, TP, TKN, and NO_3+NO_2	7/20/2017

Table 3. Site list for 2017 data collections with date(s) sampled and sample analyses.

[Data for sites can be accessed in U.S. Geological Survey (2019) using the station numbers provided in this table. M, month; DD, day; YYYY, year; PO_4, dissolved orthophosphate; TP, total phosphorus; TKN, total Kjeldahl nitrogen; NO_3+NO_2, nitrate plus nitrite; Chl, chlorophyll; MC, total microcystin]

Site identifier	Site name	U.S. Geological Survey station number	Sample analyses	Date(s) sampled (M/DD/YYYY)
R21	Republican River near Wakefield, Kansas	391406097004000	PO_4, TP, TKN, and NO_3+NO_2	7/20/2017
M57	Milford Lake, Kansas Site 57	391339097000300	PO_4, TP, TKN, and NO_3+NO_2	7/20/2017
WK	Milford Lake near Wakefield, Kansas	391259097001800	PO_4, TP, TKN, NO_3+NO_2, Chl, and MC	7/20/2017, 8/24/2017–8/25/2017
M58	Milford Lake, Kansas Site 58	391232096594100	PO_4, TP, TKN, and NO_3+NO_2	7/20/2017
M59	Milford Lake, Kansas Site 59	391202096590600	PO_4, TP, TKN, and NO_3+NO_2	7/20/2017
M60	Milford Lake, Kansas Site 60	391149096582300	PO_4, TP, TKN, and NO_3+NO_2	7/20/2017
M61	Milford Lake, Kansas Site 61	391135096572700	PO_4, TP, TKN, NO_3+NO_2, Chl, and MC	7/20/2017, 8/24/2017–8/25/2017
M62	Milford Lake, Kansas Site 62	391121096563300	PO_4, TP, TKN, and NO_3+NO_2	7/20/2017
M63	Milford Lake, Kansas Site 63	391108096554600	PO_4, TP, TKN, and NO_3+NO_2	7/20/2017

Twenty discrete samples were collected in the Republican River upstream from Milford Lake (sites 06856600 and R2–R20; fig. 1, table 3). An additional sample was collected at site P (fig. 1, table 3), which was a small pond to the side of the main river channel. Starting at site R4, samples in the Republican River were collected 0.5 kilometer (km) apart. Nine samples were collected 1 km apart in the main reservoir pool from the confluence of the wetlands with the pool to the boundary between Zones C and B (sites R21, M57, WK, M58–M63; fig. 1, table 3).

The sample at site 06856600 was collected as a grab from the bridge deck using a weighted basket. All other samples were collected as grab samples by submerging bottles just below the surface until full. Samples for sites R2 through R20 were collected from kayaks, and samples for sites R21 through M63 were collected from a pontoon boat.

A Yellow Springs Instruments (YSI) EXO2 multiparameter water-quality sonde (Yellow Springs Instruments, 2017) was attached to the kayak or pontoon boat and logged data every 30 seconds to determine instantaneous water-quality conditions during discrete samples, similarly to methods presented in Foster and others (2016). The sonde collected water temperature, specific conductance, dissolved oxygen, pH, turbidity, chlorophyll fluorescence, phycocyanin fluorescence, and dissolved organic matter fluorescence data.

24-Hour Synoptic

Discrete samples were collected at two sites during a 24-hour period from 12:10 p.m. on August 24 to 12:30 p.m. on August 25, 2017. During the 24-hour synoptic, the lake elevation was within 0.5 foot of the multipurpose pool, and streamflow at site 06856600 was less than one-half the median daily value at the site (table 2). Samples were collected at the continuous water-quality monitor (site WK, fig. 1, table 3) and at a site near the center of Zone C (site M61, fig. 1, table 3). Samples were collected approximately 75 minutes apart and alternated between the two sites. For each sample set, discrete samples were collected at three depths: the water surface, the middle of the water column, and just above the bottom sediment. Site WK was 2 to 3 m deep and site M61 was 6 to 7.5 m deep. Twenty sample sets were collected—10 at each site.

Samples were collected from a pontoon boat using a peristaltic pump and weighted tubing at the three depths. At each depth, the tubing was purged with at least three tubing volumes of native water before filling the sample bottles. A YSI EXO2 multiparameter water-quality sonde was used to collect vertical profile data (Leiker, 2020c) at each site during each sample for the following constituents: water temperature, specific conductance, dissolved oxygen, pH, turbidity, chlorophyll fluorescence, phycocyanin fluorescence, and dissolved organic matter fluorescence. Photosynthetically active radiation (measured using a LI-COR LI-193 spherical underwater quantum sensor; LI-COR Biosciences, 2019; data available in Leiker, 2020c) and Secchi depth were measured during each sample collection with daylight present. Vertical profile data were collected at 0.5-m increments for the first 3 m and at 1.0-m increments at depths greater than 3 m.

Samples were filtered within 60 minutes of collection and kept in the dark and on ice until shipment to the analyzing laboratories. Filtering equipment was field rinsed with deionized water (DIW) three times between sites. In addition to nutrient analyses by the NWQL, surface samples were also analyzed for chlorophyll concentration and total microcystin concentration according to methods in table 1.

Whole-Lake Synoptics

There were three whole-lake synoptics in 2018 on July 10, August 9, and October 16–17; the October synoptic was 2 days because of limited hours of daylight. For all three synoptics, samples were collected at the same 30 Milford Lake sites (table 4, fig. 1) located throughout the lake, from the confluence of the wetlands with the main reservoir pool to the dam. Sites in Milford Lake were located through the middle of the lake, along the shoreline, and in coves. In July and October, a grab sample was also collected at site 06856600 (table 4, fig. 1) the day before the whole-lake synoptics began to determine general conditions entering Milford Lake from the Republican River.

During the whole-lake synoptics in July and August 2018, the lake elevation was within 1.5 feet of the multipurpose pool, and streamflow at site 06856600 was low (about one-third of the median daily value at the site; table 2). In October, the lake elevation was approximately 9 feet above the multipurpose pool, and streamflow at site 06856600 was high (6–7 times the median daily value at the site; table 2). There were no inflow events (greater than median daily value) between the July and August synoptics; there were five inflow events between the August and October synoptics (fig. 3).

Samples were collected just below the water surface from a pontoon boat using a peristaltic pump and tubing. The tubing was purged with at least three tubing volumes of native water before filling the sample bottles. A YSI EXO2 multiparameter water-quality sonde was mounted about 0.5 m below the deck of the pontoon boat and logged data every 30 seconds to determine instantaneous water-quality conditions during discrete samples, which is similar to methods presented in Foster and others (2016, 2017). The sonde collected water temperature, specific conductance, dissolved oxygen, pH, turbidity, chlorophyll fluorescence, and phycocyanin fluorescence data. For the August synoptic only, continuous dissolved organic matter fluorescence data also were collected.

Samples were filtered within 30 minutes of collection and kept dark and on ice until shipment to the analyzing laboratory. Filtering equipment was field rinsed with DIW three times between sites. In addition to nutrient analyses by the NWQL, all samples were analyzed for chlorophyll concentration according to methods in table 1.

Table 4. Site list for 2018 data collections with dates sampled and sample analyses.

[Data for sites can be accessed in U.S. Geological Survey (2019) using the station numbers provided in this table. M, month; DD, day; YYYY, year; PO_4, dissolved orthophosphate; TP, total phosphorus; TKN, total Kjeldahl nitrogen; NO_3+NO_2, nitrate plus nitrite; Chl, chlorophyll; Phyco, phycocyanin; MC, total microcystin; Phyto, phytoplankton]

Site identifier	Site name	U.S. Geological Survey station number	Sample analyses	Date(s) sampled (M/DD/YYYY)
06856600	Republican River at Clay Center, Kansas	06856600	PO_4, TP, TKN, and NO_3+NO_2	7/9/2018, 10/15/2018
M1	Milford Lake, Kansas Site 1	391340097003400	PO_4, TP, TKN, NO_3+NO_2, and Chl	7/10/2018, 8/9/2018, 10/16/2018
M32	Milford Lake, Kansas Site 32	391332097001100	PO_4, TP, TKN, NO_3+NO_2, Chl, Phyco, MC, and Phyto	7/10/2018, 8/9/2018, 10/17/2018
WK	Milford Lake near Wakefield, Kansas	391259097001800	PO_4, TP, TKN, NO_3+NO_2, Chl, Phyco, MC, and Phyto	7/10/2018, 8/9/2018, 10/16/2018
M41	Milford Lake, Kansas Site 41	391306096590000	PO_4, TP, TKN, NO_3+NO_2, and Chl	7/10/2018, 8/9/2018, 10/17/2018
M45	Milford Lake, Kansas Site 45	391240096593800	PO_4, TP, TKN, NO_3+NO_2, and Chl	7/10/2018, 8/9/2018, 10/16/2018
M16	Milford Lake, Kansas Site 16	391147096595300	PO_4, TP, TKN, NO_3+NO_2, and Chl	7/10/2018, 8/9/2018, 10/17/2018
M56	Milford Lake, Kansas Site 56	391225096574100	PO_4, TP, TKN, NO_3+NO_2, and Chl	7/10/2018, 8/9/2018, 10/16/2018
M60	Milford Lake, Kansas Site 60	391149096582300	PO_4, TP, TKN, NO_3+NO_2, and Chl	7/10/2018, 8/9/2018, 10/17/2018
M51	Milford Lake, Kansas Site 51	391109096585800	PO_4, TP, TKN, NO_3+NO_2, and Chl	7/10/2018, 8/9/2018, 10/16/2018
M42	Milford Lake, Kansas Site 42	391207096565500	PO_4, TP, TKN, NO_3+NO_2, Chl, Phyco, MC, and Phyto	7/10/2018, 8/9/2018, 10/17/2018
M27	Milford Lake, Kansas Site 27	391128096564200	PO_4, TP, TKN, NO_3+NO_2, and Chl	7/10/2018, 8/9/2018, 10/16/2018
M64	Milford Lake, Kansas Site 64	391106096565700	PO_4, TP, TKN, NO_3+NO_2, and Chl	7/10/2018, 8/9/2018, 10/17/2018
M63	Milford Lake, Kansas Site 63	391108096554600	PO_4, TP, TKN, NO_3+NO_2, Chl, Phyco, MC, and Phyto	7/10/2018, 8/9/2018, 10/16/2018
M65	Milford Lake, Kansas Site 65	391116096550500	PO_4, TP, TKN, NO_3+NO_2, and Chl	7/10/2018, 8/9/2018, 10/17/2018
M66	Milford Lake, Kansas Site 66	391009096553700	PO_4, TP, TKN, NO_3+NO_2, and Chl	7/10/2018, 8/9/2018, 10/16/2018
M6	Milford Lake, Kansas Site 6	391005096545800	PO_4, TP, TKN, NO_3+NO_2, and Chl	7/10/2018, 8/9/2018, 10/17/2018
M7	Milford Lake, Kansas Site 7	390910096551800	PO_4, TP, TKN, NO_3+NO_2, Chl, Phyco, MC, and Phyto	7/10/2018, 8/9/2018, 10/16/2018
M67	Milford Lake, Kansas Site 67	390910096543300	PO_4, TP, TKN, NO_3+NO_2, and Chl	7/10/2018, 8/9/2018, 10/17/2018
M68	Milford Lake, Kansas Site 68	390830096545800	PO_4, TP, TKN, NO_3+NO_2, and Chl	7/10/2018, 8/9/2018, 10/16/2018
M69	Milford Lake, Kansas Site 69	390804096555000	PO_4, TP, TKN, NO_3+NO_2, and Chl	7/10/2018, 8/9/2018, 10/17/2018
M20	Milford Lake, Kansas Site 20	390734096543800	PO_4, TP, TKN, NO_3+NO_2, Chl, Phyco, MC, and Phyto	7/10/2018, 8/9/2018, 10/16/2018
M11	Milford Lake, Kansas Site 11	390655096535300	PO_4, TP, TKN, NO_3+NO_2, and Chl	7/10/2018, 8/9/2018, 10/17/2018
M70	Milford Lake, Kansas Site 70	390656096550900	PO_4, TP, TKN, NO_3+NO_2, and Chl	7/10/2018, 8/9/2018, 10/16/2018
M71	Milford Lake, Kansas Site 71	390603096570600	PO_4, TP, TKN, NO_3+NO_2, and Chl	7/10/2018, 8/9/2018, 10/16/2018

Table 4. Site list for 2018 data collections with dates sampled and sample analyses.

[Data for sites can be accessed in U.S. Geological Survey (2019) using the station numbers provided in this table. M, month; DD, day; YYYY, year; PO_4, dissolved orthophosphate; TP, total phosphorus; TKN, total Kjeldahl nitrogen; NO_3+NO_2, nitrate plus nitrite; Chl, chlorophyll; Phyco, phycocyanin; MC, total microcystin; Phyto, phytoplankton]

Site identifier	Site name	U.S. Geological Survey station number	Sample analyses	Date(s) sampled (M/DD/YYYY)
M21	Milford Lake, Kansas Site 21	390610096555500	PO_4, TP, TKN, NO_3+NO_2, Chl, Phyco, MC, and Phyto	7/10/2018, 8/9/2018, 10/17/2018
M72	Milford Lake, Kansas Site 72	390533096552700	PO_4, TP, TKN, NO_3+NO_2, and Chl	7/10/2018, 8/9/2018, 10/17/2018
M22	Milford Lake, Kansas Site 22	390527096543400	PO_4, TP, TKN, NO_3+NO_2, and Chl	7/10/2018, 8/9/2018, 10/16/2018
M73	Milford Lake, Kansas Site 73	390448096555500	PO_4, TP, TKN, NO_3+NO_2, and Chl	7/10/2018, 8/9/2018, 10/17/2018
M74	Milford Lake, Kansas Site 74	390416096544600	PO_4, TP, TKN, NO_3+NO_2, and Chl	7/10/2018, 8/9/2018, 10/16/2018
M23	Milford Lake, Kansas Site 23	390435096540200	PO_4, TP, TKN, NO_3+NO_2, Chl, Phyco, MC, and Phyto	7/10/2018, 8/9/2018, 10/17/2018

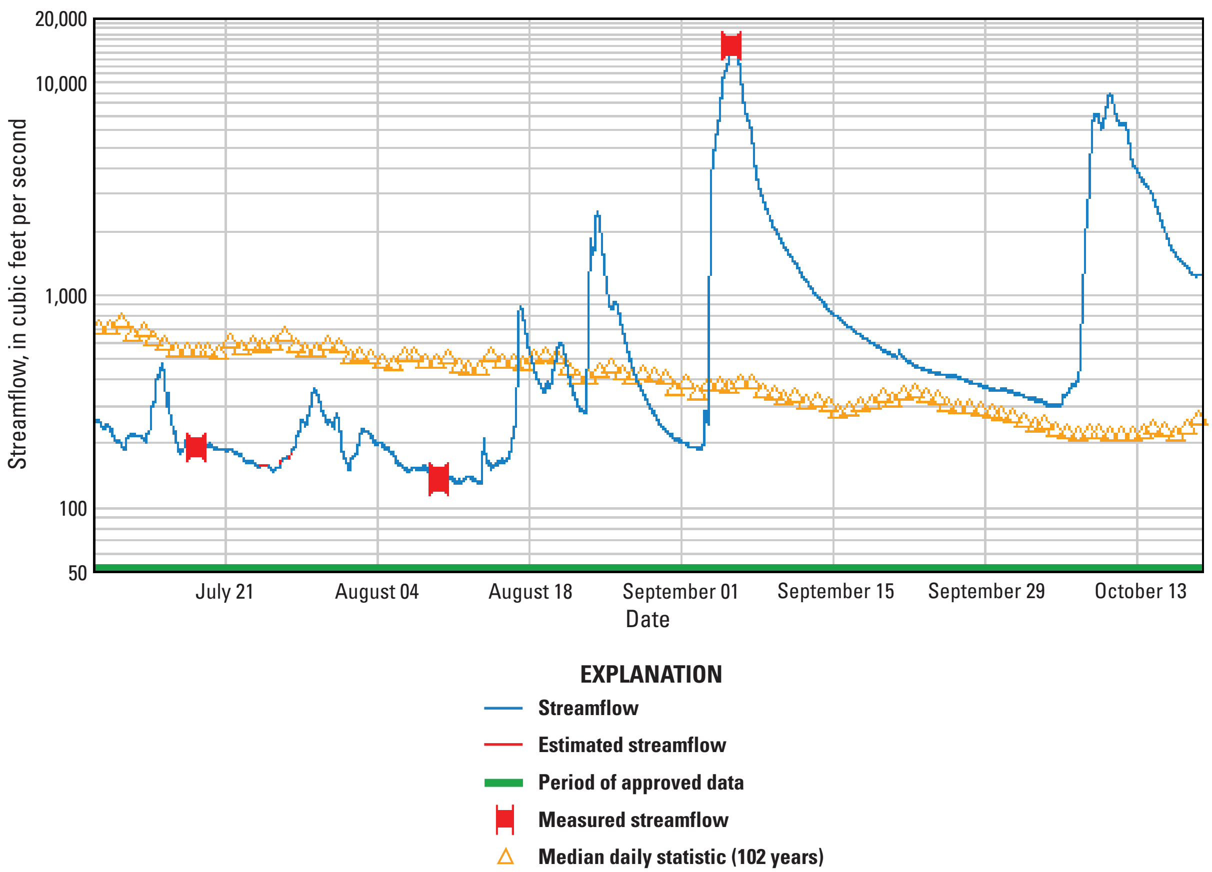


Figure 3. Instantaneous streamflow at the Republican River at Clay Center, Kansas (U.S. Geological Survey station 06856600), July 9–October 18, 2018. Data from U.S. Geological Survey (2019).

Phycocyanin, microcystin, and phytoplankton samples were collected at eight sites (sites M32, WK, M42, M63, M7, M20, M21, M23; fig. 1, table 4); the same eight sites were sampled in all three whole-lake synoptics and generally were located in a longitudinal transect through the center of the lake. A microcystin sample was not collected at site M20 in July. Phytoplankton samples were preserved with a 9:1 Lugol's iodine:glacial acetic acid solution. Samples were analyzed for phycocyanin, total microcystin, and phytoplankton community composition and abundance according to methods in table 1.

Quality Assurance and Quality Control

Quality assurance and quality-control methods and protocols were in accordance with USGS policies and USGS Kansas Water Science Center quality-assurance plans (U.S. Geological Survey, 2006; Rasmussen and others, 2014). Approximately 12 percent of discrete water-quality samples collected were quality-control samples used to characterize the integrity of the water-quality data presented in this report. Sequential field replicates were used to quantify variability in all steps of sample collection, processing, and analysis. Field blanks were used to determine and document sample contamination or bias; for example, incomplete cleaning of sampling equipment, field collection methods, field rinsing methods, and (or) sample analysis methods. During the study period, 22 replicate pairs were analyzed for nutrients, 14 replicate pairs were analyzed for chlorophyll, and 8 replicate pairs were analyzed for total microcystin.

Relative percentage difference (RPD) was used to evaluate sequential field replicate sample pairs without censored data (below the reporting limit) analyzed for nutrients and chlorophyll (table 5). The RPD is calculated by dividing the difference between replicate sample pair values by the mean of the replicate sample pair values and multiplying by 100. Mean and median RPDs were larger for chlorophyll than for nutrients. Mean and median RPDs were within acceptable limits (<20 percent) for all nutrients and chlorophyll.

Relative standard deviation (RSD) was used to evaluate sequential field replicate sample pairs without censored data analyzed for total microcystin (Foster and others, 2017). The RSD is calculated by dividing the standard deviation of replicate sample pair values by the mean of the replicate sample pair values and multiplying by 100. The RSDs of the two sequential replicate sample pairs without a censored value

Table 5. Relative percentage difference summary for sequential field replicate sample pairs analyzed for nutrients and chlorophyll without censored data.

[Min, minimum; RPD, relative percentage difference; %, percent; Max, maximum; mg/L-P, milligram per liter as phosphorus; mg/L-N, milligram per liter as nitrogen; µg/L, microgram per liter]

Constituent, unit	Total replicate pairs	Uncensored replicate pairs	Min RPD (%)	Max RPD (%)	Mean RPD (%)	Median RPD (%)
Dissolved orthophosphate, mg/L-P	22	22	0	14.1	3.5	2.6
Total phosphorus, mg/L-P	22	22	0	3.2	1.3	1.5
Total Kjeldahl nitrogen, mg/L-N	22	22	0	22.2	8.5	7.2
Dissolved nitrate plus nitrite, mg/L-N	22	8	0	5.1	2.5	2.7
Chlorophyll a, uncorrected, µg/L	14	14	0.6	40.5	12.1	7.4

were 15.3 percent and 19.6 percent, and both were within the threshold of acceptability of 28.3 percent (Foster and others, 2017).

Fourteen sequential field replicate sample pairs for dissolved nitrate plus nitrite and six sequential replicate pairs for total microcystin had at least one left-censored result (below the reporting limit). These replicate sample pairs were designated as either “matched” or “unmatched.” In matched pairs, both results in the replicate pair were censored; in unmatched pairs, only one result in the replicate pair was censored. Of the 14 replicate sample pairs for dissolved nitrate plus nitrite with at least one censored result, 13 were matched (both results <0.01 milligram per liter as nitrogen [mg/L-N]); the nitrate plus nitrite values for the sole unmatched pair were 0.01 mg/L-N and <0.01 mg/L-N. Five of the six replicate sample pairs for total microcystin with at least one censored result were matched (both results <0.10 microgram per liter [µg/L]); the total microcystin values for the sole unmatched pair were 0.10 µg/L and <0.10 µg/L. The unmatched pairs for nitrate plus nitrate and microcystin were collected on different dates.

Four field blanks were collected and analyzed for nutrients. Two blanks were collected during the low-flow floating synoptic to determine if preparing the capsule filters the day before use affected nutrient levels; one blank used a capsule filter prepared the day before the sample and the other blank used a capsule filter prepared immediately before use. Two blank samples were collected during the 24-hour synoptic to evaluate the efficacy of field-rinsing techniques using DIW. There were no detections in the blank samples for the four nutrients of interest (dissolved orthophosphate, total phosphorus, TKN, and dissolved nitrate plus nitrite).

To evaluate the variability in phytoplankton data, the absolute value logarithmic difference (AVLD) between field replicates was calculated as described in Graham and others (2017), with AVLDs <1.0 log cells per milliliter (cells/mL) considered acceptable. Because of the limited size of the Milford-only replicate dataset (*n*=4; Leiker, 2020a), additional data collected in the Kansas River and tributaries to the Kansas River (*n*=15; Kramer and others, 2018) were also used to evaluate variability. Data are summarized in appendix 2.

For total phytoplankton abundance, 18 of 19 replicate pairs (95 percent) had total AVLD <1.0, and the other replicate pair had a total AVLD equal to 1.0. Of the 19 replicate pairs, 18 had cyanobacteria present in at least one replicate sample. For cyanobacterial abundance, 9 of 18 replicate pairs (50 percent) had cyanobacteria AVLD <1.0. Most (8 of 9, 89 percent) replicate pairs with cyanobacteria AVLDs greater than 1.0 were present in samples with low relative cyanobacterial abundance (cyanobacterial abundance <10 percent of total phytoplankton abundance, *n*=7) and (or) low total abundance (total phytoplankton abundance <3,000 cells/mL, *n*=2) (appendix 2).

To evaluate phycocyanin data, relations between extracted phycocyanin and other data also related to algae and cyanobacteria were analyzed using the Pearson *r* and Spearman Rho correlation measures (Helsel and others, 2020). The other data related to algae and cyanobacteria were instantaneous sensor-measured phycocyanin fluorescence and chlorophyll fluorescence (data available in NWIS using station numbers in tables 3 and 4, U.S. Geological Survey, 2019), extracted chlorophyll (data available in NWIS using station numbers in tables 3 and 4, U.S. Geological Survey, 2019), and phytoplankton and cyanobacterial abundance data (available in Leiker, 2020a). The 31 phycocyanin samples collected in 2018 had significant ($p<0.10$) linear relations (as determined by Pearson *r*) with chlorophyll fluorescence data and significant ($p<0.10$) nonparametric relations (as determined by Spearman Rho) with all five algae- and cyanobacteria-related constituents (appendix 3).

Continuous Water-Quality Site—Milford Lake near Wakefield, Kansas

Continuous, real-time water-quality data were collected at site WK (USGS station number 391259097001800; fig. 1, tables 3 and 4) to characterize variability during the recreation season from June 8 through November 1, 2017, and from May 16 through November 22, 2018. Two (2017) or one (2018) YSI EXO2 multiparameter sonde(s) measured water temperature, specific conductance, dissolved oxygen, pH, chlorophyll fluorescence, and phycocyanin fluorescence. In 2017 there were two monitors (“shallow” and “deep”); in 2018 there was a shallow monitor only. The shallow monitor was maintained within the photic zone (typically between 0.5 and 1.0 m below the water surface) using flotation buoys. The deep monitor was approximately 0.5 m above the lakebed and was installed to determine if anoxic conditions (0 mg/L dissolved oxygen) developed near the bottom of the water column. Near-anoxic conditions were observed in 2017 and 2018 (table 6).

Measurements were recorded every 15 minutes and transmitted hourly. The centralized wiper on each monitor was programmed to wipe before every measurement. The water-quality monitors were suspended from the Highway 82 bridge east of Wakefield (also known as the Wakefield causeway, fig. 1) and were operated and maintained according to standard USGS procedures (Wagner and others, 2006; Bennett and others, 2014) and manufacturer recommendations (Yellow Springs Instruments, 2017). Data from the water-quality monitors are available at U.S. Geological Survey (2019). Chlorophyll fluorescence and phycocyanin fluorescence data are reported in relative fluorescence units (RFU) because the sensors were calibrated to rhodamine dye, a secondary standard.

During this study period, <7 percent of unit-value continuous water-quality data were unavailable (table 6). Missing water-quality data were not estimated. Data may be missing because of equipment malfunction, fouling caused by excessive algal growth, or other factors. Sensor maxima were not exceeded for any of the measured constituents during this study period.

Time-Lapse Photography

Three time-lapse cameras (Wingscape model WCT-00125, Moultrie, Birmingham, Alabama) were deployed at three locations in Zone C (site WK, the South causeway, and the Fort Riley Marina; fig. 1, table 7), to capture images of cyanobacteria bloom accumulation and movement in accordance with methods described in Foster and others (2019). The camera at site WK captured images every 15 minutes from June 21 through November 1, 2017, and from June 5 through September 9, 2018. The site WK camera was attached to the north side of the bridge and pointed down toward the continuous water-quality monitor. The South causeway camera captured images every 5 minutes from June 8 through

Table 6. Summary of continuous water-quality data from Milford Lake near Wakefield, Kansas (U.S. Geological Survey station number 391259097001800), June–November 2017 and May–November 2018. Data summarized from U.S. Geological Survey (2019).

Water-quality constituent	Maximum	Minimum	Mean	Median	Percent missing unit values
Shallow monitor, June–November 2017					
Water temperature, degrees Celsius	36.1	4.4	24.2	25.5	1.2
Specific conductance, microsiemens per centimeter	1,100	316	728	729	2.9
Dissolved oxygen, milligrams per liter	26.4	0.1	6.9	6.9	3.1
pH, standard units	9.5	7.3	8.3	8.3	1.0
Chlorophyll, relative fluorescence units	21.6	0.8	6.0	5.3	2.6
Phycocyanin, relative fluorescence units	29.0	0.23	1.75	1.47	0.7
Deep monitor, June–November 2017					
Water temperature, degrees Celsius	33.7	4.7	23.5	25.0	0.7
Specific conductance, microsiemens per centimeter	1,090	221	744	779	0.7
Dissolved oxygen, milligrams per liter	21.4	0.2	6.2	6.2	3.5
pH, standard units	9.2	7.3	8.1	8.2	1.0
Chlorophyll, relative fluorescence units	23.5	1.0	7.6	7.4	1.5
Phycocyanin, relative fluorescence units	16.0	0.32	1.79	1.65	6.5
Shallow monitor, May–November 2018					
Water temperature, degrees Celsius	33.4	2.6	22.6	25.4	0.1
Specific conductance, microsiemens per centimeter	1,150	173	634	644	0.7
Dissolved oxygen, milligrams per liter	21.7	0.4	6.7	6.4	0.4
pH, standard units	8.9	7.0	8.0	8.1	0
Chlorophyll, relative fluorescence units	39.0	0.7	6.5	4.3	1.7
Phycocyanin, relative fluorescence units	6.12	0.19	1.21	0.94	1.8

July 15 and August 1 through November 1, 2017, and June 26 through July 10, 2018. Because of site accessibility and equipment issues, images from the South causeway camera were not available between July 15 and August 1, 2017. The South causeway camera was attached to a T-post and pointed southwest. The Fort Riley Marina camera captured images every 5 minutes from June 5 through November 9, 2018. The Fort Riley Marina camera was attached to a light pole and pointed southwest. Images not obscured by fog, insects, rain events, brush, or other factors are available in Leiker (2020b).

Harmful Algal Bloom Advisories and Bloom Photographs

Milford Lake had confirmed HABs every summer from 2011 through 2017 (Kansas Department of Health and Environment, 2020b). Between 2011 and 2014, advisories applied to the whole lake. Since the KDHE designated Zones A, B, and C in the lake in 2015, advisories in 2015 and after were designated by zones. The KDHE provides three types of advisories: watch—to notify the public of expected unsafe conditions for human exposure; warning—to notify the public of possible or present hazardous conditions; and closure—to notify the public of extreme hazardous conditions (Kansas Department of Health and Environment, 2019b). Advisory level is determined by cyanobacterial cell counts and (or) microcystin concentrations at the following thresholds (Kansas Department of Health and Environment, 2019b):

- Watch: cyanobacteria cell counts greater than or equal to (≥) 80,000 cells/mL and <250,000 cells/mL, or microcystin concentrations ≥4 µg/L and <20 µg/L;
- Warning: cyanobacteria cell counts ≥250,000 cells/mL and <10,000,000 cells/mL, or microcystin concentrations ≥20 µg/L and <2,000 µg/L; and
- Closure: cyanobacteria cell counts ≥10,000,000 cells/mL, or microcystin concentrations ≥2,000 µg/L.

In 2017, advisories were posted for Zones A, B, and C from June 22 through September 7 (Kansas Department of Health and Environment, 2017). Bloom movement in 2017 was captured in time-lapse photos collected at the South causeway camera (fig. 4; Leiker, 2020b). Previous investigations at Milford Lake also captured variability of bloom accumulations (Foster and others, 2019; King, 2019). There were no advisories for the lake posted in 2018 (Kansas Department of Health and Environment, 2018).

Table 7. Site list for time-lapse photography, including dates time-lapse photography is available, time increment between photos, and camera direction.

Site identifier	Site name	U.S. Geological Survey station number	Dates time-lapse photography available	Time increment between photographs	Camera direction
WK camera	Milford Lake near Wakefield, Kansas	391259097001800	June 21–November 1, 2017; June 5–September 9, 2018	15 minutes	Down.
South causeway camera	Milford Lake, Kansas South causeway Camera	391259097001000	June 8–July 15, August 1–November 1, 2017; June 26–July 10, 2018	5 minutes	Southwest.
Fort Riley Marina camera	Milford Lake, Kansas Fort Riley Marina Camera	391235096573800	June 5–November 9, 2018	5 minutes	Southwest.

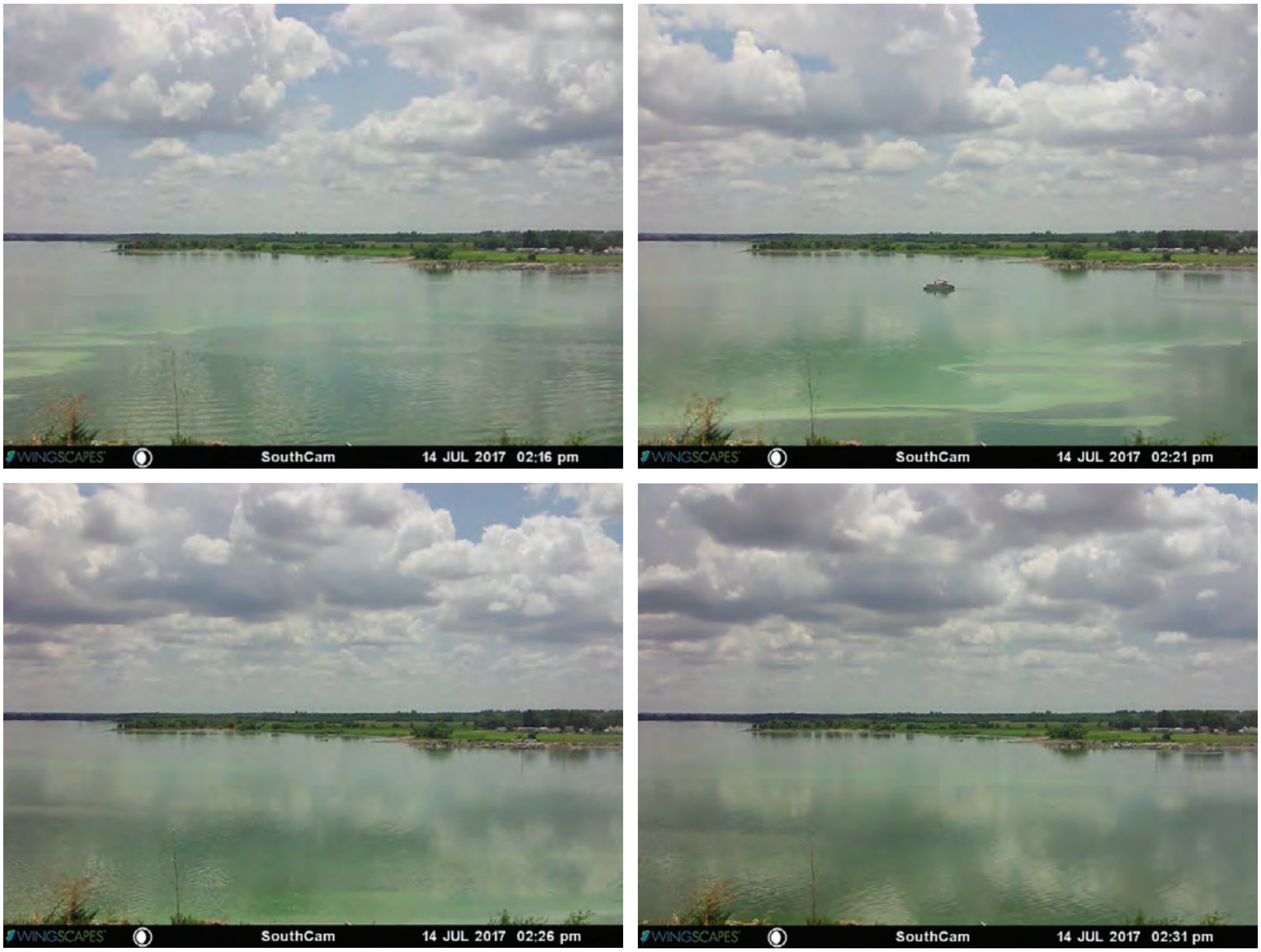


Figure 4. Time-lapse photographs showing bloom movement over 15 minutes, South causeway, Milford Lake, Kansas, July 14, 2017.

Nutrient and Algal Concentrations in the Republican River and Milford Lake

Nutrient concentrations and algal concentrations and abundances are presented in this section for the low-flow floating synoptic, 24-hour synoptic, and whole-lake synoptics. Median values and benchmarks for nutrients, dissolved oxygen, and cholorophyll are presented first to provide context for the concentrations measured in this study.

Nutrient, Dissolved Oxygen, and Chlorophyll Long-Term Median Values and Benchmarks

Milford Lake is currently (2020) listed as impaired by the KDHE for eutrophication and low dissolved oxygen (Kansas Department of Health and Environment, 2014a). The desired endpoint chlorophyll concentration in the impairment listing is 10 µg/L and the desired dissolved oxygen concentration throughout the entire water column is 5 mg/L (Kansas Department of Health and Environment, 2014a). The long-term (1996–2012) median values in the main basin of Milford Lake for samples collected by the KDHE and the U.S. Army Corps of Engineers were 0.18 milligram per liter as phosphorus (mg/L-P) total phosphorus, 1.09 mg/L-N total nitrogen, and 13.08 µg/L chlorophyll (Kansas Department of Health and Environment, 2014a). Total nitrogen is the sum of TKN (also known as ammonia plus organic nitrogen) and dissolved nitrate plus nitrite (USGS parameter codes 00625 and 00631, respectively). The long-term median values were calculated based on 8 years of KDHE data at site LM019001 and 17 years of U.S. Army Corps of Engineers data at site MI-1; these sites are in the southern section of Zone A (fig. 1; Kansas Department of Health and Environment, 2014a; Chelsea Paxson, Kansas Department of Health and Environment, written commun., 2020). There are also statewide lake and reservoir benchmark values: 0.023 mg/L-P total phosphorus, 0.625 mg/L-N total nitrogen, and 8 µg/L chlorophyll (Dodds and others, 2006, in Kansas Department of Health and Environment, 2014a). According to the KDHE, eutrophic conditions are generally seen when chlorophyll concentrations exceed 12 µg/L and hypereutrophic conditions are present when concentrations exceed 30 µg/L (Kansas Department of Health and Environment, 2014a).

Low-Flow Floating Synoptic (July 20, 2017)

Results from the low-flow floating synoptic indicated that the Republican River was not contributing dissolved orthophosphate or total phosphorus concentrations higher than those in the main body of Milford Lake (figs. 5, 6). There was a substantial increase in dissolved orthophosphate concentrations between sites M57 and WK (fig. 5); concentrations at and upstream from site M57 were approximately one-half of the concentrations at and downlake of site WK. There was a similar pattern in the fraction of total phosphorus consisting of dissolved orthophosphate: at and upstream from site M57, dissolved orthophosphate was 37–60 percent of the total phosphorus, whereas at and downlake from site WK, dissolved orthophosphate was 71–85 percent of the total phosphorus (data not shown). Total phosphorus concentrations increased farther uplake (farther from the outlet) in Zone C than the increase in orthophosphate concentrations (between sites R21 and M57; fig. 6). Total phosphorus concentrations at and downlake from site M57 were almost double concentrations at and upstream from site R21. At all lake sites (sites M57–M63, WK), concentrations of total phosphorus exceeded the long-term median value in the lake (0.18 mg/L-P) and the statewide lake and reservoir benchmark value (0.023 mg/L-P).

The pond to the side of the main river channel (site P) had a dissolved orthophosphate concentration in the range of other river sites sampled (fig. 5) but concentrations of total phosphorus and TKN in the pond were substantially higher than all river and lake sites (figs. 6, 7). The pond was not contributing surface flow to the Republican River on July 20, 2017, but could be a source of nutrients into the river under different flow conditions. No other major nutrient hotspots were identified in the Republican River (sites 06856600, R2–R21).

Dissolved nitrate plus nitrite was not detected in any of the Republican River samples or the pond (reporting limit 0.01 mg/L-N); concentrations in the lake ranged from <0.01 to 0.05 mg/L-N (data not shown) and total nitrogen was dominated (95–100 percent) by TKN. Because total nitrogen was dominated by TKN and dissolved nitrate plus nitrite values were less than or near the reporting limit, TKN was used for analysis and interpretation. Unlike phosphorus, TKN concentrations did not have a solely increasing pattern downstream along the Republican River, and some TKN concentrations in the river were as high as those in Zone C (fig. 7). There may have been unidentified sources of TKN flowing into the river during the synoptic, or this variability in concentrations could be caused by microbial activity in the water column and (or) bed sediment (Bernhard, 2010). At the lake sites (sites M57–M63, WK), concentrations of TKN (and therefore also total nitrogen) were similar to the long-term (1996–2012) in-lake median total nitrogen value of 1.09 mg/L-N and exceeded the statewide lake and reservoir total nitrogen benchmark value of 0.625 mg/L-N.

24-Hour Synoptic (August 24–25, 2017)

During the 24-hour synoptic, dissolved orthophosphate concentrations were lower at site WK than site M61 (fig. 8*A*) and total phosphorus concentrations were similar at both sites (fig. 8*B*). Accordingly, the fraction of total phosphorus consisting of dissolved orthophosphate was 46–77 percent at site WK and 88–99 percent at site M61 for all samples at all depths (data not shown). No patterns in nutrient concentrations during the 24-hour period were evident. Orthophosphate concentrations were similar at the three depths except for a few lower concentrations in WK bottom samples. For total phosphorus, concentrations at the bottom depth were highest at M61 throughout the 24-hour synoptic and highest at WK during the second one-half of the sampling period.

Concentrations of TKN did not vary substantially with depth or time at either site, and concentrations were higher at site WK than site M61 (fig. 9*A*). Total nitrogen was dominated by TKN at both sites (fig. 9). At site WK, nitrogen concentrations peaked at night and were highest in the bottom samples. At site M61, nitrogen concentrations were relatively stable and were also highest in the bottom samples. Most (22 of 30) samples at site WK had concentrations of nitrate plus nitrite less than the reporting limit of 0.01 mg/L-N (data not shown).

Chlorophyll concentrations oscillated at site WK but did not vary substantially at site M61 during the 24-hour sampling period (fig. 10*A*). Chlorophyll concentrations at site WK were approximately three to six times higher than concentrations at site M61; conditions at both sites were indicative of eutrophic conditions (at least 12 µg/L; Kansas Department of Health and Environment, 2014a). There was an increase in the surface chlorophyll concentrations and the continuous shallow chlorophyll fluorescence values at site WK before sunrise (fig. 10*A*). Many cyanobacteria are able to control their position in the water column by using gas vacuoles to regulate buoyancy (Graham and others, 2008). The increase in chlorophyll in the predawn hours indicates that there was some movement of cyanobacteria near the water surface.

At site WK, the rapid increases in the continuous shallow chlorophyll fluorescence values at approximately 3 a.m., 5 a.m., and 7 a.m. were accompanied by moderate decreases in the continuous shallow dissolved oxygen concentration (fig. 10*A*) and a decrease in the dissolved orthophosphate concentration (the biologically available form of the nutrient; fig. 8*A*), demonstrating the effect that algae can have on nutrient and dissolved oxygen concentrations. Although continuous sensor data were not collected at site M61, the absence of oscillation in the discrete dissolved orthophosphate (fig. 8*A*), surface chlorophyll (fig. 10*A*), and instantaneous dissolved oxygen (fig. 10*B*) concentrations at site M61 illustrates the variable nature of algal accumulations and their effects on nutrient and dissolved oxygen concentrations.

Dissolved oxygen concentrations showed typical diurnal patterns at site WK but were relatively stable and lower at site M61. Dissolved oxygen concentrations ranged from 4.6 to 9.8 mg/L with the four observed concentrations <5 mg/L associated with the four bottom samples at site M61 between 3:40 p.m. and 10:50 p.m. on August 24 (fig. 10*B*).

Total microcystin concentrations ranged from 0.18 to 0.75 µg/L (fig. 11), substantially below 4 µg/L, which is the concentration indicating the lowest KDHE advisory level (watch). Between sunset on August 24 and sunrise on August 25, concentrations at M61 decreased, whereas concentrations at site WK increased until the 1:30 a.m. sample and then decreased. Both sites had their lowest concentrations in the samples just before sunrise. No diel patterns in total microcystin were evident.

There were different patterns in chlorophyll and microcystin concentrations (fig. 10*A*, 11) at sites WK and M61. Chlorophyll was consistently higher at site WK but microcystin concentrations were generally higher at site M61, which indicates that the relation between algal biomass and cyanotoxin concentrations were different at the two sites. This variability may have been caused by differences in the algal communities present at each site. Because cyanobacteria can control their position in the water column, the collection of surface samples only (for chlorophyll and microcystin) may have also affected the concentrations that were observed (Graham and others, 2008, 2012; Foster and others, 2017).

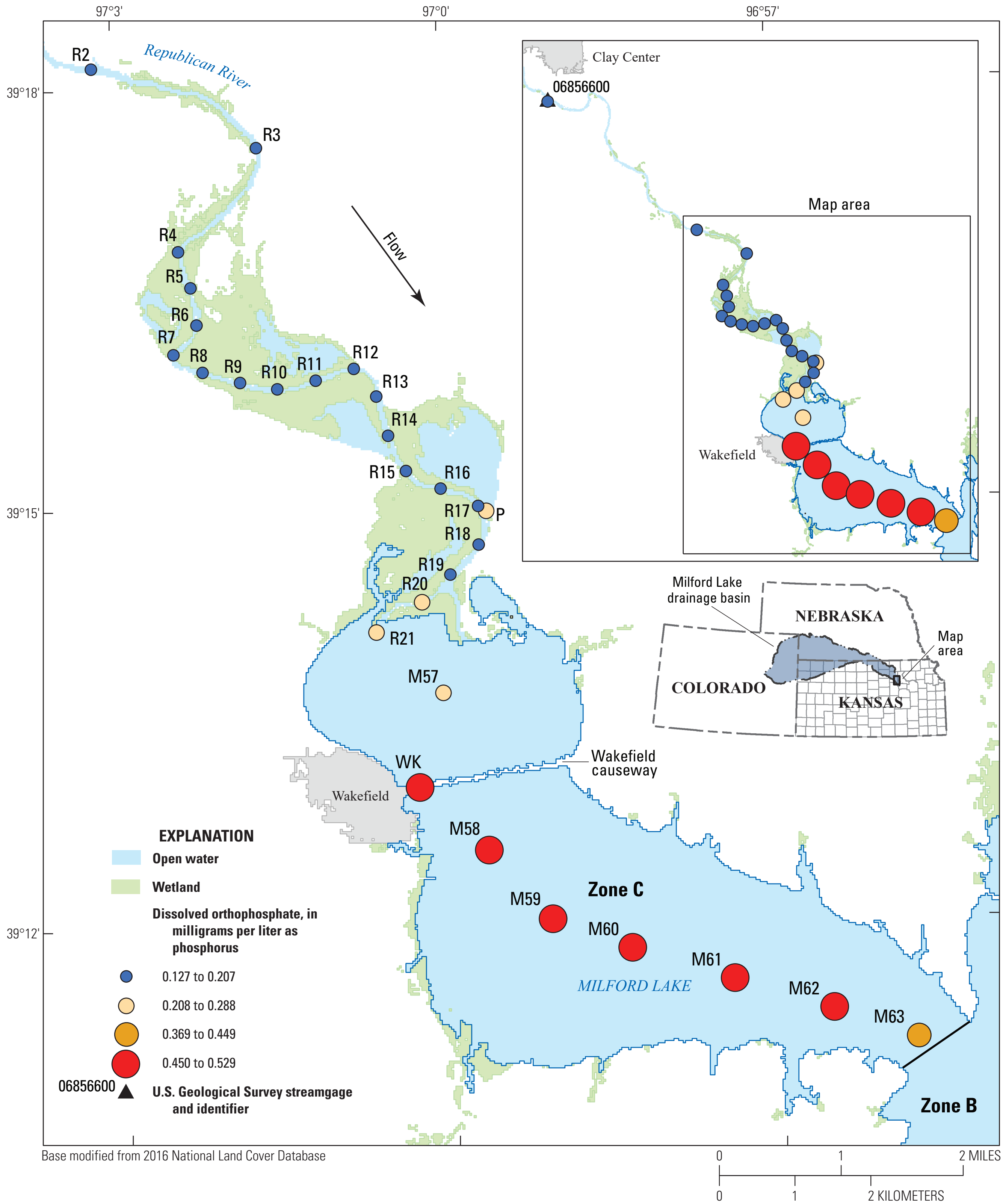


Figure 5. Dissolved orthophosphate concentrations, Republican River and Milford Lake, Kansas, low-flow floating synoptic, July 20, 2017. Sampling locations shown in figure 1.

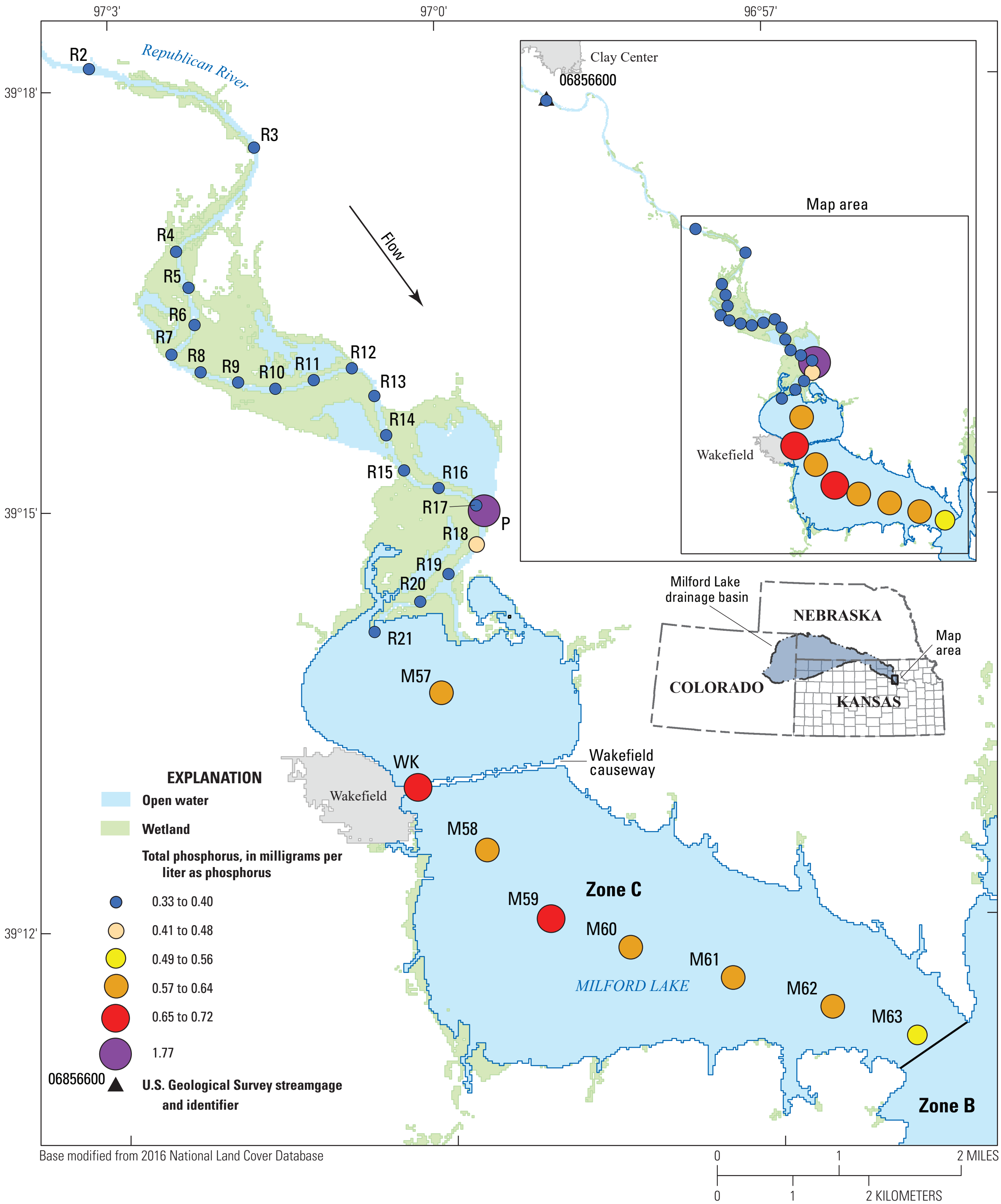


Figure 6. Total phosphorus concentrations, Republican River and Milford Lake, Kansas, low-flow floating synoptic, July 20, 2017. Sampling locations shown in figure 1.

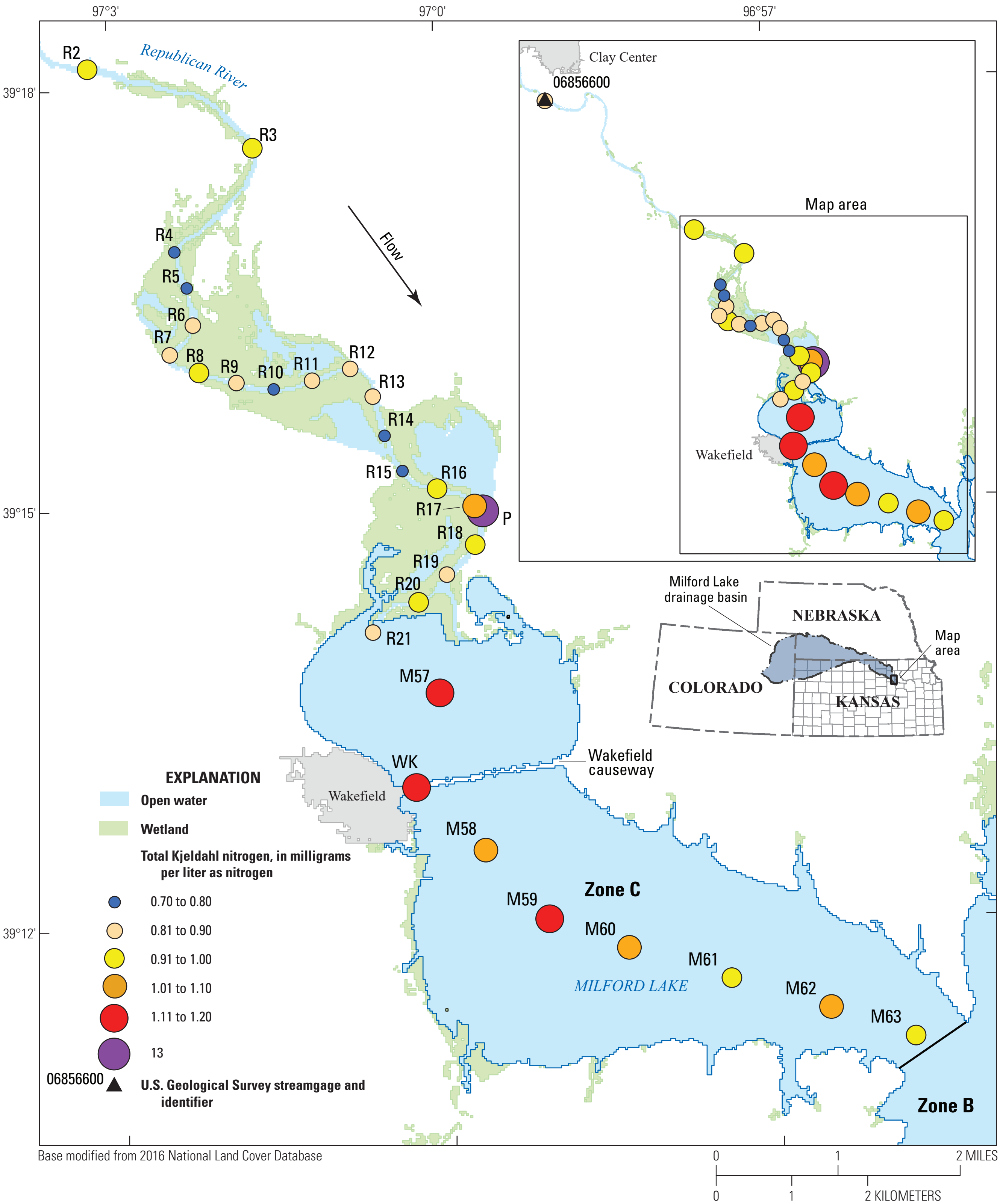


Figure 7. Total Kjeldahl nitrogen concentrations, Republican River and Milford Lake, Kansas, low-flow floating synoptic, July 20, 2017. Sampling locations shown in figure 1.

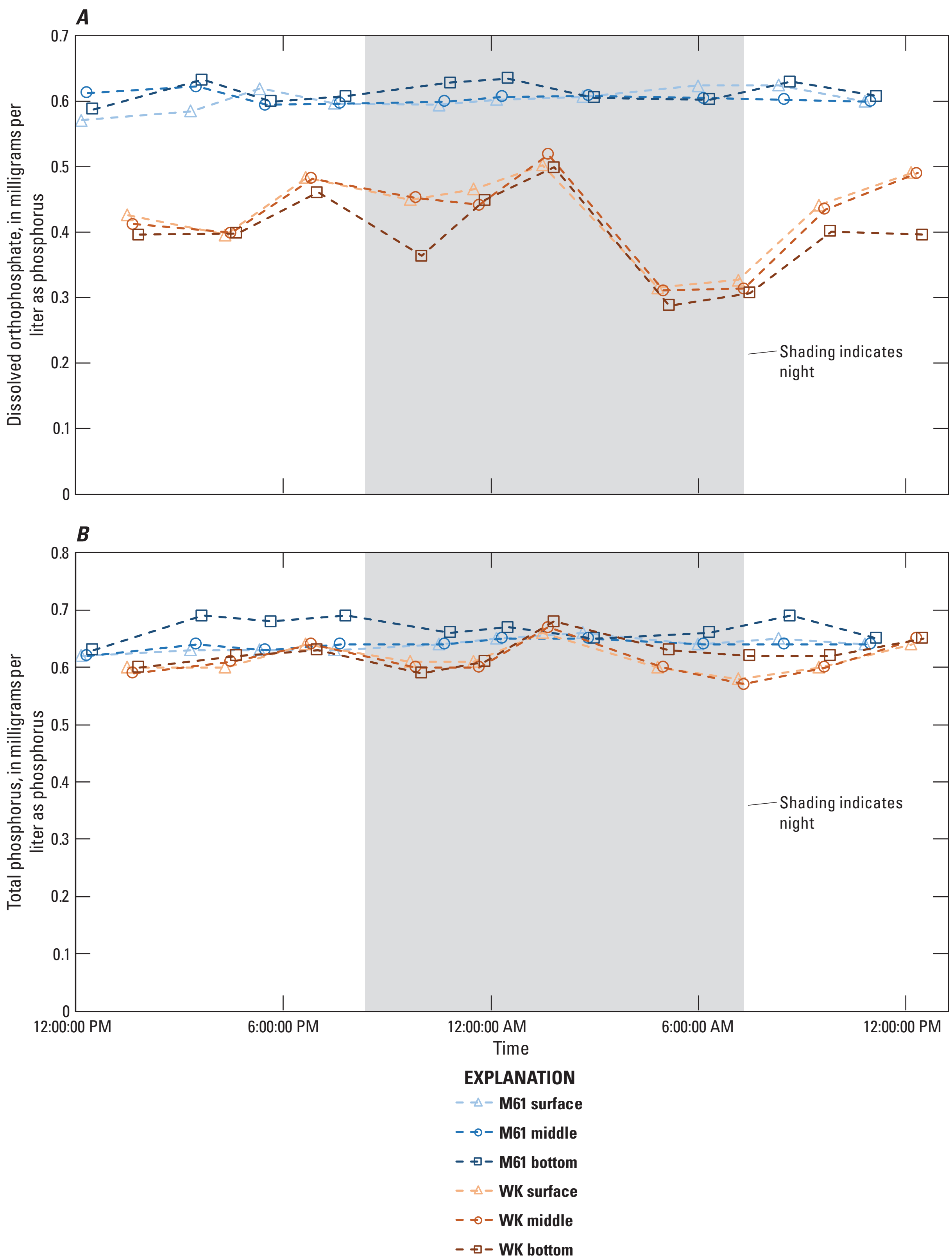


Figure 8. Concentrations of phosphorus at three depths in Milford Lake, Kansas, at sites WK and M61, 24-hour synoptic, August 24–26, 2017. *A*, Dissolved orthophosphate. *B*, Total phosphorus. Sampling locations shown in figure 1.

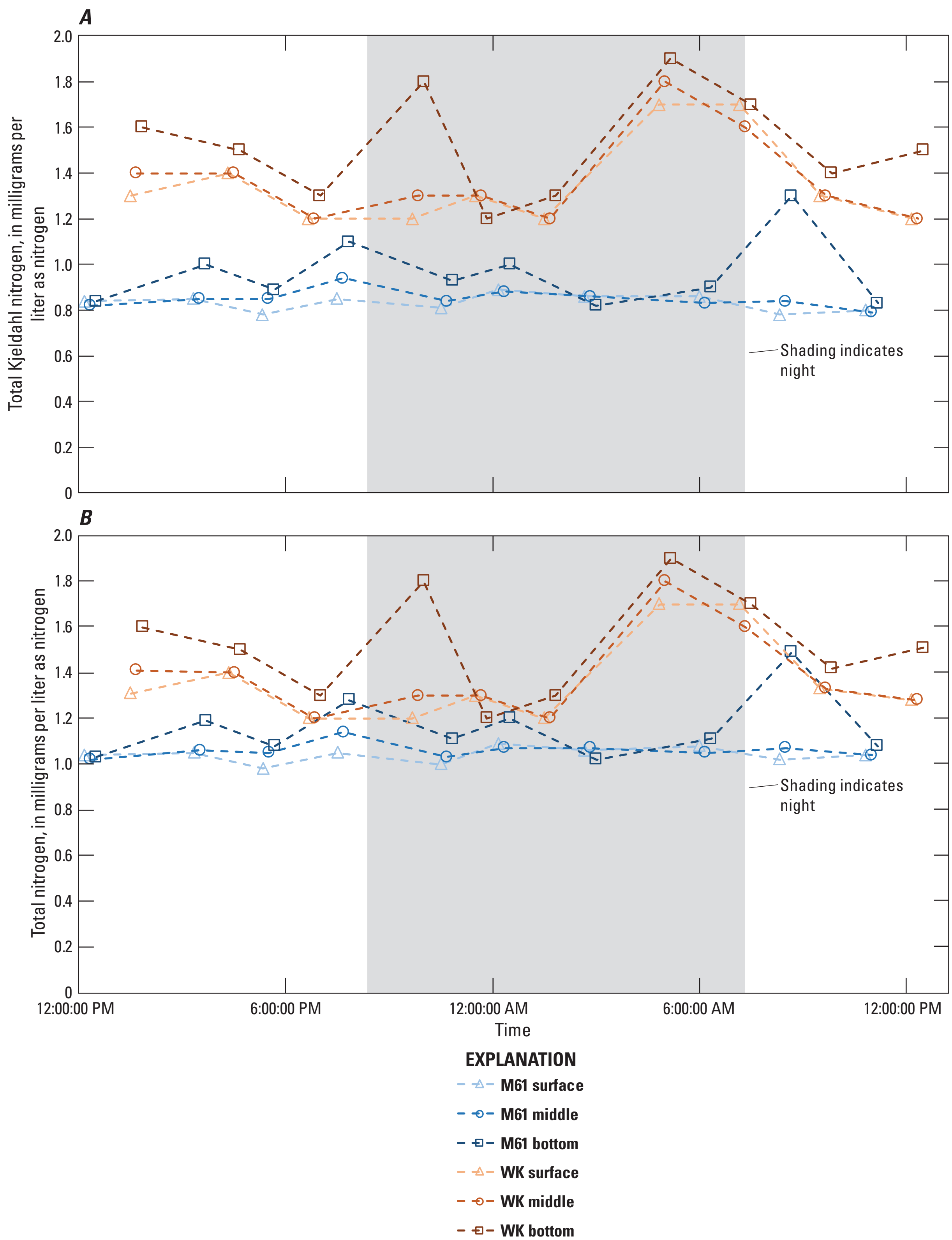


Figure 9. Concentrations of nitrogen at three depths in Milford Lake, Kansas, at sites WK and M61, 24-hour synoptic, August 24–25, 2017. *A*, Total Kjeldahl nitrogen. *B*, Total nitrogen. Sampling locations shown in figure 1.

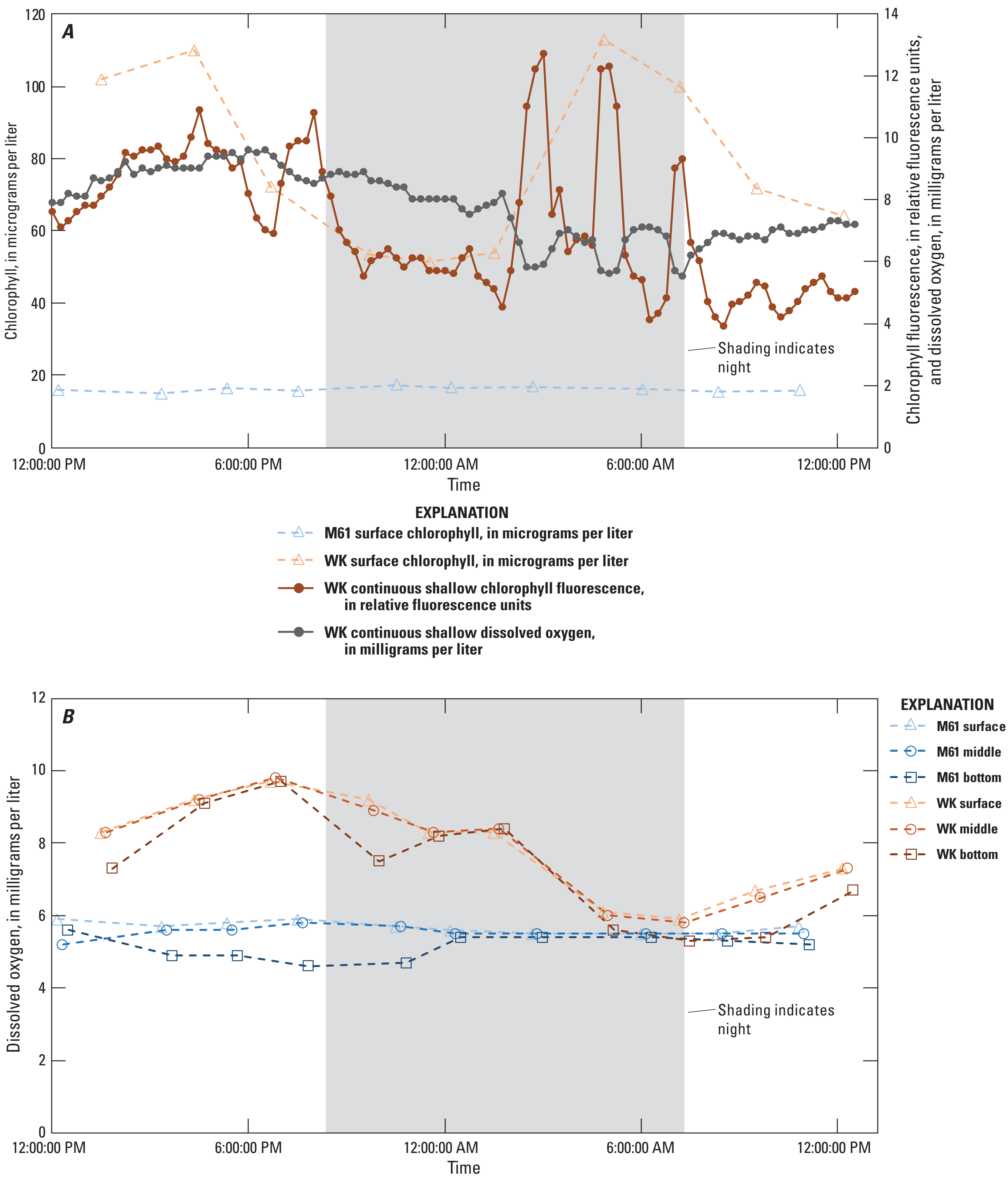


Figure 10. Concentrations of chlorophyll and dissolved oxygen in Milford Lake, Kansas, at sites WK and M61, 24-hour synoptic, August 24–25, 2017. *A*, Surface chlorophyll concentration at both sites and continuous shallow chlorophyll fluorescence and dissolved oxygen at site WK. *B*, Instantaneous dissolved oxygen at both sites. Sampling locations shown in figure 1.

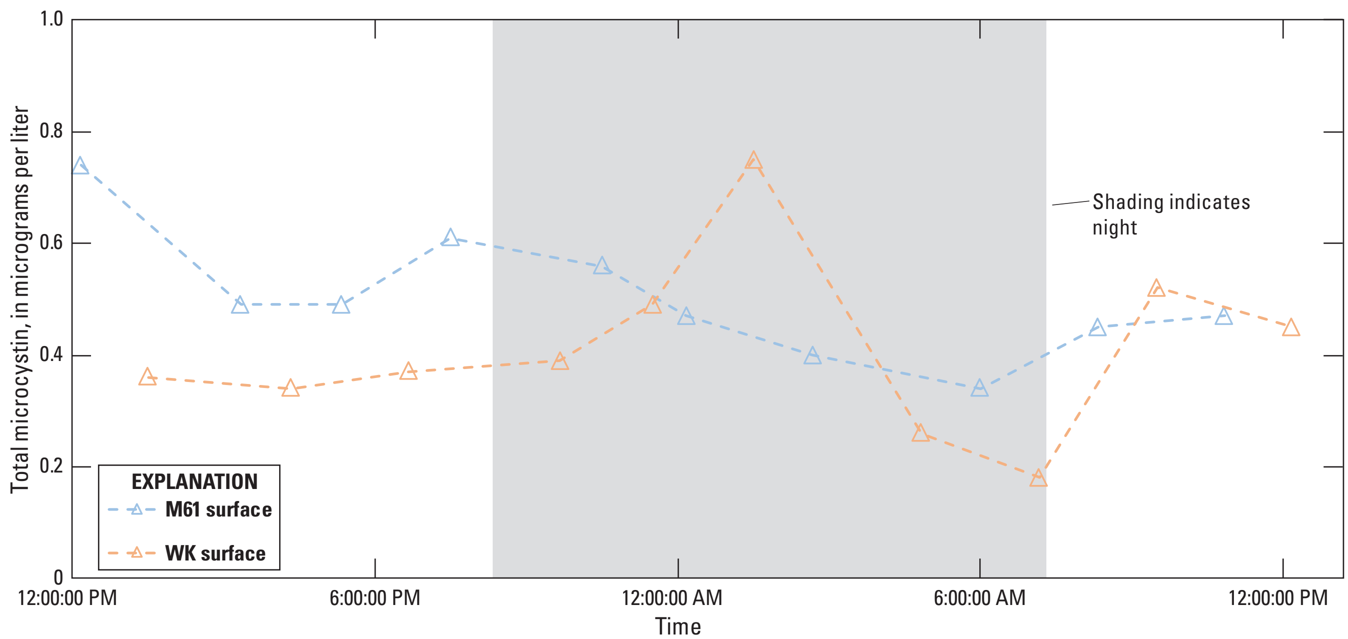


Figure 11. Concentrations of total microcystin in Milford Lake, Kansas, at sites WK and M61, 24-hour synoptic, August 24–25, 2017. Sampling locations shown in figure 1.

Whole-Lake Synoptics (July 10, August 9, and October 16–17, 2018)

Nutrient concentrations and algal concentrations and abundances are presented in this section for the whole-lake synoptics. Figure sets are arranged by constituent.

Dissolved Orthophosphate and Total Phosphorus

Concentrations of dissolved orthophosphate and total phosphorus increased from July to August and from August to October at all sites except three in Zone C: sites M1, M32, and M51 (figs. 12, 13). In July, sites M56 and M63 had lower concentrations of dissolved orthophosphate than the rest of Zone C and site M63 had a lower concentration of total phosphorus than the rest of Zone C (figs. 12*A*, 13*A*). In August, sites M1 and M32 had the lowest dissolved orthophosphate concentrations in Zone C (fig. 12*B*).

In July and August, Zone C had dissolved orthophosphate concentrations higher than all sites in Zones B and A (figs. 12*A*, 12*B*). By October, dissolved orthophosphate concentrations were fairly consistent across the whole lake, and the range (difference between maximum and minimum values) in dissolved orthophosphate concentrations across the lake was about one-quarter of the range in July and August (fig. 12*C*). As previously stated, orthophosphate is the biologically available form of phosphorus. Higher concentrations of dissolved orthophosphate in October than in July and August were likely caused by reduced biological activity (less uptake of nutrients) and lower air and water temperatures. Multiple inflow events (streamflow greater than median daily value) between August and October (fig. 3) also may have moved nutrients through the lake.

Orthophosphate was consistently at least 77 percent of total phosphorus at all sites except site M1 and M32 (data not shown). At sites M1 and M32, orthophosphate was between 52 and 72 percent of the total phosphorus present at the site (data not shown). Lower contributions of orthophosphate to total phosphorus at sites M1 and M32 indicate that more nutrients may have been tied up in algal biomass in the area of the lake that is uplake from the Wakefield causeway.

In July, Zone C, except site M63, had total phosphorus concentrations higher than all sites in Zones B and A (fig. 13*A*). The range in total phosphorus concentrations across the lake was smaller in August and October than the range in July (fig. 13). At all lake sites, concentrations of total phosphorus exceeded the long-term median value in the lake (0.18 mg/L-P) and the statewide lake and reservoir benchmark value (0.023 mg/L-P).

Total Kjeldahl Nitrogen, Dissolved Nitrate Plus Nitrite, and Total Nitrogen

There was no consistent increasing or decreasing pattern through time for TKN concentrations; some sites had their highest concentrations in July, some in August, and others in October (fig. 14). The July TKN value at site M32 was unavailable because of laboratory error. The highest TKN concentrations in July (site M1 only), August, and October were at sites M1 and M32, which were uplake from site WK in a shallow area of the lake (fig. 14), although downlake site M6 (in Zone B downlake from site WK) matched the M32 value in August. In July, Zone C generally had the highest concentrations, although site M63 was substantially lower than the rest of the zone and site M69, in a cove in Zone B, had a concentration in the Zone C range (fig. 14*A*). August was the only month in which concentrations exceeded 1.0 mg/L-N outside Zone C: site M65 was 1.1 mg/L-N and site M6 was 1.3 mg/L-N (fig. 14*B*). The range of concentrations across the lake was fairly consistent through July, August, and October (fig. 14).

Total nitrogen was dominated by TKN in July and August. Dissolved nitrate plus nitrite is the biologically available form of nitrogen and was detected at only one site in July (site M21, 0.01 mg/L-N) and August (site M41, 0.01 mg/L-N) (data not shown). Very low concentrations of dissolved nitrate plus nitrite indicate that the nutrient was likely tied up in algal biomass. Because dissolved nitrate plus nitrite concentrations were so low in July and August, concentrations of TKN were also the concentrations of total nitrogen in July and August.

By October, nitrate plus nitrite concentrations at all sites were well above the reporting limit of 0.01 mg/L-N (fig. 15*A*). In October, total nitrogen was approximately one-half TKN (46 to 55 percent) and one-half dissolved nitrate plus nitrite (45 to 54 percent). Zone C had higher concentrations of nitrate plus nitrite than all sites in Zones B and A in October; sites M1 and M32 had particularly elevated nitrate plus nitrite and were the only sites with concentrations exceeding 1.0 mg/L-N (fig. 15*A*). Total nitrogen was highest in October at all sites except M6 (highest in August) (figs. 14*A*, 14*B*, 15*B*). Similarly to dissolved orthophosphate, higher concentrations of dissolved nitrate plus nitrite in October than in July and August were likely caused by reduced biological activity (less uptake of nutrients) and lower air and water temperatures. Multiple inflow events (streamflow greater than median daily value) between August and October (fig. 3) also may have moved nutrients through the lake. In July and August, concentrations of TKN (and therefore also total nitrogen) were generally similar to or less than the long-term (1996–2012) in-lake median total nitrogen value of 1.09 mg/L-N. In October, all sites exceeded the in-lake median total nitrogen value. All sites (except sites M70, M21, M23, and M74 in July only) exceeded the statewide lake and reservoir total nitrogen benchmark value of 0.625 mg/L-N.

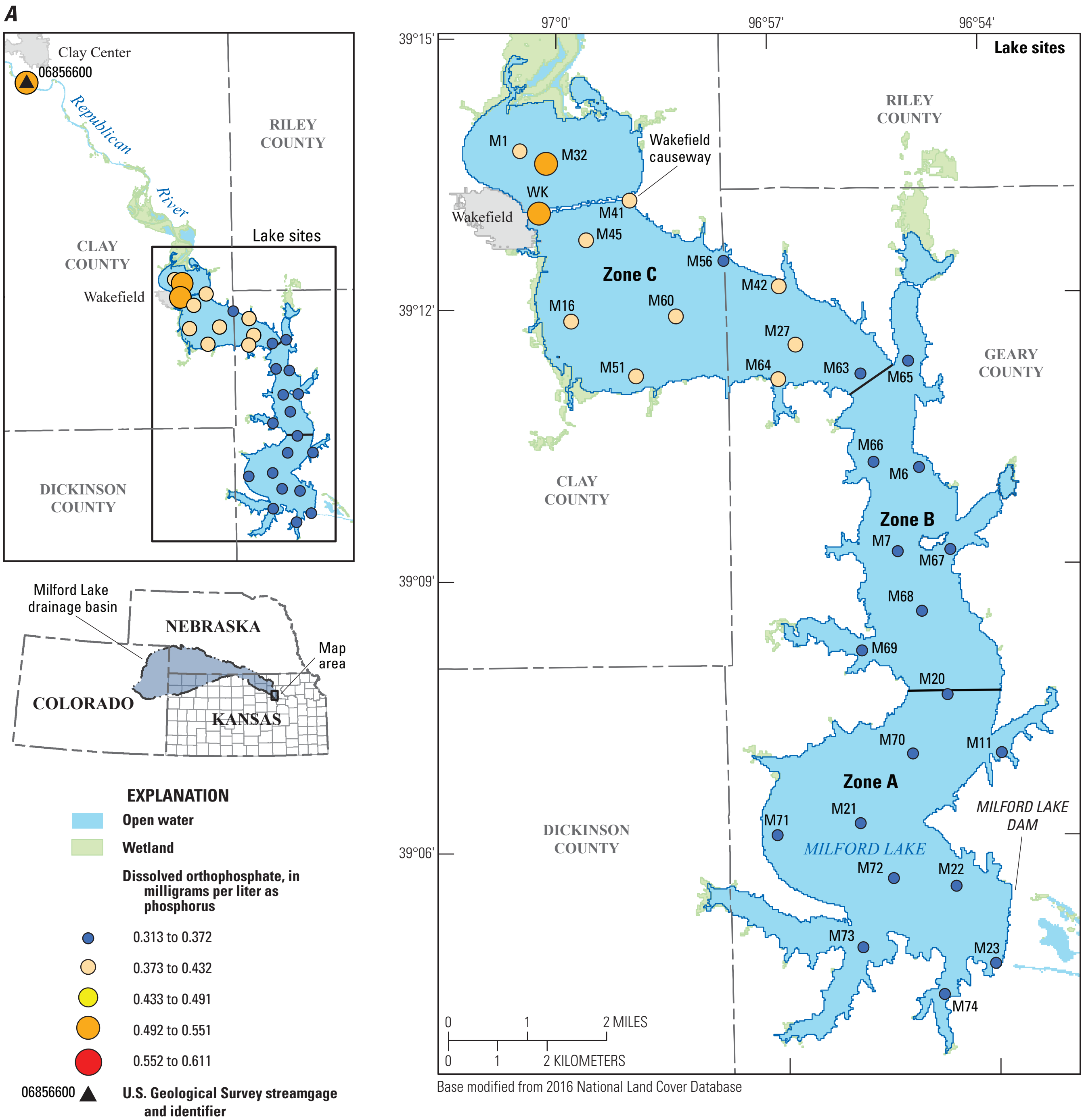
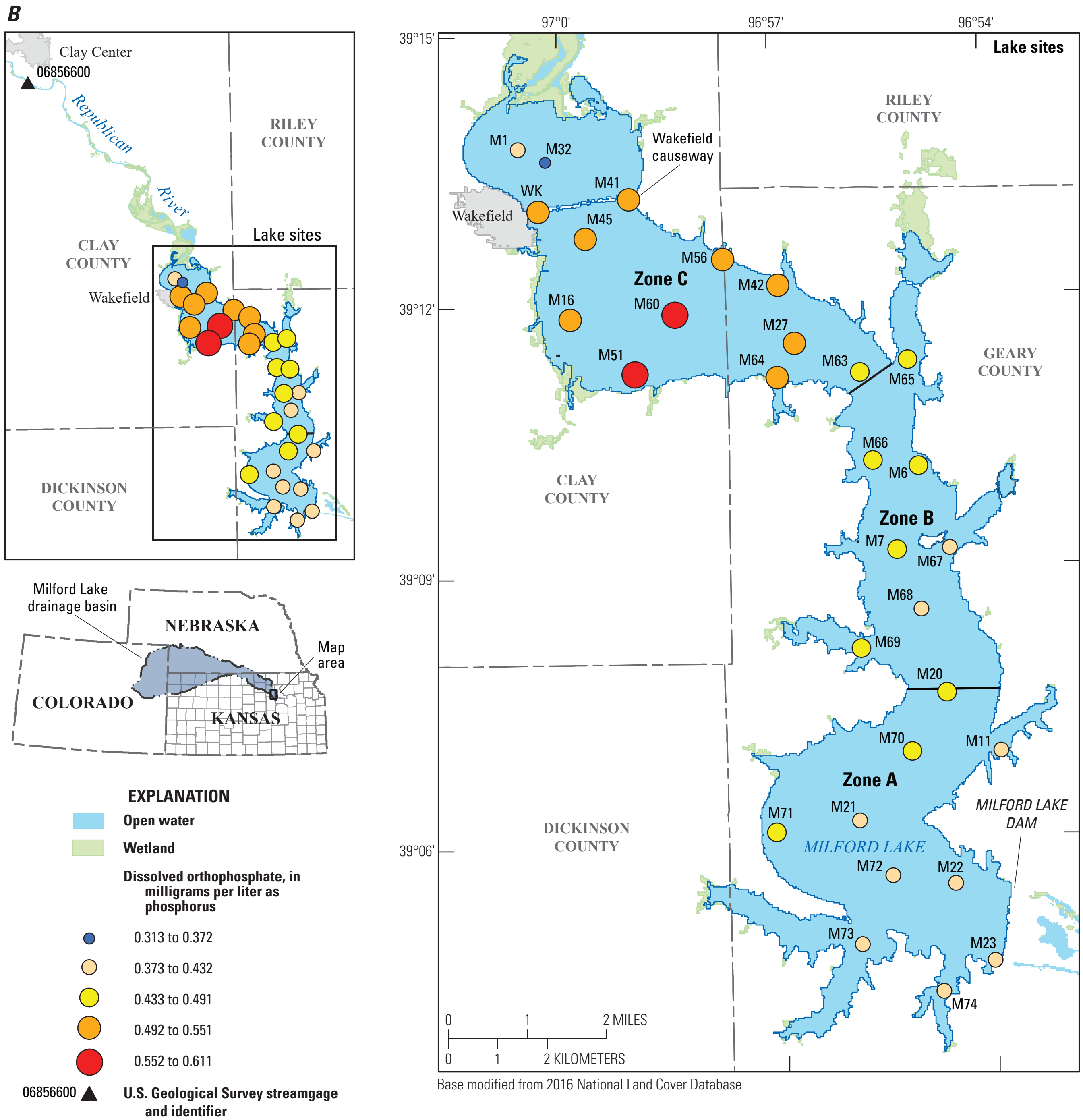
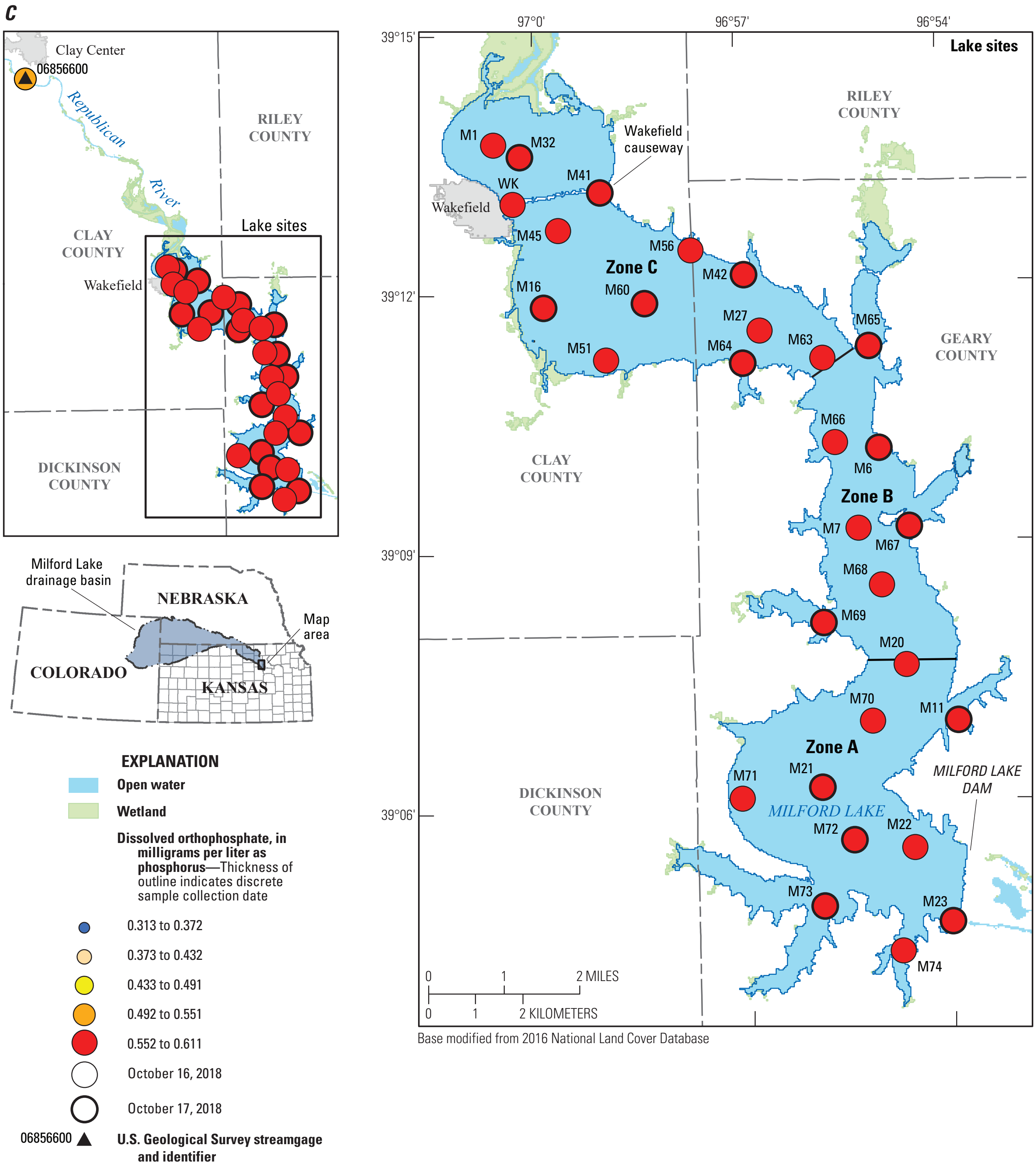


Figure 12. Concentrations of dissolved orthophosphate in Milford Lake, Kansas, whole-lake synoptics. *A*, July 10, 2018. *B*, August 9, 2018. *C*, October 16–17, 2018. Sampling locations shown in figure 1.



Base modified from 2016 National Land Cover Database

Figure 12.



Base modified from 2016 National Land Cover Database

Figure 12.

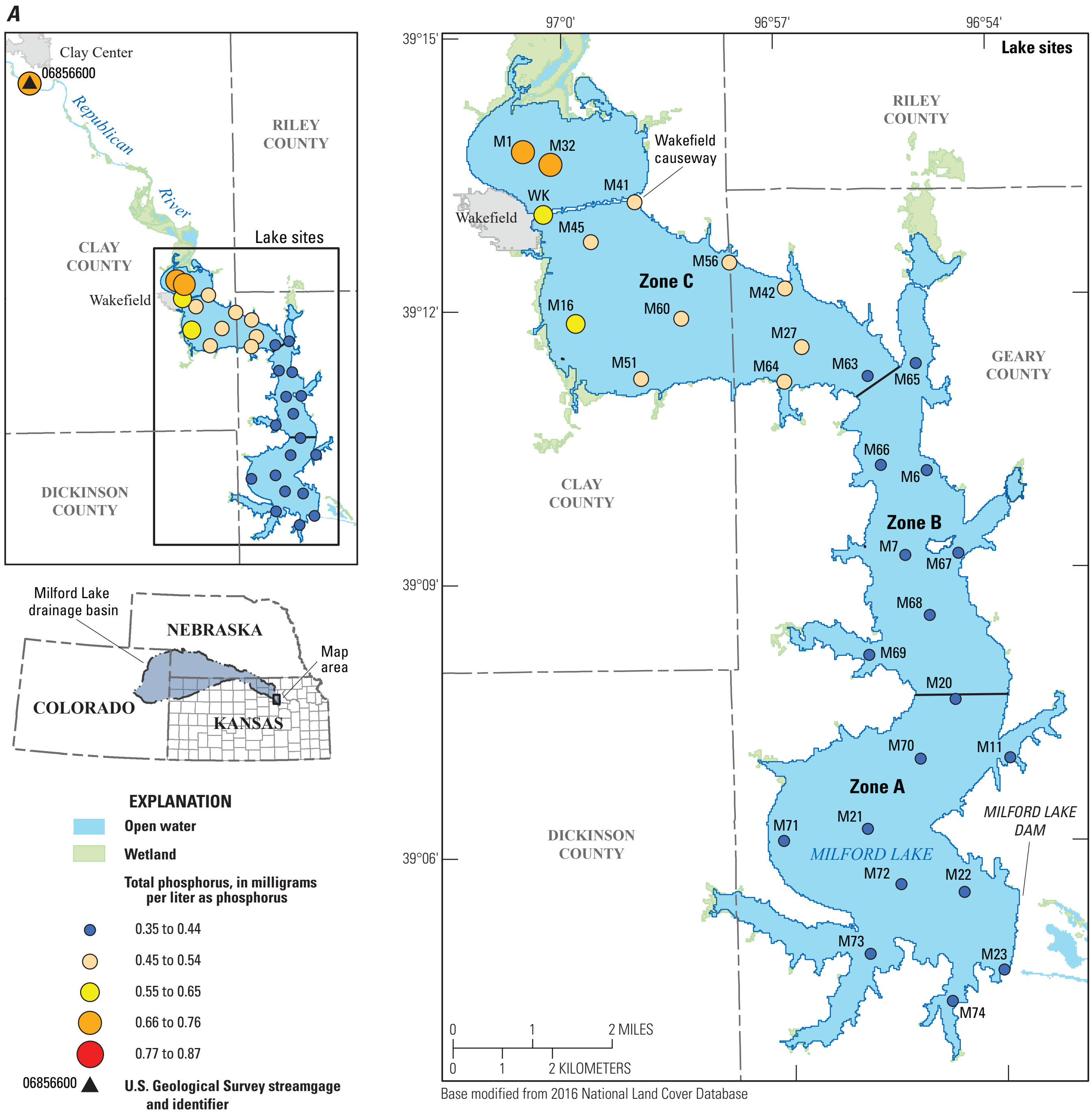
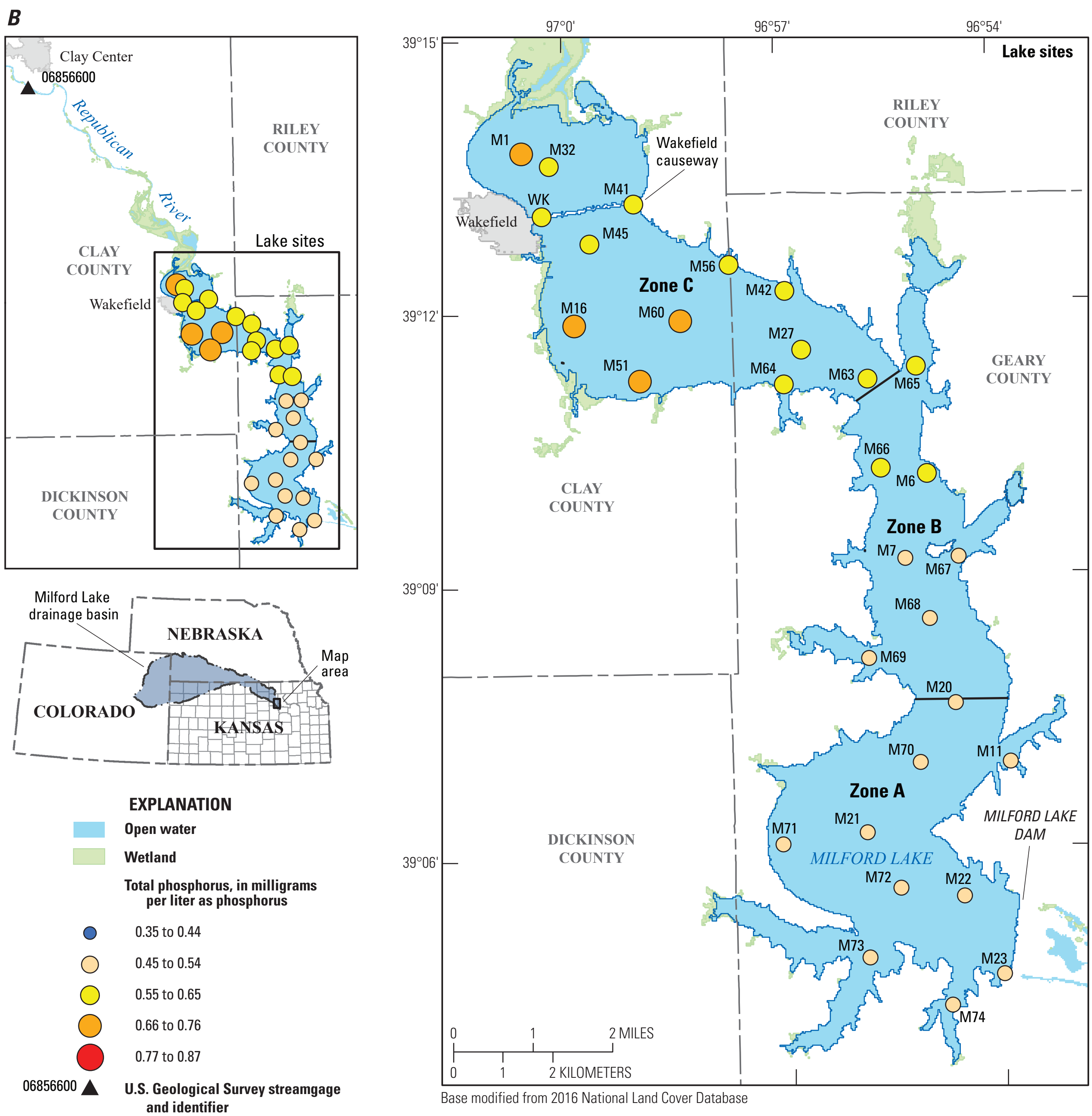


Figure 13. Concentrations of total phosphorus in Milford Lake, Kansas, whole-lake synoptics. *A*, July 10, 2018. *B*, August 9, 2018. *C*, October 16–17, 2018. Sampling locations shown in figure 1.



Base modified from 2016 National Land Cover Database

Figure 13.

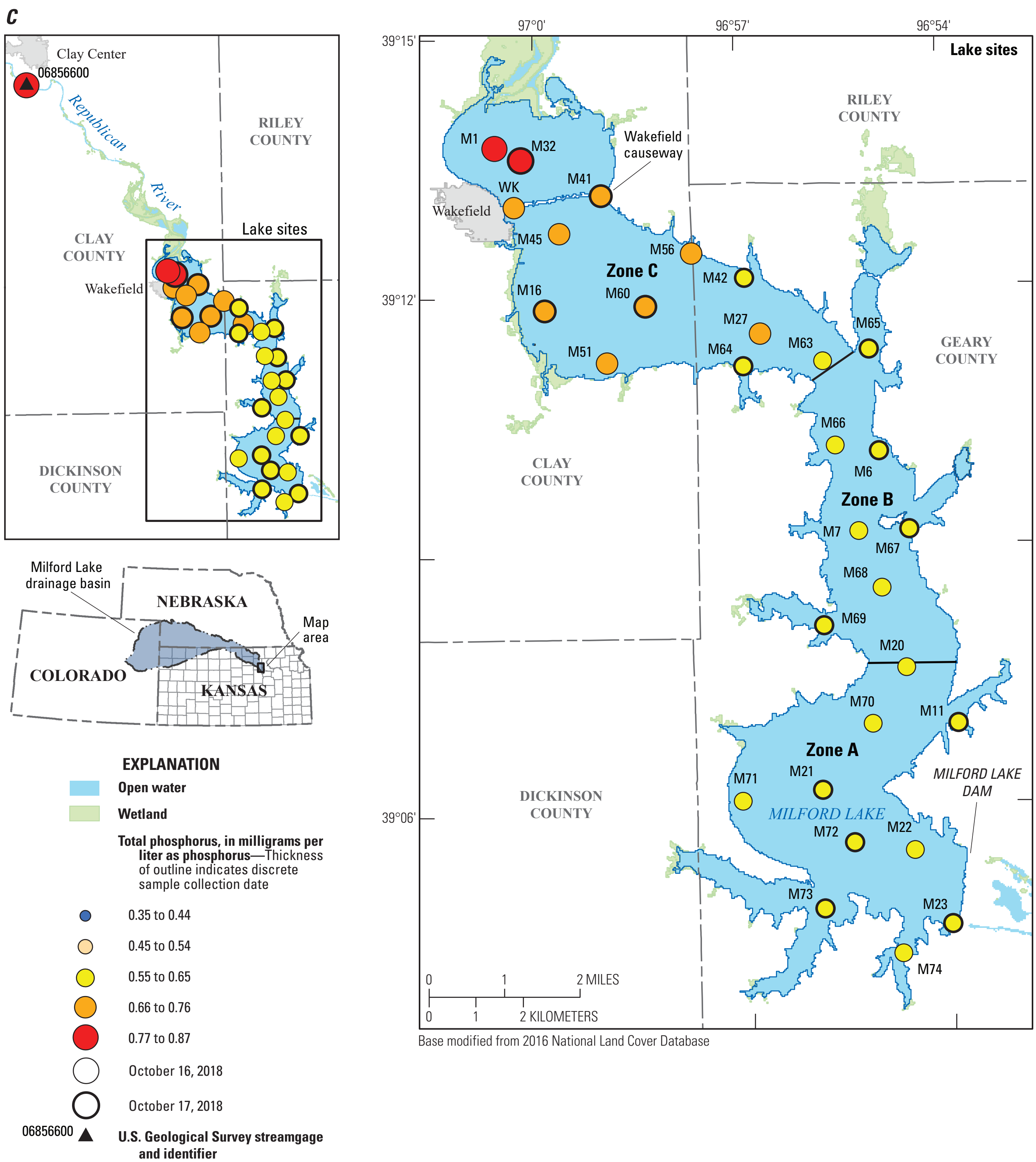

C
Clay Center
06856600
Republican
River
RILEY COUNTY
CLAY COUNTY
Wakefield
Lake sites
DICKINSON COUNTY
Milford Lake drainage basin
NEBRASKA
Map area
COLORADO
KANSAS
EXPLANATION
Open water
Wetland
Total phosphorus, in milligrams per liter as phosphorus—Thickness of outline indicates discrete sample collection date
0.35 to 0.44
0.45 to 0.54
0.55 to 0.65
0.66 to 0.76
0.77 to 0.87
October 16, 2018
October 17, 2018
06856600
U.S. Geological Survey streamgage and identifier
97°0'
96°57'
96°54'
39°15'
39°12'
39°06'
Lake sites
RILEY COUNTY
M1
M32
Wakefield causeway
M41
WK
Wakefield
M45
M56
Zone C
M42
M16
M60
M27
M65
GEARY COUNTY
M51
M64
M63
M66
CLAY COUNTY
M6
Zone B
M7
M67
M68
M69
M20
M70
M11
Zone A
MILFORD LAKE DAM
M71
M21
DICKINSON COUNTY
MILFORD LAKE
M72
M22
M73
M23
M74
0 1 2 MILES
0 1 2 KILOMETERS
Base modified from 2016 National Land Cover Database

Figure 13.

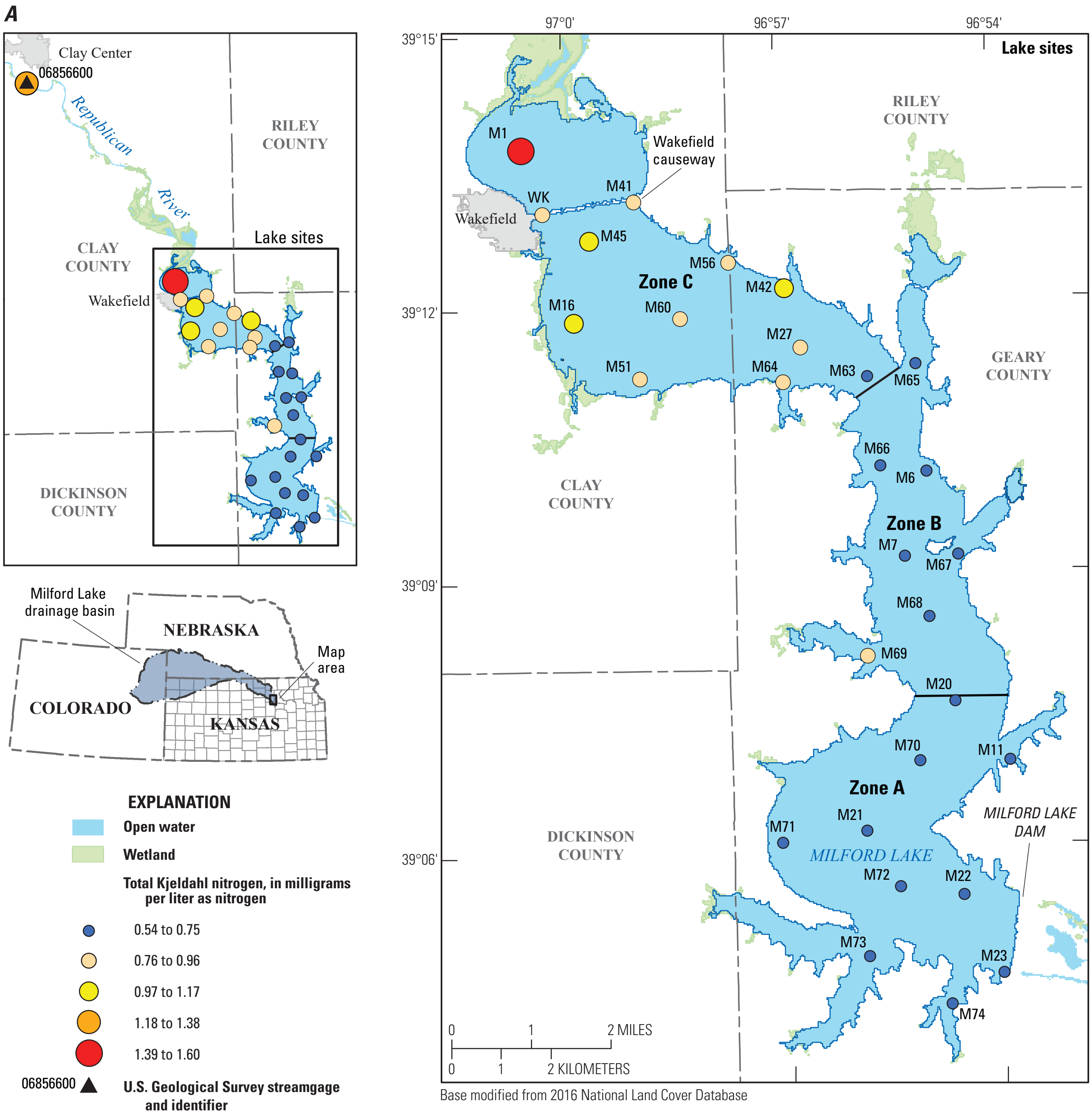


Figure 14. Concentrations of total Kjeldahl nitrogen in Milford Lake, Kansas, whole-lake synoptics. *A*, July 10, 2018. *B*, August 9, 2018. *C*, October 16–17, 2018. Sampling locations shown in figure 1.

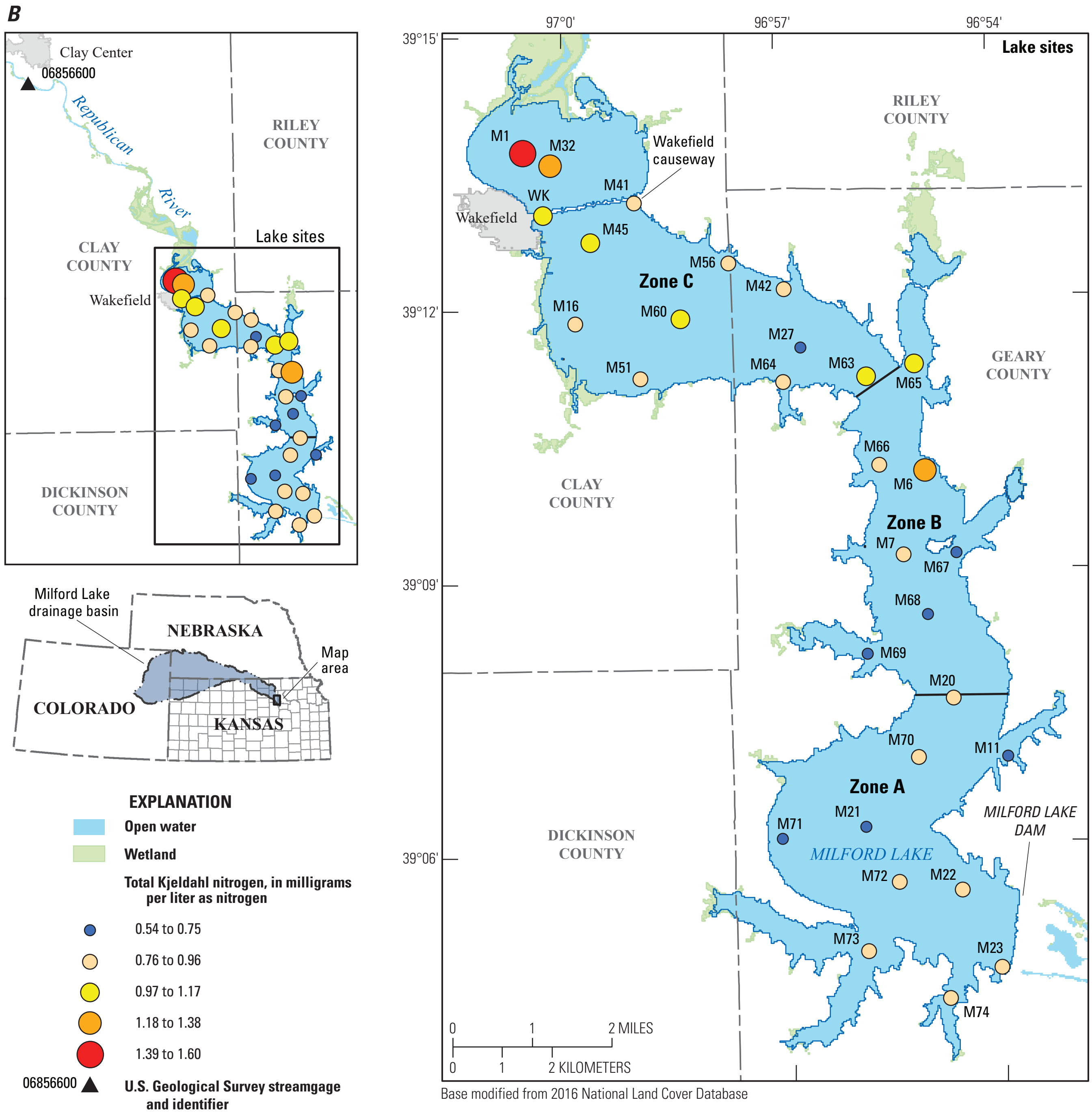
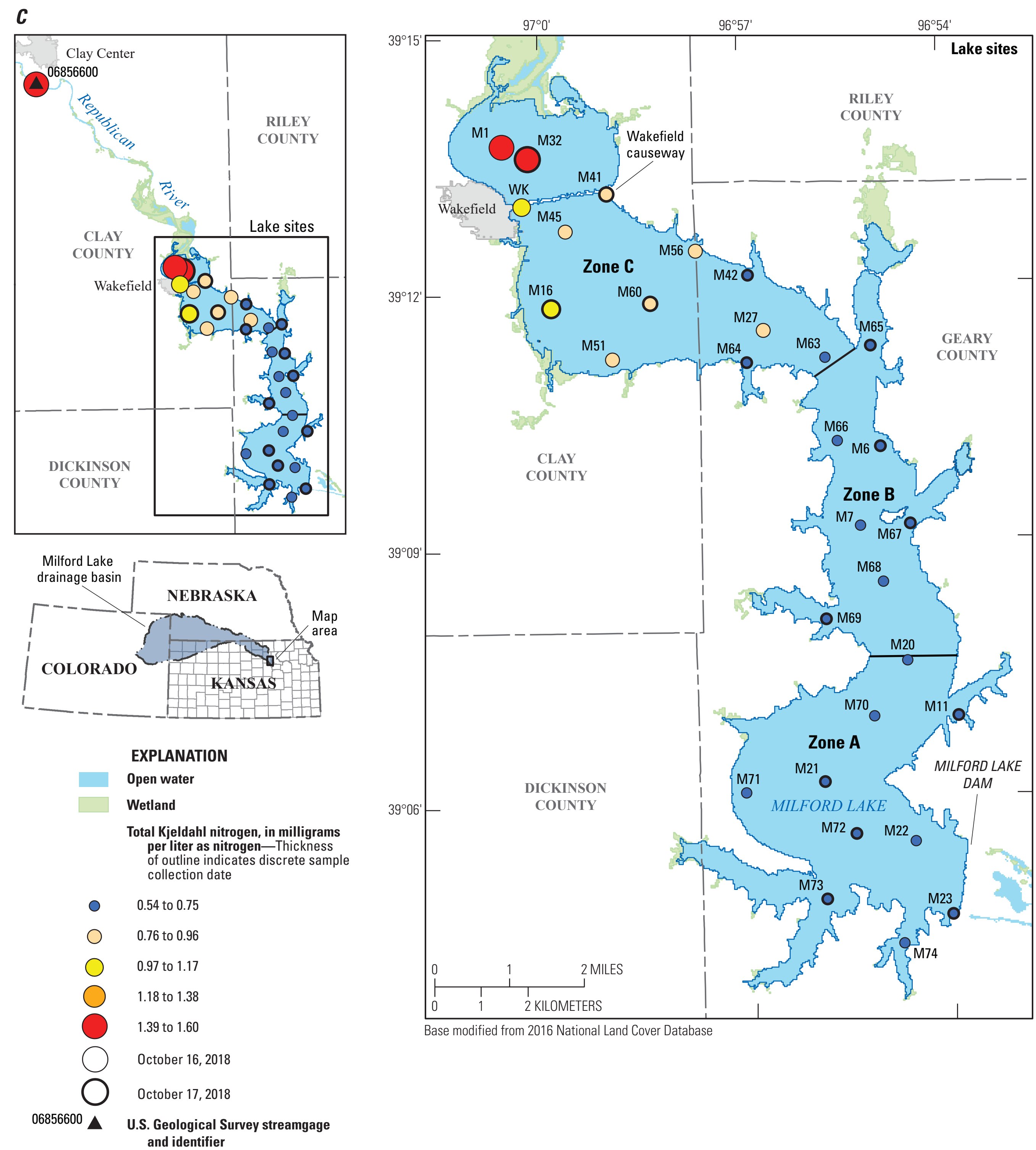

B
Clay Center
06856600
Republican
River
RILEY COUNTY
CLAY COUNTY
Wakefield
Lake sites
DICKINSON COUNTY
Milford Lake drainage basin
NEBRASKA
Map area
COLORADO
KANSAS
EXPLANATION
Open water
Wetland
Total Kjeldahl nitrogen, in milligrams per liter as nitrogen
0.54 to 0.75
0.76 to 0.96
0.97 to 1.17
1.18 to 1.38
1.39 to 1.60
06856600
U.S. Geological Survey streamgage and identifier
97°0'
96°57'
96°54'
39°15'
39°12'
39°09'
39°06'
Lake sites
RILEY COUNTY
M1
M32
Wakefield causeway
M41
WK
Wakefield
M45
M56
Zone C
M42
M16
M60
M27
M51
M64
M63
M65
GEARY COUNTY
M66
M6
CLAY COUNTY
Zone B
M7
M67
M68
M69
M20
M70
M11
Zone A
M71
M21
MILFORD LAKE DAM
DICKINSON COUNTY
MILFORD LAKE
M72
M22
M73
M23
M74
0 1 2 MILES
0 1 2 KILOMETERS
Base modified from 2016 National Land Cover Database

Figure 14.



Base modified from 2016 National Land Cover Database

Figure 14.

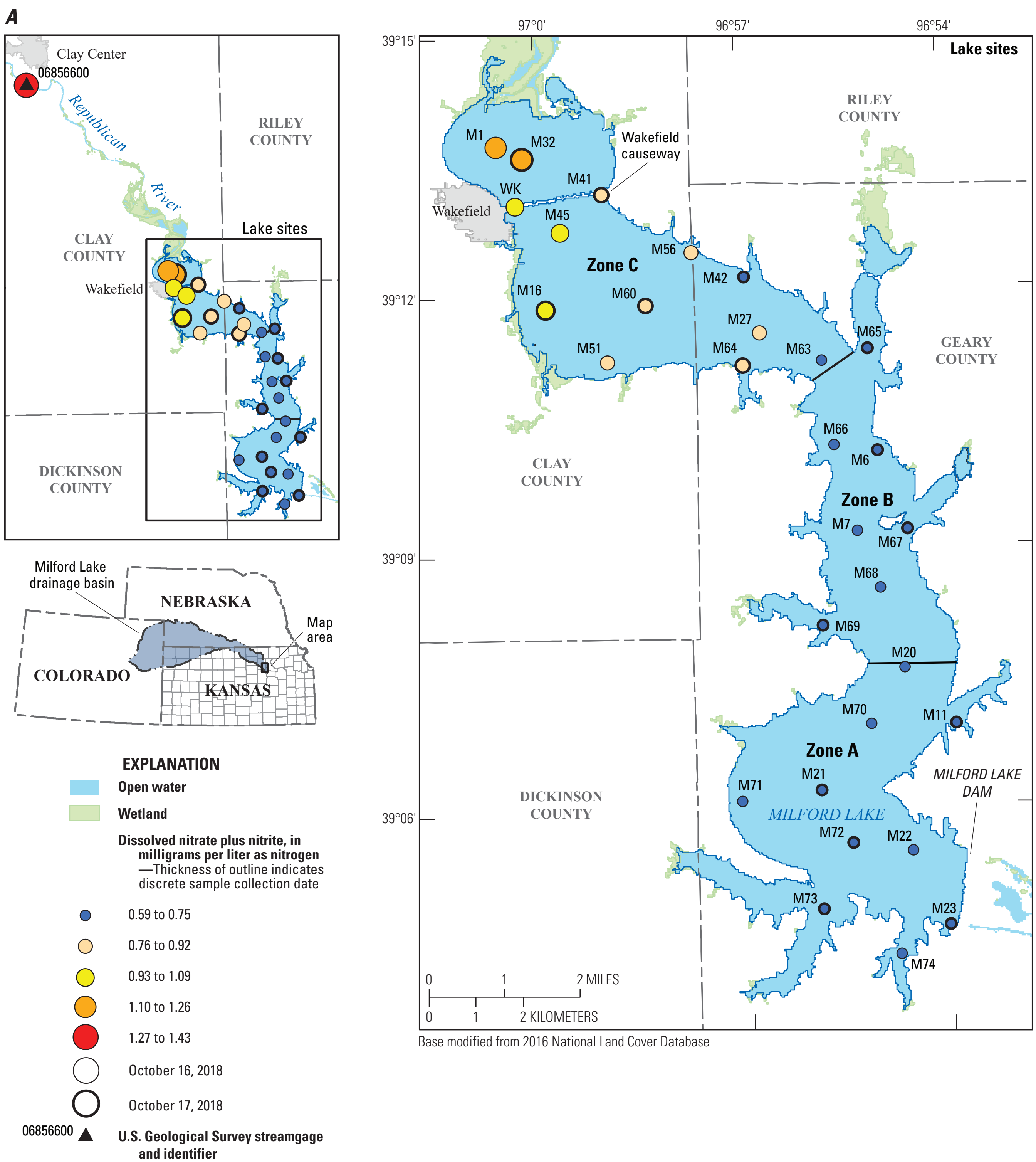


Figure 15. Concentrations of nitrogen in Milford Lake, Kansas, whole-lake synoptic, October 16–17, 2018. *A*, Dissolved nitrate plus nitrite. *B*, Total nitrogen. Sampling locations shown in figure 1.

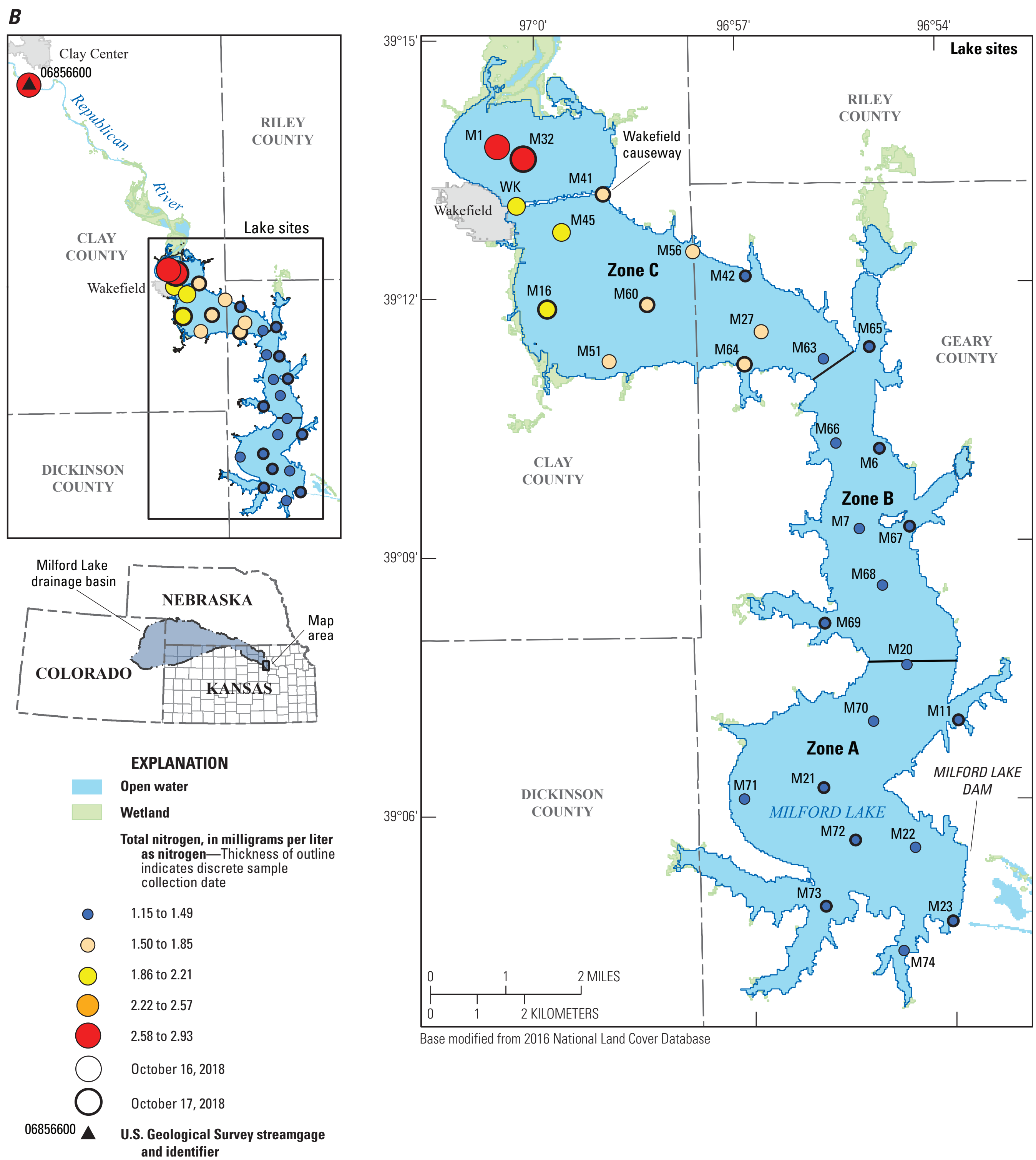

B
Clay Center
06856600
Republican River
RILEY COUNTY
CLAY COUNTY
Wakefield
Lake sites
DICKINSON COUNTY
Milford Lake drainage basin
NEBRASKA
COLORADO
KANSAS
Map area
EXPLANATION
Open water
Wetland
Total nitrogen, in milligrams per liter as nitrogen—Thickness of outline indicates discrete sample collection date
1.15 to 1.49
1.50 to 1.85
1.86 to 2.21
2.22 to 2.57
2.58 to 2.93
October 16, 2018
October 17, 2018
06856600
U.S. Geological Survey streamgage and identifier
97°0'
96°57'
96°54'
39°15'
39°12'
39°09'
39°06'
Lake sites
RILEY COUNTY
M1
M32
Wakefield causeway
M41
WK
Wakefield
M45
M56
Zone C
M42
M16
M60
M27
M65
GEARY COUNTY
M51
M64
M63
CLAY COUNTY
M66
M6
Zone B
M7
M67
M68
M69
M20
M70
M11
Zone A
MILFORD LAKE DAM
M71
M21
DICKINSON COUNTY
MILFORD LAKE
M72
M22
M73
M23
M74
0 1 2 MILES
0 1 2 KILOMETERS
Base modified from 2016 National Land Cover Database

Figure 15.

Chlorophyll, Phycocyanin, and Microcystin Concentrations and Phytoplankton Community Composition and Abundance

Phytoplankton community composition mainly consisted of Bacillariophyta, Chlorophyta, Cryptophyta, and Cyanobacteria (fig. 16). In July and August, Cyanobacteria dominated (more than 50 percent of total phytoplankton abundance) at seven of eight sampled sites and Bacillariophyta dominated the other site (figs. 16*A*, 16*B*). In October, Cyanobacteria dominated three sites, Cryptophyta dominated two sites, Bacillariophyta dominated one site, and two sites did not have a dominant division (fig. 16*C*). Phytoplankton community composition and abundance data collected in 2018 described broad seasonal patterns and did not capture the full range of possible conditions at each site. Cyanobacteria typically dominate the algal communities in Milford Lake, constituting more than 90 percent of the community when sampled by the KDHE in 2006, 2009, and 2012 (Kansas Department of Health and Environment, 2014a) and when sampled by Foster and others (2019) in 2016.

Seven of the eight sites (all but site M42) had their highest chlorophyll concentration in August (fig. 17). Site M42 had its highest chlorophyll concentration in July (fig. 17*A*). The three most uplake sites (M32, WK, M42) had their highest phycocyanin concentrations in July, whereas the other five sites had their highest phycocyanin concentrations in August (fig. 17). Site M32 was the only site with a phycocyanin detection in October (fig. 17*C*). There was one detection of total microcystin in July (0.12 µg/L at site M32) and there was one detection of total microcystin in August (0.11 µg/L at site M63; data not shown). All other total microcystin results were less than the reporting limit of 0.10 µg/L. The concentrations of the two total microcystin detections were substantially less than 4 µg/L, which is the concentration indicating the lowest KDHE advisory level (watch).

In July, seven sites (all but M21) exceeded the desired endpoint chlorophyll concentration of 10 µg/L (Kansas Department of Health and Environment, 2014a). The three most uplake sites had chlorophyll concentrations indicative of hypereutrophic conditions (at least 30 µg/L) and four others had chlorophyll concentrations indicative of eutrophic conditions (at least 12 µg/L) (Kansas Department of Health and Environment, 2014a). In August, all eight sites exceeded the desired endpoint chlorophyll concentration. Five sites had chlorophyll concentrations indicative of hypereutrophic conditions and the other three sites had concentrations indicative of eutrophic conditions. By October, all eight sites were below the chlorophyll concentration indicative of eutrophic conditions and desired endpoint. Lower air and water temperatures in October than in July and August likely caused the decrease in chlorophyll concentrations. Five sites in July and seven sites in August exceeded the long-term (1996–2012) in-lake median chlorophyll concentration of 13.08 µg/L. No sites exceeded the long-term median concentration in October.

Phytoplankton abundance decreased from July to August and from August to October at all sites except M32 and M20, which increased from July to August (fig. 17). Phytoplankton abundance was lowest in October for all sites. Cyanobacterial abundance decreased from July to August and from August to October at all sites except M32 and M20 (fig. 17); a small increase at site WK from August to October was negligible. At sites M32 and M20, cyanobacterial abundance increased from July to August (fig. 17). Cyanobacterial abundance was lowest in October for all sites except WK (fig. 17). Site WK had its lowest cyanobacterial abundance in August (fig. 17).

In July, cyanobacterial abundances at three sites (WK, M21, M23) exceeded the KDHE warning threshold of 250,000 cells/mL and three other sites (M42, M63, M7) were in the KDHE watch threshold of between 80,000 and 250,000 cells/mL (fig. 17*A*; Kansas Department of Health and Environment, 2019b). By August, cyanobacterial abundance was generally reduced (except at sites M32 and M20), and only two sites (M42, M20) were in the KDHE watch threshold of between 80,000 and 250,000 cells/mL; the three sites that were in the KDHE warning threshold in July all dropped below the KDHE watch threshold by August (fig. 17*B*; Kansas Department of Health and Environment, 2019b). None of the sites exceeded either the watch or warning thresholds in October (fig. 17*C*).

The KDHE collects samples for toxin or phytoplankton analysis based on common public access points (namely beaches and boat ramps) (Kansas Department of Health and Environment, 2019b) and only samples public lakes “in response to complaints of human or animal illness or visual sighting of possible blue-green algae by the public or lake officials” (Kansas Department of Health and Environment, 2019a). The KDHE did not collect any samples for algal analysis at Milford Lake in 2018 (Kansas Department of Health and Environment, 2020a). Conditions at the sites sampled in this study (generally located in a longitudinal transect through the center of the lake) were not indicative of conditions at the common public access points (beaches and boat ramps along the shore).

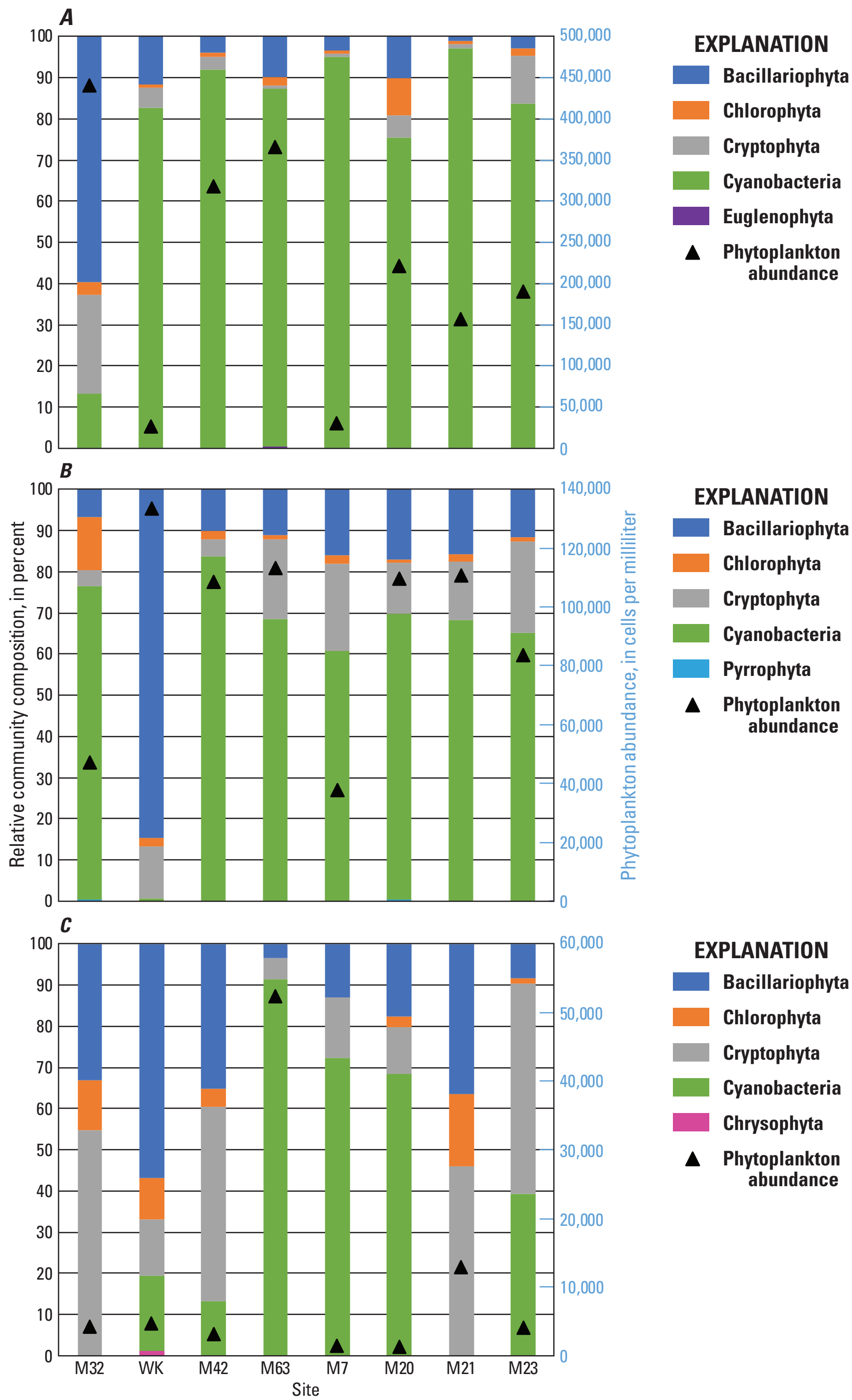


Figure 16. Phytoplankton community composition and phytoplankton abundance in Milford Lake, Kansas, whole-lake synoptics. Sites are arranged from uplake (left) to downlake (right). Note differences in abundance scale. *A*, July 10, 2018. *B*, August 9, 2018. *C*, October 16–17, 2018. Sampling locations shown in figure 1.

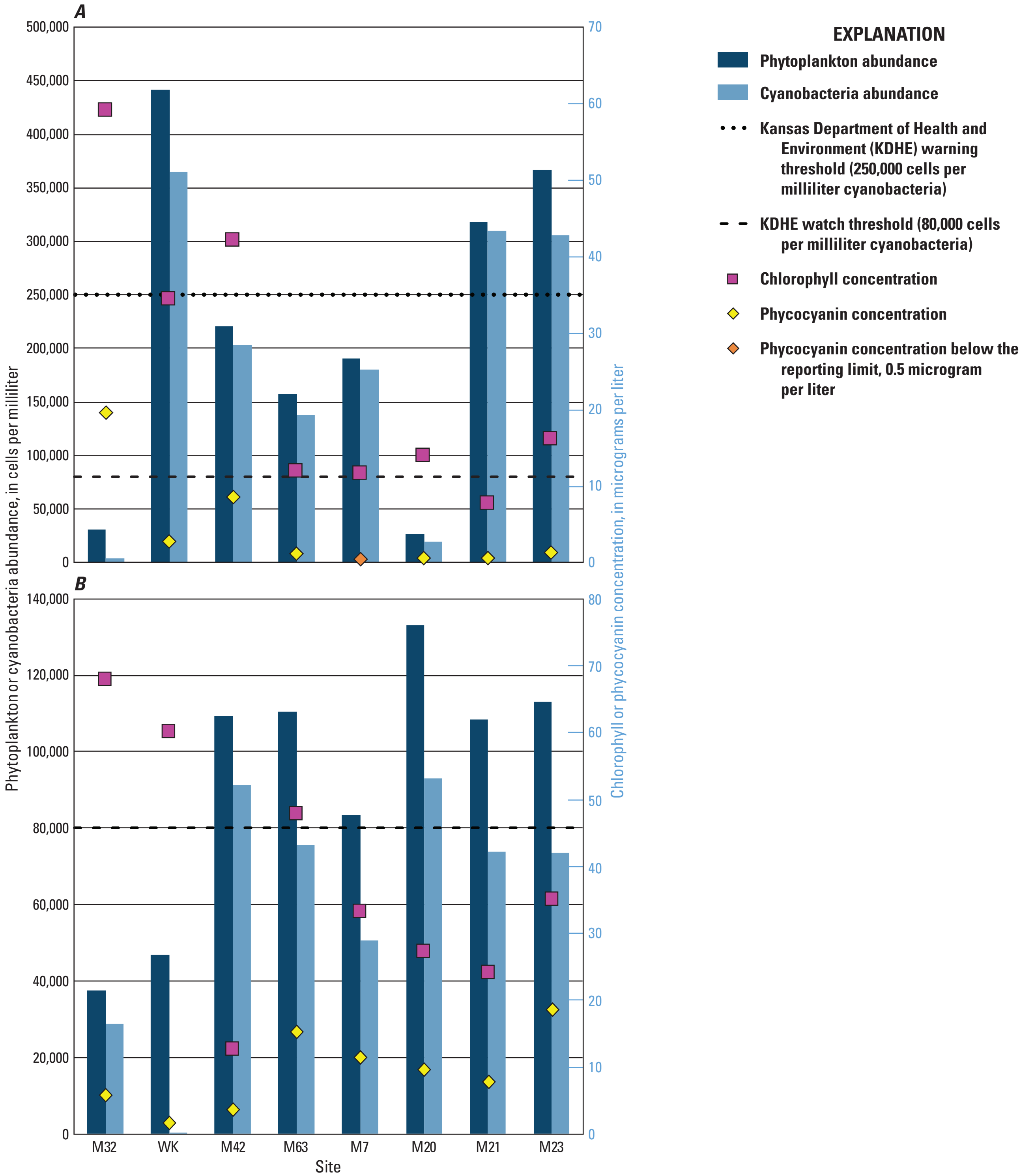


Figure 17. Phytoplankton and cyanobacterial abundance and chlorophyll and phycocyanin concentration in Milford Lake, Kansas, whole-lake synoptics. Sites are arranged from uplake (left) to downlake (right). Note differences in abundance and concentration scales. *A*, July 10, 2018. *B*, August 9, 2018. *C*, October 16–17, 2018. Sampling locations shown in figure 1.

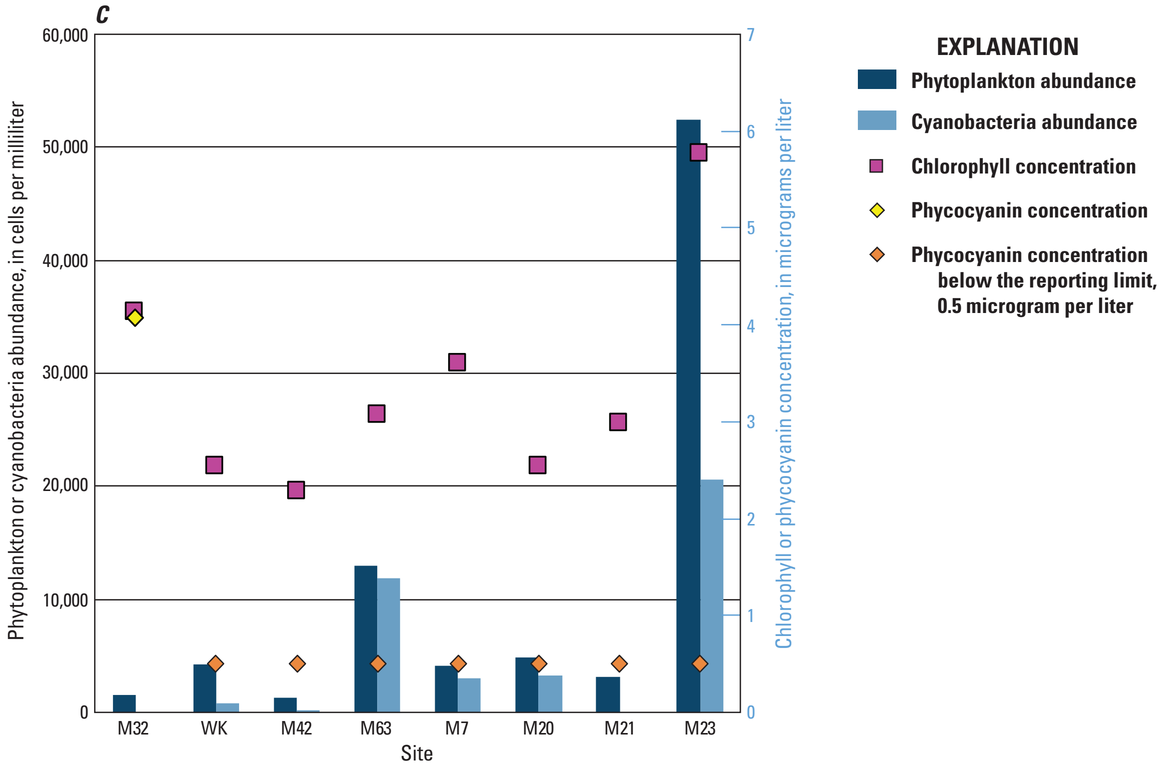


Figure 17.

Continuous Water Quality in Milford Lake

In 2017, the deep continuous water-quality monitor at site WK (fig. 1, tables 3 and 4) collected data approximately 0.5 m above the lakebed. Concentrations of dissolved oxygen measured by the deep continuous water-quality monitor ranged from 0.2 to 21.4 mg/L (table 6, fig. 18). Anoxic conditions (0 mg/L) were not observed, but hypoxic conditions (<2–3 mg/L; U.S. Environmental Protection Agency, [n.d.] b) were observed. Concentrations of dissolved oxygen at the deep monitor were less than the benchmark value of 5 mg/L (Kansas Department of Health and Environment, 2014a) in 29 percent (3,982 of 13,520) of unit values and were <3 mg/L in 7 percent (892 of 13,520) of unit values. According to the U.S Army Corps of Engineers [n.d.]b, orthophosphate was released from lakebed sediments in late summer 2017. Anoxic conditions are necessary for sediment phosphorus release (Hawley and others, 2006). Based on data from the deep monitor, it is unlikely that orthophosphate was released from the bed sediments on a regular basis in the upper reaches of the reservoir. However, further study is needed to determine the frequency of occurrence and contribution of lakebed sediment nutrient release, and their contributions to the overall phosphorus budget of the lake.

Variability of continuously measured water-quality constituents at site WK was compared to variability at the 30 measured sites during the whole-lake synoptics in 2018. At site WK, the range of values was calculated over the time between the first and last discrete whole-lake synoptic samples of the day. The range of observed values generally was greater throughout the lake from discrete measurements during the synoptics than at the continuously monitored site WK, except for dissolved oxygen (table 8). However, the range of values for dissolved oxygen was greater at site WK than throughout the lake in July and October but not August. One possible cause of higher variability in dissolved oxygen at site WK than throughout the lake is differences in phytoplankton abundance: site WK had the highest abundance of the eight sites sampled in July and the second-lowest abundance of the eight sites sampled in August (fig. 17). Phytoplankton abundance was generally low (<5,000 cells/mL) in October (fig. 17*C*). Variability in specific conductance, chlorophyll fluorescence, and phycocyanin fluorescence was always greater throughout the lake than at the site WK. For water temperature and pH, variability was greater at site WK than throughout the lake in July but not August or October.

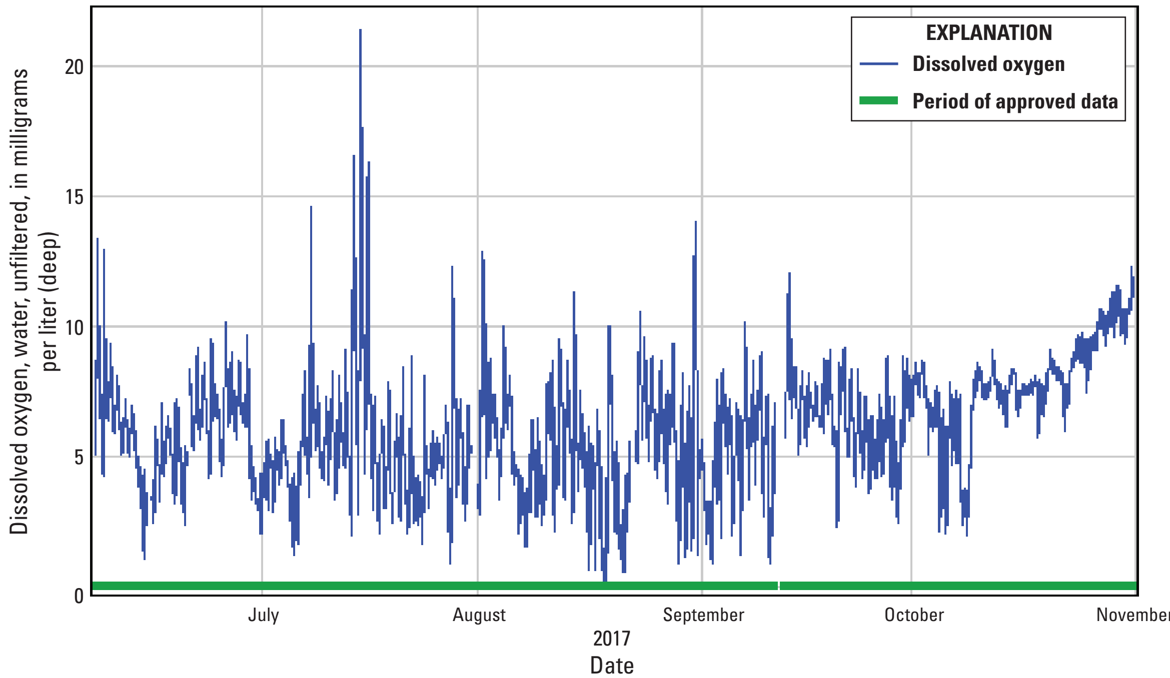


Figure 18. Continuous dissolved oxygen concentration data from the deep continuous water-quality monitor at site WK (U.S. Geological Survey station number 391259097001800), Milford Lake, Kansas, June–November 2017. Data from U.S. Geological Survey (2019).

Table 8. Comparison of ranges in observed water-quality constituent values between a continuously monitored site and 30 discrete-sampling sites during whole-lake synoptics, Milford Lake, Kansas, July 10, August 9, and October 16–17, 2018.

[°C, degree Celsius; µS/cm, microsiemen per centimeter; mg/L, milligram per liter; std. units, standard unit; RFU, relative fluorescence unit; WK, continuous-monitor site Milford Lake near Wakefield, Kansas; Lake, 30 discrete-sampling sites across Milford Lake. Shading indicates the larger range of values]

Date in 2018	Range in water temperature (°C)		Range in specific conductance (µS/cm)		Range in dissolved oxygen (mg/L)		Range in pH (std. unit)		Range in chlorophyll fluorescence (RFU)		Range in phycocyanin fluorescence (RFU)	
	WK	Lake	WK	Lake	WK	Lake	WK	Lake	WK	Lake	WK	Lake
July 10	3.2	2.2	33	111	11.2	9.3	0.5	0.4	1.6	8.2	0.32	1.60
August 9	3.6	4.6	100	314	10.4	15.5	0.6	1.0	3.8	10.1	1.04	2.32
October 16	1.3	7.5	115	298	1.7	0.3	0.3	0.7	0.6	1.3	0.25	0.36
October 17	1.5	7.4	39	277	2.8	1.2	0.3	0.7	0.2	1.1	0.07	0.30

Spatial and Temporal Variability of Nutrients and Algae in the Republican River and Milford Lake

Concentrations of biologically available nutrients (dissolved orthophosphate, dissolved nitrate plus nitrite) were not higher in the Republican River than in Milford Lake on July 17, 2017. Results from the 24-hour synoptic on August 24–25, 2017, demonstrated the variable nature of algal accumulations and their effects on nutrient and dissolved oxygen concentrations.

On July 10, August 9, and October 16–17, 2018, nutrient concentrations in the lake generally decreased along the uplake to downlake gradient, except for dissolved orthophosphate in October, which had generally uniform concentrations across the lake. In July and August 2018, nutrient concentrations were generally higher in Zone C than in Zones B and A. By October 2018, nutrient concentrations were more consistent across the lake than in July and August 2018. For the biologically available nutrients, this decrease in gradient was likely a result of reduced biological activity (less uptake of nutrients by plants) from lower air and water temperatures. Multiple inflow events (streamflow greater than median daily value) between August and October (fig. 3) also may have moved nutrients through the lake. The highest TKN concentrations were generally found in the shallow area of the lake uplake from the Wakefield causeway. Chlorophyll concentrations were generally highest in August, whereas phytoplankton abundance and cyanobacterial abundance were generally highest in July.

In addition to external (relative to the lake) nutrient loads from the Republican River and other inflows, accumulated legacy (historical) nutrients bound in lake sediment may be remobilized into the water column and contribute to internal nutrient loading. Under anoxic conditions, phosphorus can be released from the bed sediment in a lake (Hawley and others, 2006). Data from the continuous monitor at site WK did not indicate that fully anoxic conditions (0 mg/L dissolved oxygen) were achieved in 2017 or 2018, although low (<5 mg/L) dissolved oxygen concentrations were observed. The 2014 total maximum daily load for Milford Lake calls for an 88-percent reduction in total phosphorus load and an 86-percent reduction in total nitrogen load (Kansas Department of Health and Environment, 2014a). Even if these reductions were achieved, water quality may still be adversely affected by legacy nutrients already present in the lake (Stackpoole and others, 2019). Analyzing concentrations of nutrients in the lakebed sediments and (or) creation of nutrient budgets may provide a greater understanding of the potential for internal loading of nutrients.

Anthropogenic nutrient inputs into waterbodies are the drivers for HABs that have received considerable global scientific attention (O’Neil and others, 2012). Anthropogenic climate change is another driver that could affect the frequency, duration, and size of HABs. According to the Fourth National Climate Assessment (Kloesel and others, 2018), climate change is expected to increase the frequency and intensity of heavy precipitation in the Southern Great Plains (Kansas, Oklahoma, and Texas). Frequent and intense precipitation events may affect runoff in the drainage basin upstream from Milford Lake and could lead to more nutrients being washed from the agricultural-dominated watershed into the lake (U.S. Environmental Protection Agency, [n.d.]a).

Climate change is also expected to increase air temperatures, leading to increased water temperatures. Cyanobacteria dominate phytoplankton communities in higher temperatures because of cell-level physiological factors and waterbody-level physical factors (O’Neil and others, 2012). Under models evaluated by Chapra and others (2017), the mean number of cyanobacteria HAB-occurrence days is expected to increase from about 7 days per waterbody per year under current conditions to 16–23 days per waterbody per year in 2050 and to 18–39 days per waterbody per year in 2090. Between 2010 and 2018, there were between 0 and 135 HAB-occurrence days each calendar year within Milford Lake (Kansas Department of Health and Environment, 2010, 2011, 2012, 2013, 2014b, 2015, 2016, 2017, 2018). Estimates of future change in HAB occurrence over time could benefit from incorporating methods and approaches that can quantify these anticipated outcomes and effects of climate change.

Summary

Milford Lake has been listed as impaired and designated hypereutrophic because of excessive nutrient loading, specifically biologically available orthophosphate. It is the largest lake by surface area in Kansas and is a reservoir built for purposes including water supply and recreation. In 2015, the Kansas Department of Health and Environment divided the lake into three zones (Zones A, B, and C) for recreational monitoring of harmful algal blooms (HABs). Upstream Zone C has historically been more affected by HABs than Zones B and A, and Zone C has historically had the highest phosphorus concentrations.

The U.S. Geological Survey, in cooperation with the Kansas Department of Health and Environment, completed a study in 2017–18 to assess the spatial and temporal variability of nutrients and algae in the Republican River (the primary inflow to Milford Lake) and Milford Lake using spatially and temporally dense data. During the study period, discrete water-quality samples were collected at 36 lake sites, 21 river sites, and 1 pond. All samples were analyzed for nutrients; some samples were also analyzed for chlorophyll, phycocyanin, microcystin, and (or) phytoplankton community composition and abundance. In 2017 and 2018, continuous water-quality data were collected at one site to characterize variability during the recreational season. Results from this study provide perspective for understanding the potential role nutrient and

algal conditions have in facilitating the formation of HABs and may inform future actions to prevent and mitigate HABs and their potential effects on human and environmental health.

In 2017, one low-flow floating synoptic on the Republican River into Zone C of Milford Lake and one 24-hour synoptic in Zone C of Milford Lake were completed, including sensor-based water-quality measurements and discrete nutrient samples. At a subset of sites, discrete chlorophyll and microcystin samples were also collected. In 2018, three whole-lake nutrient synoptics through Zones A, B, and C in Milford Lake were completed using sensor-based water-quality measurements and discrete nutrient and chlorophyll samples. At a subset of sites, phycocyanin, microcystin, and phytoplankton samples were also collected. During the study period, discrete water-quality samples were collected at 36 lake sites, 21 river sites, and 1 pond. In 2017 and 2018, continuous water-quality data were collected at one site in Zone C.

Results from the low-flow floating synoptic on July 17, 2017, at 21 river sites, 8 lake sites, and 1 pond site indicated that the Republican River was not contributing dissolved orthophosphate or total phosphorus concentrations higher than those in the main body of Milford Lake. Unlike the phosphorus species, total Kjeldahl nitrogen (TKN) did not have increasing concentrations in the downstream direction along the Republican River, and some TKN concentrations in the river were as high as those in Zone C of Milford Lake.

No patterns in nutrient or total microcystin concentrations were evident from the 24-hour synoptic at two sites on August 24–25, 2017. Total nitrogen was dominated by TKN at both sites. Algal biomass as chlorophyll was relatively stable at the site near the center of Zone C during the 24-hour sampling period but oscillated at the other site more upstream in Zone C. Observed dissolved oxygen concentrations just above the bed sediment ranged from 4.6 to 9.8 milligrams per liter. Different oscillation activity at the two sites demonstrated the variable nature of algal accumulations and their effects on nutrient and dissolved oxygen concentrations. Microcystin concentrations were generally higher at the site near the center of Zone C, whereas chlorophyll was consistently higher at the site more upstream in Zone C. This difference in concentration indicates that the relation between algal biomass and cyanotoxin concentrations were different at the two sites, possibly because of differences among algal communities present at each site.

Three whole-lake synoptics through Zones A, B, and C in Milford Lake were completed on July 10, August 9, and October 16–17, 2018, at 30 lake sites. Concentrations of dissolved orthophosphate and total phosphorus increased from July to August and from August to October at all sites but three in Zone C. In July and August, Zone C had dissolved orthophosphate concentrations higher than all sites in Zones B and A. In July, most of Zone C had total phosphorus concentrations higher than all sites in Zones B and A. Orthophosphate was consistently at least 77 percent of total phosphorus at all sites except the two most uplake sites. At the two most uplake sites, orthophosphate was between 52 and 72 percent of the total phosphorus present at the site. Lower contributions of orthophosphate to total phosphorus at the two most uplake sites indicate that more nutrients may have been tied up in algal biomass in that area of the lake.

Concentrations of TKN were not consistently increasing or decreasing during 2018. The highest TKN concentrations in July, August, and October were at the two most uplake sites. In July, Zone C generally had the highest TKN concentrations. August was the only month in which TKN concentrations exceeded 1.0 milligram per liter as nitrogen (mg/L-N) outside Zone C. Total nitrogen was dominated by TKN in July and August and dissolved nitrate plus nitrite was detected at only one site in July and August. Very low concentrations of dissolved nitrate plus nitrite indicate that the nutrient was likely tied up in algal biomass. By October, all sites were well above the reporting limit of 0.01 mg/L-N and total nitrogen was approximately one-half TKN and one-half dissolved nitrate plus nitrite. Zone C had higher concentrations of nitrate plus nitrite than all sites in Zones B and A in October. Total nitrogen was highest in October at most sites. Higher concentrations of dissolved orthophosphate and dissolved nitrate plus nitrite in October than in July and August were likely caused by reduced biological activity (less uptake of nutrients) and lower air and water temperatures. Multiple inflow events (streamflow greater than median daily value) between August and October also may have moved nutrients through the lake.

Chlorophyll, phycocyanin, microcystin, and phytoplankton samples were collected at eight sites in 2018. Most sites had their highest chlorophyll concentrations in August. The three most uplake sites had their highest phycocyanin concentrations in July, whereas the other five sites had their highest phycocyanin concentrations in August. The most uplake site was the only site where phycocyanin was detected in October. Two of 23 samples had detections of total microcystin (0.11 and 0.12 microgram per liter).

In 2018, phytoplankton community composition mainly consisted of Bacillariophyta, Chlorophyta, Cryptophyta, and Cyanobacteria. In July and August, Cyanobacteria dominated (more than 50 percent of total phytoplankton abundance) at seven of eight sampled sites and Bacillariophyta dominated the other site. In October, Cyanobacteria dominated three sites, Cryptophyta dominated two sites, Bacillariophyta dominated one site, and two sites did not have a dominant division. Phytoplankton community composition and abundance data described broad seasonal patterns and did not capture the full range of possible conditions at each site.

Phytoplankton abundance decreased from July to August and from August to October at most sites. Phytoplankton abundance was lowest in October for all sites. Cyanobacterial abundance decreased from July to August and from August to October at most sites. Cyanobacterial abundance was lowest in October for most sites.

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Appendix 1. Extracted Phycocyanin Data from Eight Sites in Milford Lake, Kansas, June 5, July 10, August 9, and October 16–17, 2018

Extracted phycocyanin data collected from eight sites in Milford Lake (sites M32, WK, M42, M63, M7, M20, M21, M23; fig. 1, table 4 in main body of report) during the three whole-lake synoptics in 2018 are provided in table 1.1. One sample collected June 5, 2018, at site WK is also included in the dataset for completeness, but this sample was not discussed in this report. Data were analyzed by the Wilson Lab at Auburn University (table 1 in main body of report). The results of six field replicate samples are also included.

Table 1.1. Extracted phycocyanin data from eight sites in Milford Lake, Kansas, June 5, July 10, August 9, and October 16–17, 2018.

[M, month; DD, day; YYYY, year; µg/L, microgram per liter; <, less than]

Site identifier	Site	Sample date (M/DD/YYYY)	Sample time	Phycocyanin, µg/L	Sample type
WK	Milford Lake near Wakefield, Kansas	6/05/2018	1110	8.23	Regular
WK	Milford Lake near Wakefield, Kansas	7/10/2018	1010	2.75	Regular
WK	Milford Lake near Wakefield, Kansas	7/10/2018	1015	3.75	Replicate
M20	Milford Lake, Kansas Site 20	7/10/2018	1540	0.66	Regular
M21	Milford Lake, Kansas Site 21	7/10/2018	1630	0.60	Regular
M23	Milford Lake, Kansas Site 23	7/10/2018	1720	1.41	Regular
M23	Milford Lake, Kansas Site 23	7/10/2018	1725	2.44	Replicate
M32	Milford Lake, Kansas Site 32	7/10/2018	0950	19.71	Regular
M42	Milford Lake, Kansas Site 42	7/10/2018	1250	8.57	Regular
M63	Milford Lake, Kansas Site 63	7/10/2018	1310	1.26	Regular
M7	Milford Lake, Kansas Site 7	7/10/2018	1420	<0.5	Regular
WK	Milford Lake near Wakefield, Kansas	8/09/2018	0820	1.72	Regular
WK	Milford Lake near Wakefield, Kansas	8/09/2018	0825	1.77	Replicate
M20	Milford Lake, Kansas Site 20	8/09/2018	1650	9.60	Regular
M21	Milford Lake, Kansas Site 21	8/09/2018	1800	7.85	Regular
M23	Milford Lake, Kansas Site 23	8/09/2018	1920	18.59	Regular
M23	Milford Lake, Kansas Site 23	8/09/2018	1925	21.47	Replicate
M32	Milford Lake, Kansas Site 32	8/09/2018	0740	5.82	Regular
M42	Milford Lake, Kansas Site 42	8/09/2018	1130	3.64	Regular
M63	Milford Lake, Kansas Site 63	8/09/2018	1320	15.32	Regular
M7	Milford Lake, Kansas Site 7	8/09/2018	1500	11.49	Regular
WK	Milford Lake near Wakefield, Kansas	10/16/2018	0920	<0.5	Regular
WK	Milford Lake near Wakefield, Kansas	10/16/2018	0925	<0.5	Replicate
M20	Milford Lake, Kansas Site 20	10/16/2018	1440	<0.5	Regular
M63	Milford Lake, Kansas Site 63	10/16/2018	1220	<0.5	Regular
M7	Milford Lake, Kansas Site 7	10/16/2018	1350	<0.5	Regular
M21	Milford Lake, Kansas Site 21	10/17/2018	1400	<0.5	Regular
M23	Milford Lake, Kansas Site 23	10/17/2018	1450	<0.5	Regular
M23	Milford Lake, Kansas Site 23	10/17/2018	1455	<0.5	Replicate
M32	Milford Lake, Kansas Site 32	10/17/2018	0830	4.07	Regular
M42	Milford Lake, Kansas Site 42	10/17/2018	1000	<0.5	Regular

Appendix 2. Absolute Value Log Difference (AVLD) for Phytoplankton Field Replicate Samples

Absolute value log difference (AVLD) values for 15 samples collected in the Kansas River, Kansas, and 4 samples collected in Milford Lake, Kansas, are summarized in table 2.1. Because of the limited size of the Milford-only replicate dataset (*n*=4; Leiker, 2020), additional data collected in the Kansas River and tributaries to the Kansas River (*n*=15; Kramer and others, 2018) were also used to evaluate variability. See the "Quality Assurance and Quality Control" section of this report for more information on how values were calculated.

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Table 2.1. Absolute value log difference (AVLD) for quality-control field replicate samples for phytoplankton and cyanobacterial abundance, Kansas River and Milford Lake, Kansas, 2012–2018.

[M, month; DD, day; YYYY, year; phyto, phytoplankton; cells/mL, cells per milliliter; AVLD, absolute value log difference; cyano, cyanobacteria; KS, Kansas]

Site name	Sample date (M/DD/YYYY)	Data source	Replicate	Replicate type	Total phyto (cells/mL)	Phyto AVLD	Total cyano (cells/mL)	Cyano AVLD	Cyano relative abundance (%)
Kansas River at DeSoto, KS	8/27/2012	Kramer and others (2018)	A	Concurrent	166,612	0.2	16,302	0.7	10
			B		262,507	--	79,494	--	30
Kansas River at Wamego, KS	10/29/2012	Kramer and others (2018)	A	Concurrent	24,018	0.1	4,725	0.3	20
			B		27,946	--	2,200	--	8
Kansas River at DeSoto, KS	3/11/2013	Kramer and others (2018)	A	Concurrent	29,298	0.0	309	0.2	1
			B		28,340	--	508	--	2
Kansas River at Wamego, KS	6/17/2013	Kramer and others (2018)	A	Concurrent	12,951	0.1	0	5.3	0
			B		9,614	--	209	--	2
Kansas River at DeSoto, KS	7/15/2013	Kramer and others (2018)	A	Concurrent	227,323	0.1	101,711	0.8	45
			B		162,840	--	15,546	--	10
Kansas River at Wamego, KS	10/21/2013	Kramer and others (2018)	A	Concurrent	54,874	0.1	0	5.2	0
			B		67,804	--	145	--	0
Kansas River at DeSoto, KS	3/10/2014	Kramer and others (2018)	A	Concurrent	6,838	0.2	0	--	0
			B		4,833	--	0	--	0
Kansas River at Wamego, KS	6/2/2014	Kramer and others (2018)	A	Concurrent	77,363	0.0	1,768	0.1	2
			B		79,126	--	1,471	--	2
Kansas River at DeSoto, KS	7/14/2014	Kramer and others (2018)	A	Concurrent	58,178	0.0	1,944	1.1	3
			B		55,168	--	153	--	0
Kansas River at Wamego, KS	11/17/2014	Kramer and others (2018)	A	Concurrent	1,304	0.0	0	4.3	0
			B		1,328	--	18	--	1
Kansas River at Wamego, KS	6/29/2015	Kramer and others (2018)	A	Concurrent	2,798	0.1	267	0.4	10
			B		2,465	--	648	--	26
Kansas River at DeSoto, KS	7/13/2015	Kramer and others (2018)	A	Concurrent	11,709	0.1	21	1.1	0
			B		13,974	--	236	--	2
Kansas River at Wamego, KS	11/16/2015	Kramer and others (2018)	A	Concurrent	12,226	0.2	307	5.5	3
			B		7,972	--	0	--	0
Kansas River at DeSoto, KS	6/6/2016	Kramer and others (2018)	A	Concurrent	16,331	0.2	7,764	0.6	48
			B		10,857	--	1,852	--	17

Table 2.1. Absolute value log difference (AVLD) for quality-control field replicate samples for phytoplankton and cyanobacterial abundance, Kansas River and Milford Lake, Kansas, 2012–2018.

[M, month; DD, day; YYYY, year; phyto, phytoplankton; cells/mL, cells per milliliter; AVLD, absolute value log difference; cyano, cyanobacteria; KS, Kansas]

Site name	Sample date (M/DD/YYYY)	Data source	Replicate	Replicate type	Total phyto (cells/mL)	Phyto AVLD	Total cyano (cells/mL)	Cyano AVLD	Cyano relative abundance (%)
Kansas River at Wamego, KS	7/11/2016	Kramer and others (2018)	A	Concurrent	21,710	0.1	0	6.1	0
			B		16,784	--	1,162	--	7
Milford Lake near Wakefield, KS	7/10/2018	Leiker (2020)	A	Sequential	39,843	1.0	3,387	2.0	8
			B		401,726	--	361,570	--	90
Milford Lake, KS Site 23	7/10/2018	Leiker (2020)	A	Sequential	179,973	0.0	152,285	0.0	85
			B		186,459	--	153,870	--	83
Milford Lake near Wakefield, KS	10/16/2018	Leiker (2020)	A	Sequential	2,667	0.2	789	5.9	30
			B		1,636	--	0	--	0
Milford Lake, KS Site 23	10/17/2018	Leiker (2020)	A	Sequential	40,897	0.6	18,110	0.9	44
			B		11,510	--	2,524	--	22

Appendix 3. Significance of Pearson *r* and Spearman Rho (*ρ*) Correlation Measures Between Extracted Phycocyanin and Other Algae- and Cyanobacteria-Related Data

To evaluate laboratory performance, extracted phycocyanin data were compared to other collected data that are also related to algae and cyanobacteria. These data are instantaneous, sensor-measured phycocyanin fluorescence; instantaneous, sensor-measured chlorophyll fluorescence; extracted chlorophyll; phytoplankton abundance data; and cyanobacterial abundance data. Relations between extracted phycocyanin and these other data were analyzed by calculating the significance of the Pearson *r* and Spearman Rho (*ρ*) measures of correlation (Helsel and others, 2020). The Pearson *r* assumes linearity while the Spearman *ρ* is nonparametric (Helsel and others, 2020). A two-tailed *t*-test was used to determine *p*-values (Helsel and others, 2020). The results of these analyses are listed in table 3.1. The extracted phycocyanin data had a significant ($p<0.10$) linear relation (Pearson *r*) with chlorophyll fluorescence and significant ($p<0.10$) nonparametric relations (Spearman *ρ*) with all five of the algae- and cyanobacteria-related data investigated (table 3.1).

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Helsel, D.R., Hirsch, R.M., Ryberg, K.R., Archfield, S.A., and Gilroy, E.J., 2020, Statistical methods in water resources: U.S. Geological Survey Techniques and Methods, book 4, chap. A3, 458 p. [Also available at https://doi.org/10.3133/tm4a3.]

Table 3.1. Significance (*p*-value) of Pearson *r* and Spearman Rho (*ρ*) correlation measures of relationships between extracted phycocyanin and phycocyanin fluorescence, chlorophyll fluorescence, extracted chlorophyll, phytoplankton abundance, and cyanobacterial abundance data. Statistically significant values ($p<$**0.10**) are bolded.

[RFU, relative fluorescence unit; µg/L, microgram per liter; cells/mL, cells per milliliter; --, not available]

Data compared to extracted phycocyanin	Pearson *r* (linear)	Spearman *ρ* (nonparametric)
Sensor-measured phycocyanin fluorescence, RFU	0.111	**0.074**
Sensor-measured chlorophyll fluorescence, RFU	**0.077**	**0.027**
Extracted chlorophyll, µg/L	0.113	**0.037**
Phytoplankton abundance, cells/mL	0.967	**0.015**
Cyanobacteria abundance, cells/mL	--	**0.015**

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