Release of suspended sediments and phosphorus during the 2019-2020 drawdown of Morrow Lake, a reservoir on the Kalamazoo River, Michigan

S.K. Hamilton and D.B. Weed
W.K. Kellogg Biological Station
Michigan State University
October 2022

Morrow Lake, a reservoir on the Kalamazoo River above Comstock (MI), was drawn down to its original streambed level in November 2019 to conduct dam repairs, and remained drained until mid-December 2020. Although efforts to mitigate sediment release from above the dam intensified over the summer of 2020, large amounts of new sediment deposition and high concentrations of suspended sediments were visible well downstream throughout and following the drawdown period. To our knowledge this was the first time this reservoir had been drained since its filling in the late 1930s.

In this report, we summarize measurements of the concentrations of total suspended solids (TSS) and total phosphorus (P) in water samples collected above and below Morrow Lake (Fig. 1). This sampling was part of a long-term study of water quality in multiple waterbodies in the region funded by a grant from the US National Science Foundation. We sampled water over nearly 3 years preceding the drawdown as well as during the drawdown period. The concentrations were interpolated between sampling dates to estimate daily values, which were multiplied by daily discharge measurements to estimate total loads (transport). Methods are described in more detail at the end of this report.

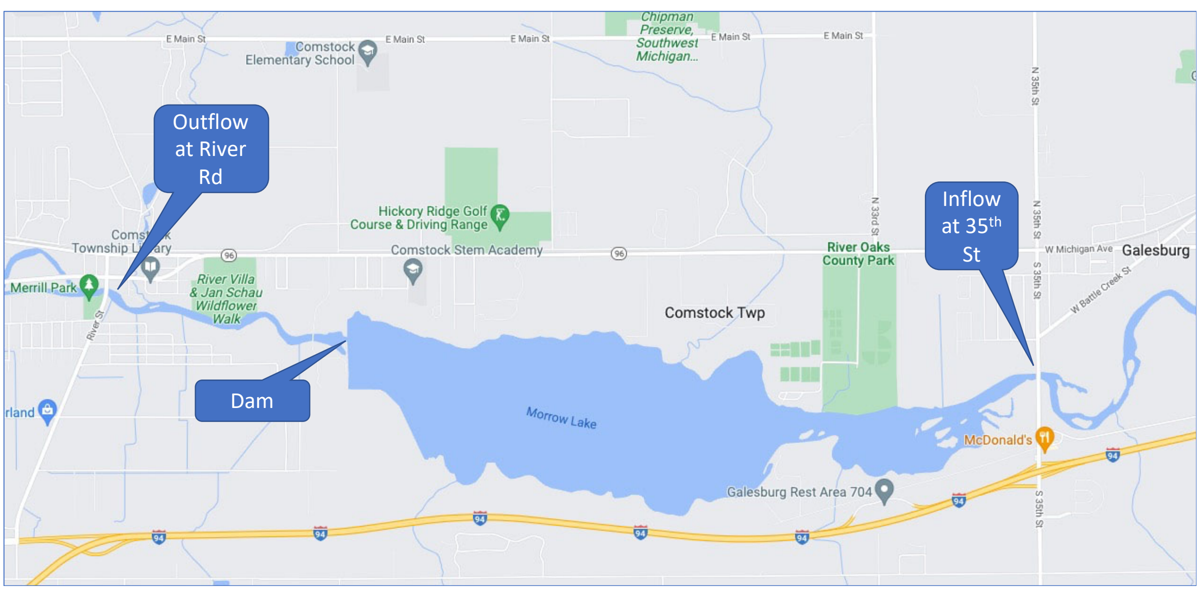


Figure 1. Map showing Morrow Lake (from Google Maps) and the two sampling locations. The USGS discharge data are from just downstream of River Rd. No major tributaries enter between the two sampling points.

The dam forming Morrow Lake is operated as a run-of-river system, meaning that reservoir water levels are kept fairly constant over the year and inflow is balanced by outflow, although short-term variation in water release creates abrupt changes in water level and discharge immediately downstream. According to the hydropower company, this variation is caused by brief shutdowns when units need regular maintenance, rather than by hydropeaking in response to electricity demand fluctuations (D. Fox, Eagle Creek Renewable Energy, Bethesda MD).

Export of suspended sediments

Prior to the drawdown, TSS concentrations in the river inflow and outflow tended to be relatively low, and there was no consistent increase or decrease as river water passed through the reservoir (Fig. 2). Reservoirs characteristically trap suspended sediments in inflowing river water as flow slows down, but growth of algae as well as occasional sediment resuspension can generate new solid material in the water column, and thus the suspended matter flowing out of Morrow Lake was probably not the same as that flowing in. Under normal water levels, most algal growth in Morrow Lake occurs during summer low discharge (Reid and Hamilton 2017).

The period of reservoir drawdown beginning in Nov 2019 coincided with elevated TSS concentrations in the outflow, but resulted in no readily visible increase in discharge compared to the preceding years. In this and the other charts presented here, chemical measurements are indicated by symbols, and the lines connecting the symbols indicate how we estimated concentrations on intervals between sampling by linear interpolation.

The drawdown period can be examined more closely in Figure 3, which shows the same data as in Figure 2, but only for the drawdown and refilling (Nov 2019–13 Jan 2021). The frequency of our sampling, which was constrained by COVID-19 restrictions, missed some of the peaks in discharge. In particular, we missed a large discharge peak in late May 2020, which might have mobilized more sediments. However, the highest TSS concentrations we observed (18 Dec 2019) did not coincide with or follow a peak in discharge.

Daily TSS concentrations estimated by interpolation between sampling dates were combined with daily means of discharge from the USGS gage to estimate the total load (transport) of suspended sediments that passed by the downstream sampling site during the drawdown period (Fig. 4A). Daily load was calculated as concentration times discharge. Variation in load during the drawdown is partly explained by pulses of inflowing river discharge (Fig. 4A), which temporarily increased reservoir water levels (Fig. 4B). However, as noted above, a high inflow period in May 2020 was not sampled, and a peak in load in Dec 2019 did not coincide with a discharge pulse.

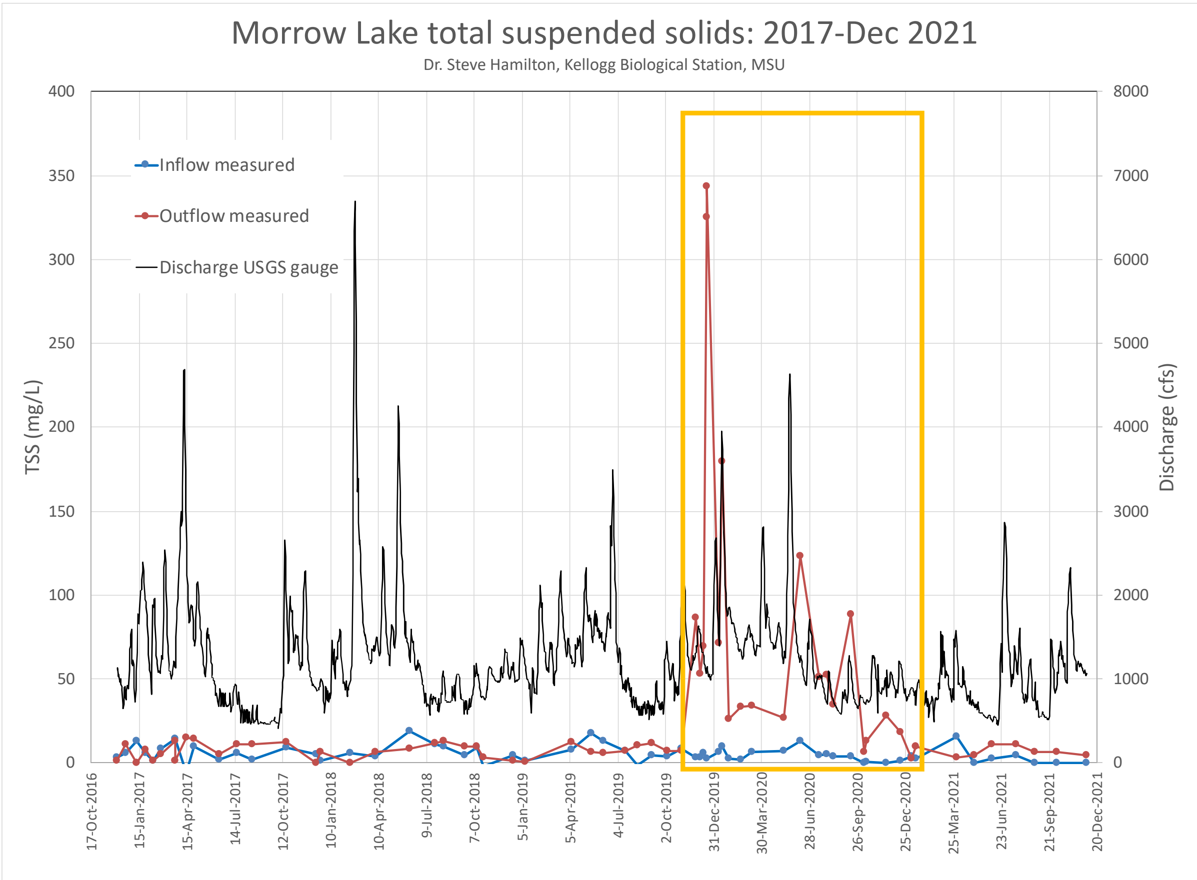


Fig. 2. TSS concentrations and river discharge preceding, during, and following the drawdown period, which is indicated approximately by the gold rectangle.

Outflow load compared to inflow load, which is the difference between the two lines in Figure 4A, showed the elevated outflow load can be attributed to sources within the reservoir. **The sum of daily outflow loads over the drawdown period, corrected for inflow loads to yield new TSS generated within the reservoir, was 78,390 metric tons** (86,385 short tons, which is the US system) on a dry weight basis.

We can roughly estimate the volume that this release of suspended sediments would occupy once it settled to the bottom of the river. For this we need to know the bulk density of sediment deposits. Assuming that the settled sediments would eventually have a similar bulk density as the fine sediment deposits in the reservoir from which they originated, we can use the average of available measurements made in Morrow Lake in recent years. Two sources of information were available: 1) the Hamilton lab took 5 sediment cores in a longitudinal transect across the reservoir in 2016, which had a mean bulk density of 0.23 g/cm^3; and 2) measurements made as part of a study of submerged oil overseen by the US EPA after the Enbridge oil spill included 13 sediment cores from the main body of the reservoir, which had a mean bulk density of 0.296 g/cm^3 (Graan and Zelt 2013). The weighted mean of these values, which is 0.278 g/cm^3, was used for present purposes.

The total volume of the TSS load, once settled on the bottom of the river, was thus estimated as its total mass divided by bulk density. After unit conversions, the volume was estimated to be 282,000 m^3 (= 9,956,600 ft^3 = 369,000 cubic yards).

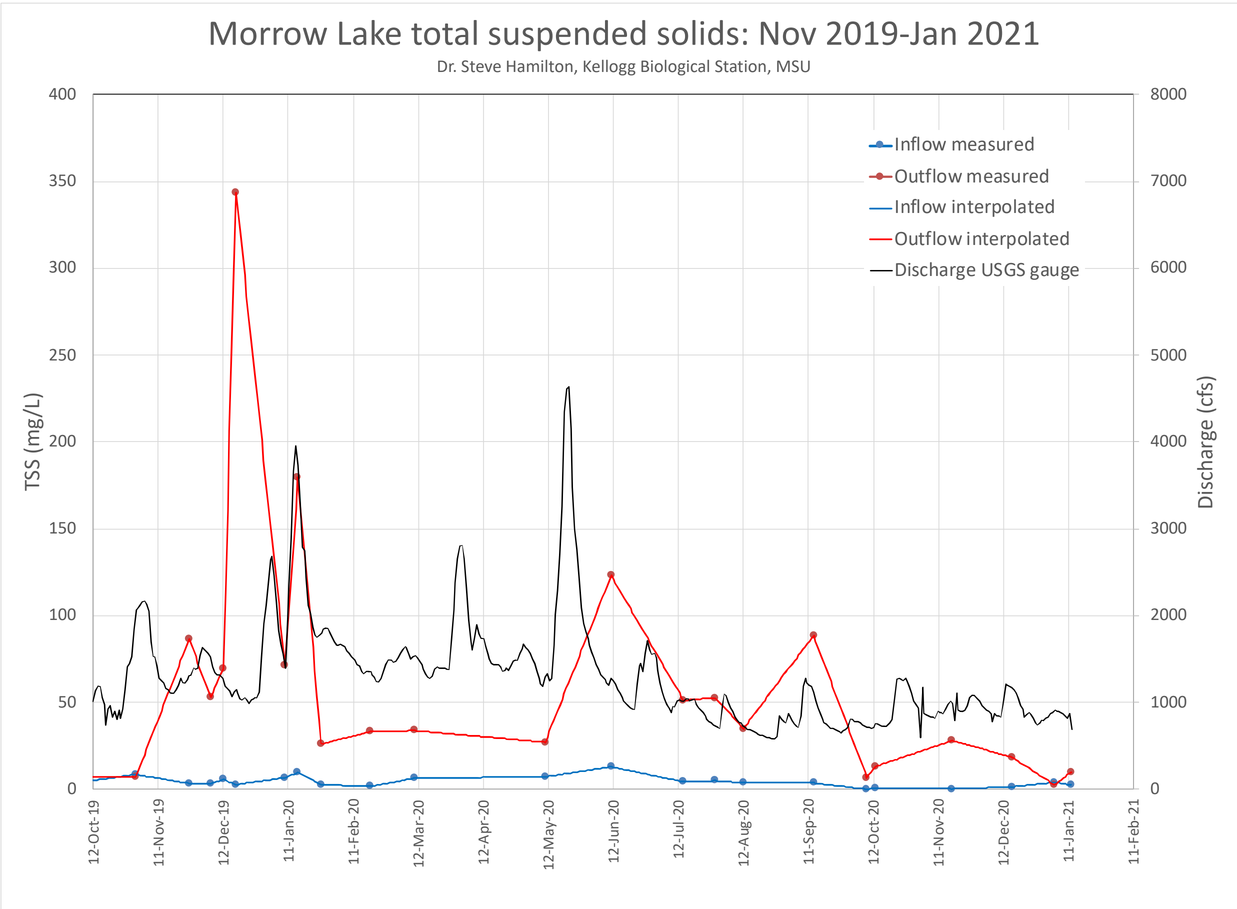


Fig. 3. TSS concentrations and river discharge during the drawdown period.

To provide an idea of how much this volume of sediment could affect the river below the dam, consider that the river width downstream of Morrow Lake is about 150 ft (46 m). **The 282,000 m^3 of sediment that was released could cover the entire river bottom with a layer 0.3 m (1 ft) thick for about 20 km (12.5 miles)**, equivalent to a total area of 940,000 m^2. A 20-km reach below the dam extends well beyond the D Avenue bridge in Cooper Township.

A similar calculation can be made to estimate the depth of the sediment layer that would have to be eroded from Morrow Lake to produce the increased TSS load in the outflow. The total area of Morrow Lake at normal water level is about 4,451,000 m^2. Erosion would undoubtedly have occurred in a spatially heterogeneous manner, but if it were evenly distributed across the lake bottom at the same bulk density (0.278 g/cm^3), the 282,000 m^3 of sediment equates to a layer only about 0.06 m (2.4 in) thick. Aerial views of the reservoir during the drawdown show the formation of channels in the center of the lake bottom (Fig. 5), and a field visit revealed stumps that had been exposed in the new river channels (Fig. 6), so the actual depth of erosion where flowing water persisted was likely considerably greater than 0.06 m. Therefore, the estimates of total sediment release based on TSS measurements appear plausible.

Export of phosphorus

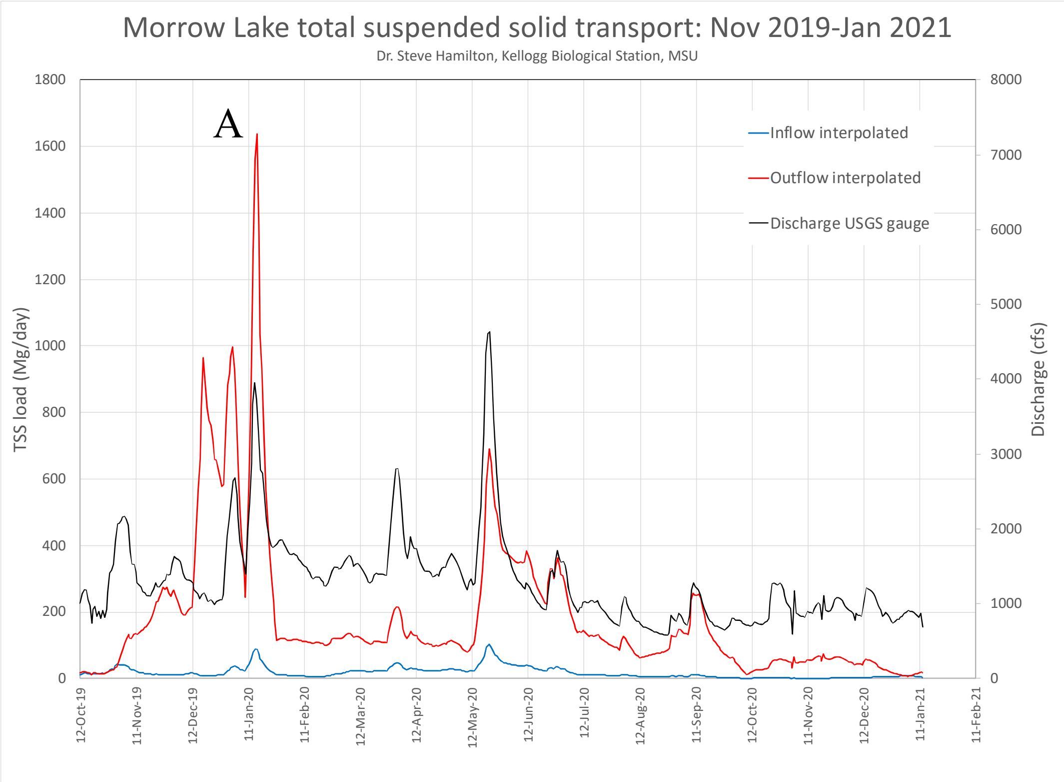
Phosphorus (P) is commonly the limiting factor for algal growth in Michigan waters, and has been implicated in causing excessive algal and weed growth (eutrophication) in lakes and reservoirs. The watershed sources and river transport of P to Lake Allegan, another reservoir on the Kalamazoo River located downstream of Morrow Lake, have been studied in connection with a phosphorus Total Maximum Daily Load (TMDL) for that reservoir, and sampling for that work has included measurements of total P in the Kalamazoo River below Morrow Lake (Heaton 2001).

Phosphorus exists in both dissolved and particulate (solid) forms, and particulate P is the predominant form (~80% of total P) in the Morrow Lake outflow during normal reservoir water levels, based on sampling during the summer (Reid and Hamilton 2007). That particulate P includes P in algal biomass. Based on comparison of inflow to outflow waters, P concentrations tend to increase in Morrow Lake during the summer, which has been attributed to release from the sediments, either as dissolved P or via disturbances by carp (Kieser & Associates 2016).

Upon drawdown of Morrow Lake, enhanced erosion and transport of sediments would be expected to carry additional P out of the reservoir. We measured total P in water samples before and during the drawdown (Fig. 7). The increased total P concentrations in the outflow are due mainly to particulate P, since total dissolved P remained within the range of pre-drawdown measurements (data not shown).

Conclusions

The emergency drawdown of Morrow Lake resulted in massive export of sediment to downstream reaches, the total quantity of which was approximated based on measurements of total suspended solids above and below the reservoir prior to and during the drawdown period. Phosphorus export in particulate forms also increased. Deep new sediment accumulations became visible downstream during and in the months after the drawdown period, confirming that some fraction of the exported solids readily sedimented out of the water column.



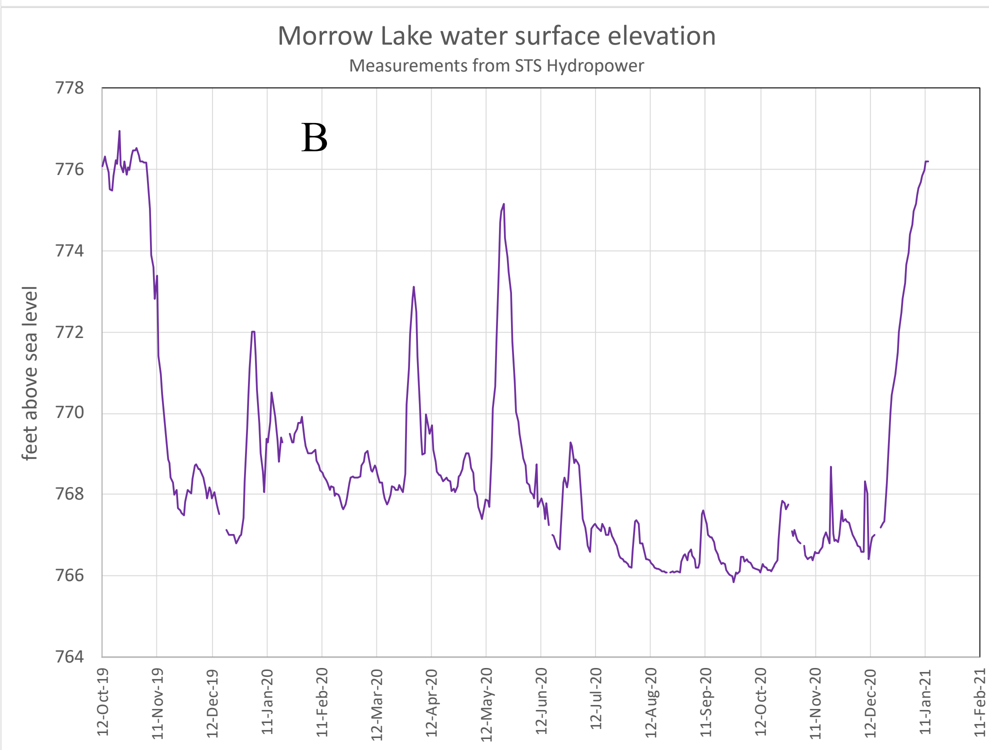


Fig. 4. A) Daily TSS loads and river discharge during the drawdown period. B) Daily reservoir elevations (water levels) measured at the dam headwater during the drawdown period.

Fig. 5. An aerial view of Morrow Lake looking east from near the dam on 13 July 2020 shows the spatially variable erosion of fine sediments while it was drawn down. Photo courtesy of the Kalamazoo River Watershed Council.

Fig. 6. Stumps and eroding organic sediments became visible during the drawdown (Sep 2020).

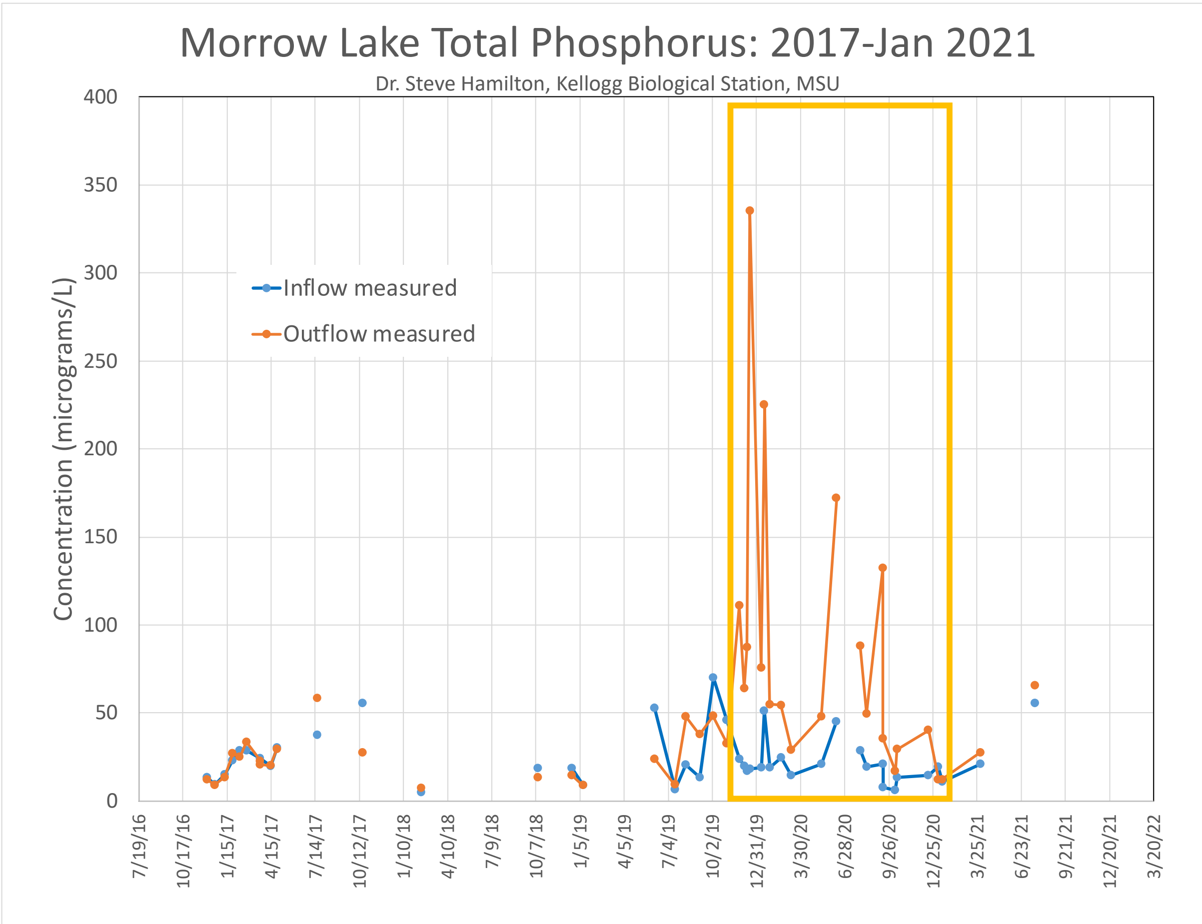


Fig. 7. Total phosphorus concentrations preceding and during the drawdown period (indicated by the gold rectangle).

Details on methods

The Morrow Lake inflow and outflow were always sampled on the same day. A polypropylene "dipper" (a collecting cup on the end of a 2-m pole) was used to collect a river water from 0-50 cm depth. After rinsing the polyethylene sample collection bottle with sample water, a 1-liter sample was collected for lab processing and analysis. A sonde that records pH, specific conductance, temperature and dissolved oxygen was placed into flowing water prior to collecting a water sample for lab analysis, and readings were taken after stabilization (at least five minutes). Pictures were occasionally taken if significant changes at the site were noted.

The upstream (inflow) sampling site is ~20 m above the 35th St bridge in Galesburg, along the right bank facing downstream. Samples were collected in flowing water ~3 m out from the river bank. The river bed is made up of large boulders at the upstream sampling location.

The downstream (outflow) sampling site is located about 20 m above the River Road bridge in Comstock, along the left bank facing downstream. Samples were collected in flowing water ~1.5

m from the river bank. The bank at this site is lined with rip rap and the water depth drops off steeply.

To measure total suspended solids, up to 1 L of water was filtered through a glass-fiber filter (Pall A/E, 1 micron pore size) until the filtration rate slowed. Prior to use each filter had been dried at 60 C and weighed (tared). Material on the filter was subsequently dried at 60°C and the filter was weighed again, with the increase in weight representing the dry weight of material on the filter. Division of that dry weight by the water volume filtered yielded the concentration in the original sample.

To measure total and total dissolved P, subsamples of unfiltered and filtered water were digested in potassium persulfate at high temperature and pressure to break down organic P forms to soluble reactive P, which was measured colorimetrically with a spectrophotometer. The difference between total and total dissolved P provided an estimate of particulate P, which worked well in this case because particulate P is a large fraction of the total P in the Kalamazoo River.

Other water quality variables were also measured, but did not show changes from inflow to outflow that were outside of the ranges observed in the pre-drawdown period. These variables included water temperature, dissolved oxygen, pH, specific conductance, nitrate, total alkalinity, silicate, dissolved organic carbon, and major ions (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, and SO_4^{2-}).

U.S. Geological Survey discharge data for the Kalamazoo River at Comstock (USGS station 04106000) were downloaded on 1 Feb 2020 from https:\\nwis.waterwatch.usgs.gov.

Acknowledgements

Eagle Creek Renewable Energy and STS Hydropower LLC provided the water level data. Support for this research was provided by the National Science Foundation (NSF) Long-term Ecological Research Program (grant no. DEB 1832042) at the Kellogg Biological Station and by Michigan State University AgBioResearch.

Suggested citation: Hamilton, S.K. and D.B. Weed. 2022. Release of suspended sediments and phosphorus during the 2019-2020 drawdown of Morrow Lake, a reservoir on the Kalamazoo River, Michigan. Kellogg Biological Station Long-term Ecological Research Special Publication. Zenodo, https://doi.org/10.5281/zenodo.7217398

References cited

Graan, T.P. and R.B. Zelt. 2013. Volume Estimation for Submerged Line 6B Oil in the Kalamazoo River, Summer 2012, Enbridge Line 6B MP 608 Marshall, MI Pipeline Release. Weston Solutions and US Geological Survey, unpublished Quantification Memo 130325.

Heaton, S., 2001. Total maximum daily load (TMDL) for total phosphorus in Lake Allegan. Michigan Department of Environmental Quality, Surface Water Quality Division. https://www.michigan.gov/-/media/Project/Websites/egle/Documents/Programs/WRD/SWAS/TMDL-Other/allegan.pdf?rev=747a873b14b44973a2f5f1a1af8e5987

Kieser & Associates. 2016. Morrow Lake Water Quality Monitoring Report. Michigan Department of Environmental Quality, project MDEQ #2015-0519.

Reid, N.J. and S.K. Hamilton. 2007. Controls on algal abundance in a eutrophic river with varying degrees of impoundment (Kalamazoo River, Michigan, USA). Lake and Reservoir Management 23: 219-230.