

Evaluating Sediment Resuspension and Internal Nutrient Loading in Tappan Lake Using Remote Sensing, Acoustic Doppler Current Profiler Observations, and EFDC+ Modeling

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Abstract

Tappan Lake, a medium-sized shallow reservoir situated in Harrison County, OH, exhibits recurring algal blooms despite having limited external nutrient loading from its predominantly forested watershed. This study examined the role of internal nutrient loading and sediment resuspension as the principal drivers of water quality degradation and increasing algal bloom in the lake using remote sensing, observed data, and hydrodynamic and water quality modeling. Initial analysis was focused on establishing the statistical correlation between Sentinel-2-derived Normalized Difference Chlorophyll Index (NDCI) and in-situ Chl-a measurements to validate the index as a reliable proxy for algal biomass at Tappan Lake. Accordingly, data collected at spatially distributed eleven monitoring stations across the lake were utilized for internal loading assessment. Measured Chl-a used for correlation against NDCI values ranged from 2.1 to 29.66 $\mu\text{g/L}$ across the monitoring network. Sentinel-2 NDCI demonstrated a statistically significant correlation with measured Chl-a concentrations ($R^2 = 0.67$), supporting its application for lake-wide spatial mapping. Annual summer NDCI composite maps generated for 2020 to 2025 revealed an initially increasing and spatially expanding pattern of elevated Chl-a, with eutrophic conditions evident across the entire lake surface in all years (NDCI: 0.008-0.316; estimated Chl-a: 8-25 $\mu\text{g/L}$).

Acoustic Doppler Current Profiler (ADCP) derived velocity profiles across ten cross-sectional transects revealed pronounced spatial heterogeneity, with depth-averaged speeds ranging from 0.041 m/s at the deep western basin near the dam to 0.231 m/s at a mid-lake hydraulic constriction.

Near-bed Relative Backscatter Index (RBI) enhancement analysis identified the mid-lake transition zone as the primary resuspension area, exhibiting the strongest near-bed particle enrichment, with values of +16.2 dB and +13.3 dB, respectively. This indicates substantially elevated suspended sediment concentrations in the bottom boundary layer relative to the overlying water column. EFDC+ simulated TSS spatial maps supported these findings, showing peak TSS concentrations of approximately 18 mg/L near the shallow eastern tributary arms and near-zero concentrations in the deep western basin near the dam, consistent with field-measured values that ranged from 6.0 mg/L at western stations to 14.5 mg/L at eastern stations ($R^2 = 0.43$). Together, these results suggest a coherent physical-biogeochemical mechanism in which wind and flow-driven sediment resuspension in the mid-lake zone may sustain internal nutrient availability and contribute to persistent algal bloom conditions independent of external tributary loading.

Introduction

Eutrophication of freshwater systems poses a globally widespread water quality challenge, driven by the cumulative impacts of anthropogenic nutrient enrichment on aquatic ecosystems (Hwang, 2020; Smith et al., 1999). Among the most important ecological and socio-economic consequences is the development of harmful algal bloom (Heisler et al., 2008), which can impair drinking water quality, limit recreational use, and create risks for human health and aquatic ecosystems (Brooks et al., 2016; US EPA, 2015). While external nutrient loading from agricultural runoff, urban stormwater, and atmospheric deposition (Carpenter et al., 1998) has historically dominated management attention, internal nutrient loading is a critical but frequently underappreciated driver of persistent eutrophication (Nürnberg, 2009; Søndergaard et al., 2003a). Internal nutrient loading is the release of nutrients, primarily phosphorus and nitrogen, from the bottom sediment into the overlying water column, where they become available to support primary productivity and

46 contribute to eutrophication (Søndergaard et al., 2003b). This process is often overlooked in many
47 lake monitoring and management strategies (Aeriyani et al., 2021; Håkanson, 2004; Zhao et al.,
48 2025) and is particularly difficult to quantify and manage because of the complexity of
49 biogeochemical processes occurring at and within the lakebed (Steinman & Spears, 2020).
50 Numerous studies have demonstrated that improvements in water quality can be delayed because
51 sediment enriched with nutrients acts as a long-term internal source of phosphorus and nitrogen
52 (Chen et al., 2017; Søndergaard et al., 2001; C. Sun et al., 2022). As a result, eutrophication can
53 persist for decades due to ongoing sediment release and resuspension processes even after external
54 nutrient inputs are reduced. Sediment-derived nutrients have the potential to contribute a
55 significant portion of the overall nutrient budget and support algal growth, particularly during
56 thermally stratified summer conditions. In many freshwater systems, lake bed sediments are now
57 recognized as a major but historically underappreciated source of phosphorus to the water column
58 (Steinman & Spears, 2020). These findings are especially relevant for reservoirs such as Tappan
59 Lake, where limited inflow during dry periods suggests that external nutrients alone may not fully
60 account for recurring algal bloom events. Given that the surrounding watershed has some
61 agricultural areas, including row crops and pastureland (Harrison Soil and Water Conservation
62 District, 2014; Sharma et al., 2023), legacy nutrients accumulated in the lakebed sediments likely
63 represent a significant and sustained internal source of phosphorus and nitrogen that continues to
64 fuel eutrophication independent of external loading. Consequently, internal nutrient recycling from
65 sediments is also expected to contribute to bloom persistence (Søndergaard et al., 2001; Song et
66 al., 2017). Capturing the true extent of these resulting blooms and evaluating the lake's changing
67 trophic state is difficult with traditional point-sampling alone. To achieve this, satellite remote
68 sensing has become an important tool for monitoring lake water quality and harmful algal blooms

at this broader scale (Topp et al., 2020). Cloud computing platforms such as Google Earth Engine (GEE) have opened up new avenues for multitemporal analysis using Sentinel-2 imagery to map surface Chl-a concentrations over extended areas of lakes (Gorelick et al., 2017; Y. Sun et al., 2024). However, remote sensing only offers measurements for the optical characteristics of the surface and provides no information on the subsurface hydrodynamic processes, which are vital to understanding the physical processes associated with sediment resuspension, internal nutrient release, and algal bloom development (Nouchi et al., 2018). This gap between surface observable water quality indicators and the underlying physical processes controlling them remains a major limitation in inland water monitoring (El Serafy et al., 2021).

To truly understand what drives these surface patterns, it is critical to examine the underlying hydrodynamic processes that regulate sediment resuspension and the release of internally stored nutrients (Søndergaard et al., 1992; Tang et al., 2020a). Specifically, phenomena such as wind-driven circulation, thermal stratification, and shear-induced mixing collectively govern the degree to which bottom sediments are mobilized and nutrients transported to the photic zone (Spigel & Imberger, 1987). Yet, these processes are notoriously difficult to capture through remote sensing or periodic grab sampling alone. Acoustic Doppler Current Profilers (ADCPs) have been widely used in river and estuary systems to measure depth-resolved velocity profiles, as well as estimate suspended sediment concentration using acoustic backscatter intensity (Gartner, 2004; Kostaschuk et al., 2005; Simpson & Olthmann, 1993a), which helps in understanding these underlying phenomena. However, the use of ADCPs in inland lakes and reservoirs has been limited (Haun & Lizano, 2018). This is due in part to the fundamentally different hydrodynamic regimes that exist within lakes, including lower velocities, wind-driven three-dimensional flow, and near-bed resuspension caused by waves (Jing et al., 2026; Le et al., 2023). While ADCP measurements

provide detailed, high-resolution information on velocity structure and Signal-to-Noise Ratio (SNR) profile, they are inherently limited to specific sampling locations and transects within the lake (Haun & Lizano, 2018). Although these observations collected along selected cross-section transects offer valuable insights into internal processes, they cannot fully capture the spatial variability of hydrodynamic conditions across an entire lake system, nor project conditions beyond the measurement period. To overcome this spatial constraint and extend the analysis to lake-wide scales, numerical hydrodynamic modeling is essential. In this study, the Environmental Fluid Dynamics Code (EFDC+), a widely used process-based model that can simulate three-dimensional hydrodynamics, sediment transport, and water quality processes in aquatic systems (Bai et al., 2018; Hamrick, 1996; Tasnim et al., 2024), has been used to examine the internal loading. Previous studies have often examined surface water quality and subsurface hydrodynamics separately, leaving an important gap in understanding the lake system as an integrated whole. Therefore, the study addresses these gaps by conducting an integrated multi-method investigation of Tappan Lake with three main objectives: (1) determining spatiotemporal trends in surface Chl-a using Sentinel-2 imagery analyzed in GEE; (2) determining in-lake velocity and backscatter profiles based on ADCP field measurements; and (3) simulating lake-wide sediment transport and internal nutrient dynamics using the EFDC+ model.

Theoretical Description

Lake Processes and Sediment Resuspension

Reservoirs and shallow lakes are especially vulnerable to the process of resuspension driven by wind-induced shear stress, which mobilizes bottom sediments and releases adsorbed nutrients, mainly phosphorus, directly into the water column (Søndergaard et al., 2003c; Tang et al., 2020b).

In stratified reservoirs, thermal stratification during summer months causes the formation of density gradients in the reservoir, resulting in the depletion of oxygen concentration in the hypolimnion and releasing phosphorus into the water column in anaerobic conditions (Orihel et al., 2017). Phosphorus accumulated in sediments during summer anoxia is released into the entire water column through seasonal nutrient cycling during fall lake turnover, when cooler surface temperature causes the entire lake to mix (Wetzel, 2001). The seasonal recycling of internally accumulated nutrients makes the system ready for spring blooms even when external nutrient input is reduced or limited, and creates a legacy effect that can last several years in lakes with nutrient-rich sediments (Nürnberg, 2009; Wetzel, 2001).

Remote Sensing

Satellite remote sensing for the assessment of inland water quality relies on the principle that optically active constituents, including Chl-a, suspended solids, and colored dissolved organic matter (CDOM), alter the spectral reflectance of water in characteristic ways that can be detected by multispectral sensors (Aggarwal, 2004; University of Minnesota, 2025). As the major pigment in phytoplankton, Chl-a absorbs strongly in the red wavelength region (approximately 665 nm) and reflects in the near infra-red (approximately 708 nm), creating a difference contrast that forms the basis of indices such as NDCI, defined as;

$$NDCI = \frac{R_{708} - R_{665}}{R_{708} + R_{665}} \quad (1)$$

Where R_{708} and R_{665} represent surface reflectance in the near-infrared and red bands, respectively (Mishra & Mishra, 2012). The Sentinel-2 MSI is especially valuable for studying the dynamics of Chl-a content in small water bodies due to its spatial resolution and frequent revisits. GEE allows for effective multitemporal analysis of satellite data from Sentinel-2 (Kislik et al., 2022).

YSI EXO Sonde and ADCP

Acoustic Doppler Current Profilers (ADCPs) measure water velocity profiles throughout the water column based on the emission of an acoustic wave with a certain frequency, which will be reflected from suspended particles moving with the water, resulting in the occurrence of the Doppler effect (Gordon, 1996; Simpson, 2001). The velocity at each depth bin is obtained by calculating the difference between the frequencies of the emitted and the received signal, giving a vertical profile of flow structure from near-surface to near-bed (Simpson & Olthmann, 1993b). The ADCP records velocity in three geographic components: eastward (V_e), northward (V_n), and vertical (V_u) from which the horizontal flow speed magnitude at each depth bin is computed as:

$$Spd = \sqrt{V_e^2 + V_n^2} \quad (2)$$

This horizontal speed magnitude is used for velocity profile analysis, as it captures the total horizontal flow energy at each depth, independent of flow direction (SonTek, 2020).

In addition to velocity, ADCPs measure the strength of the acoustic signal backscattered by the particles within the water column, which is called Signal-to-Noise Ratio (SNR), measured in decibels (dB). SNR represents the ratio of the received backscatter signal to the ambient acoustic noise floor of the instrument. Higher SNR values indicate stronger acoustic scattering, which corresponds to greater concentrations or larger sizes of suspended particles (Gartner, 2004; Hoitink & Hoekstra, 2005). The SonTek M9 ADCP records SNR independently for each of its four acoustic beams at every depth cell and ensemble, providing spatially resolved backscatter data throughout the water column (SonTek, 2020).

Raw SNR values, however, are not purely a function of suspended particle concentration. Two additional physical processes attenuate the acoustic signal with increasing distance from the

transducer, regardless of the particle field: (1) spherical spreading, where the sound intensity is inversely proportional to the square of the distance travelled because the sound beam spreads out; and (2) water absorption, where the medium itself loses sound intensity along the beam path. If these two are not compensated for, cells that are nearer the transducer will seem to have higher backscatter than those deeper, despite having the same concentration of particles (Gartner, 2004; Sassi et al., 2012).

To isolate the particle-related component of the backscatter signal, raw SNR values can be corrected for spherical spreading following the working sonar equation of (Deines, 1999) as applied by (Venditti et al., 2016), yielding the Relative Backscatter Index (RBI):

$$RBI(dB) = SNR(mean) + 20\log(r) \quad (3)$$

where SNR (mean) is the arithmetic mean of the four-beam SNR values and r is the slant range from the transducer face to the cell center (m).

A full correction should also contain a term for water absorption to represent the attenuation of sound energy; however, for shallow lacustrine environments, this contribution is small relative to the spherical spreading correction and has been shown to be negligible in previous ADCP backscatter studies (Sassi et al., 2012; Venditti et al., 2016). The spherical spreading correction, therefore, represents the dominant and sufficient geometric compensation applied in this study.

The YSI EXO Sonde is a multiparameter water quality instrument capable of simultaneously measuring temperature, dissolved oxygen, pH, specific conductance, turbidity, and Chl-a fluorescence at discrete depths or continuously through vertical profiling (Espinola, 2017). In the

context of this study, EXO Sonde measurements provide ground-truth validation for satellite-derived surface water quality estimates.

Environmental Fluid Dynamics Code Plus (EFDC+)

The Environmental Fluid Dynamics Code Plus (EFDC+) is a process-based three-dimensional hydrodynamic model that simulates coupled hydrodynamic, sediment transport, and water quality processes in rivers, lakes, estuaries, and reservoirs (Bai et al., 2018; Tasnim et al., 2024). The model solves the Reynolds-averaged Navier-Stokes equations in the horizontal plane, combined with the hydrostatic assumption in the vertical, enabling computationally efficient simulation of three-dimensional flow fields, thermal stratification, and turbulent mixing in large water bodies (Tetra Tech, Inc., 2007). EFDC+ is simulated through advection-diffusion equations that govern the erosion, transport, and deposition of both cohesive and non-cohesive sediments, with erosion rates governed by the relationship between bed shear stress and a critical threshold for sediment mobilization:

$$\tau_b = \rho C_D U^2 \quad (4)$$

Here, τ_b is the bed shear stress (N/m²), ρ is the water density (kg/m³), C_D is the drag coefficient, and U is the depth-averaged flow velocity (m/s). When τ_b exceeds the critical shear stress (τ_{cr}) of the bed sediment, erosion, and resuspension are initiated (Hamrick, 1996; Kim et al., 2024). Water quality modeling is conducted using the simulation of nutrient cycling, which involves the transformation of various types of nitrogen and phosphorus nutrients through sediment-water exchange fluxes that provide the internal nutrient loading from bottom sediments (Tetra Tech, Inc., 2007). Model inputs include lake bathymetry, meteorological forcing, tributary discharge, and initial and boundary conditions for water quality constituents. Calibration and

validation are performed against field-measured TSS, total nitrogen (TN), and total phosphorus (TP), ensuring that simulated sediment and nutrient dynamics are consistent with observed lake conditions.

Materials and Methods

Study Area

Tappan Lake is an inland reservoir in Harrison County, Ohio, within the Muskingum River Watershed. The lake was formed by impounding Little Stillwater Creek, which flows into the Stillwater Creek and finally enters the Tuscarawas River. The lake has an approximate surface area of 2,350 acres and a shoreline length of about 47 miles, making it one of the larger reservoirs managed jointly by Muskingum Watershed Conservancy District (MWCD) and United States Army Corps of Engineers (USACE). The Tappan Lake watershed encompasses approximately 71 square miles and includes three primary sub watersheds: Upper Little Stillwater Creek, Clear Fork, and Standingstone Fork. These tributaries, along with several smaller inflowing streams, flow into the reservoir and serve as the primary sources of external sediment and nutrient inputs. The watershed is predominantly rural, with an estimated population of approximately 2,216, and includes a mix of forested (73%), agricultural (16%), and minor urban (6%) areas (Harrison County, Ohio, 2014; MWCD, 2026).

The reservoir supports multiple ecological and socio-economic benefits to the region. Initially constructed for flood control and water resource management, the reservoir now also functions as a major recreational destination, supporting activities such as boating, fishing, and swimming, and attracting substantial seasonal visitors. Beyond recreation, it contributes to regional water supply and ecosystem service through the support of aquatic habitat and the regulation of downstream

flow. As a multi-purpose reservoir connected to tributary systems within the Muskingum River basin, the maintenance of water quality in Tappan Lake is of considerable regional importance. Continued concerns over sedimentation, nutrient enrichment, and algal bloom development emphasize the need for ongoing monitoring and a better understanding of both external and internal loading processes. Together, these factors make Tappan Lake an important system for studying water quality dynamics and for developing integrated reservoir management strategies.

In-Situ Field Data Collection

To achieve reliable, comprehensive, and spatially representative water quality characterization across Tappan Lake, in-situ field data collection was conducted through a structured sampling program combining multiparameter water quality monitoring and acoustic current profiling. Eleven discrete monitoring stations were strategically selected throughout Tappan Lake to ensure comprehensive spatial coverage of the lake's hydrological and ecological diversity. Station locations were deliberately distributed across four functional lake zones: inlet zones, outlet zones, mid-lake, and areas identified as most vulnerable to nutrient enrichment and pollution loading. Precise GPS coordinates were documented for each station to ensure spatial consistency and repeatability across all sampling events. The spatial distribution of the eleven monitoring stations across Tappan Lake is illustrated in Figure 1.

In-situ water quality data were collected at all eleven monitoring stations using a YSI EXO2 multiparameter water quality sonde equipped with high-precision sensors. At each station, the sonde was deployed to simultaneously record temperature, pH, specific conductance, dissolved oxygen, turbidity, blue-green algae (BGA) phycocyanin, Chl-a, and water depth. While all parameters were recorded to characterize the broader limnological conditions of the lake, Chl-a

concentration ($\mu\text{g/L}$) was designated as the primary variable for subsequent remote sensing validation and regression analysis, given its wide utility as a proxy for phytoplankton biomass and algal bloom intensity (He et al., 2022; Johansen et al., 2018; Søndergaard et al., 2011). Field sampling was conducted across ten discrete sampling events spanning April through October 2024. This temporal sampling design captured the full seasonal progression of water quality conditions from pre-bloom spring conditions through peak summer bloom development and into post-bloom fall recession, providing a temporally rich dataset to characterize intra-seasonal variability in Chl-*a* dynamics across the lake. All measurements were collected in-situ directly by the YSI EXO2 sonde without supplementary laboratory analysis, consistent with the intended application of the dataset for satellite image validation rather than absolute nutrient load quantification.

ADCP Deployment and Data Processing

ADCP data were collected at Tappan Lake in collaboration with the Muskingum Watershed Conservancy District (MWCD) over three consecutive days, June 16, 17, and 18, 2025, during the summer stratification period. A SonTek M9 ADCP was deployed using the moving-boat method along 10 cross-sectional transects spatially corresponding to the water quality monitoring stations established during the 2024 YSI EXO2 campaign. At each transect, the instrument traversed the full width from bank to bank, acquiring continuous velocity and acoustic backscatter profiles. The M9 operates at dual acoustic frequencies (1.0 and 3.0 MHz) with a 0.5 MHz vertical beam echosounder, and its SmartPulseHD technology adaptively selects the optimal pulse scheme based on ambient depth, velocity, and turbulence conditions, making it well-suited for the variable and shallow bathymetry of Tappan Lake (SonTek, 2020). Data acquisition and real-time monitoring were conducted using RiverSurveyor Live (RSL) software, which simultaneously records velocity profiles, bottom-track depth, and acoustic backscatter intensity at each ensemble (SonTek, 2020).

Raw data were exported from RSL in Excel format for processing. Only 1 MHz ensemble data were retained, as scattering intensity is frequency-dependent and 1 MHz and 3 MHz backscatter cannot be directly compared on the same scale (Thorne & Hanes, 2002). A transducer depth offset of 0.14 m was added to reference all cell depths to the water surface. The velocity and backscatter data sets were then applied with two subsequent filters. First, the artifact filter removed depth bins whose ensembles count exceeded three times the median, corresponding to 3MHz vertical beam data that leaks into 1MHz export. Second, the minimum ensemble threshold of $N \geq 10$ removed depth bins with insufficient measurements near the banks. Additionally, the bottom 6% of the total water column was excluded from all analyses to eliminate depth cells contaminated by acoustic side-lobe interference from the lake bed, following standard ADCP processing practice (SonTek, 2020; Teledyne RD Instruments, 2011). Therefore, the valid velocity and SNR profiles for each transect span from the first cell unaffected by the transducer blanking distance and 94 % of the mean depth of the water column.

The horizontal flow speed for a given transect was computed at every depth cell from eastward and northward velocity components recorded in the ENU coordinate system (SonTek, 2020). The true depth of each measurement cell below the water surface was calculated as:

$$\begin{aligned} \text{Transducer depth (m)} &= \text{Cell location} + \\ &\text{Transducer depth offset} \end{aligned} \tag{5}$$

The cell location is simply the distance from the transducer face to the middle of the depth cell per the RiverSurveyor Live readings, and the transducer depth offset of 0.14 m accounts for the submersion depth of the M9 instrument below the water surface during deployment. Left and Right bank transect profiles were then plotted together for each station to characterize the cross-sectional flow structure.

For each depth cell and ensemble, the mean four-beam SNR was computed, and the relative backscatter index (RBI) was calculated following the formula described in the theoretical section and averaged across valid ensembles to produce a depth-resolved profile per transect. As described in the theoretical description, acoustic backscatter intensity recorded by ADCPs has been demonstrated as a proxy for suspended particle concentration throughout the water column, with higher backscatter indicating greater particle load (Gartner, 2004; Hoitink & Hoekstra, 2005). Station-averaged RBI profiles were generated by projecting left and right bank profiles onto a common depth grid. Building on this principle, the near-bed RBI enhancement was defined as the mean RBI in the bottom 20% of the water column minus the mean RBI in the mid-column (30-70% depth), the latter serving as the ambient background reference, removed from both surface turbulence effects and near-bed sediment influences. Positive enhancement indicates that suspended particle concentrations are elevated near the bed relative to the overlying water column, a pattern consistent with active sediment resuspension driven by hydrodynamic bottom forcing, as near-bed sediment concentration increases when hydrodynamic disturbance mobilizes bed material into the bottom boundary layer (Jalil et al., 2019), while negative or near-zero enhancement indicates vertically uniform or settling-dominated conditions.

Satellite Data and Image Processing

Satellite remote sensing was integrated into this study to characterize the spatio-temporal distribution and inter-annual trends of chlorophyll a across the surface of Tappan Lake from 2020 to 2025. Unlike point-based in-situ measurements, which are limited to discrete monitoring locations, satellite imagery provides spatially continuous and temporally repeatable observations of surface water quality, allowing lake-wide assessment of algal bloom dynamics. Sentinel-2 MSI was selected as the sole remote sensing platform for this component of the study based on its 10-

meter spatial resolution, 5-day revisit cycle, and the availability of a dedicated red-edge band (B5, 704.1 nm) that is particularly sensitive to Chl-a absorption and reflectance characteristics in the phytoplankton-dominated spectral range (Bramich et al., 2021; NASA Earthdata, 2025). Sentinel-2 Level-2A Harmonized imagery was accessed and processed within GEE, a cloud-based geospatial computing platform that enables large-scale multitemporal satellite image processing. The Level-2A imagery contains atmospherically corrected surface reflectance data derived through the Sen2Cor processor algorithm, making it suitable for direct spectral analysis and water quality index computation without additional atmospheric correction steps (Copernicus, 2025).

The correspondence between satellite image acquisition dates and field sampling events is summarized in Table 1. Image collections were limited to the area of Tappan Lake and restricted to scenes with a scene-level cloudy pixel percentage limited to 50%. This way, heavily clouded images were excluded from processing. The Scene Classification Layer (SCL) band is integrated with each Level-2A product to identify and remove cloudy pixels and non-water surfaces, where only the pixels classified as water (SCL class 6) were retained for analysis. This process also excluded clouds, cloud shadows, cirrus, vegetation, and bare soil surfaces from the lake area. This water-specific pixel masking approach is appropriate for Tappan Lake, where shallow margins, emerging vegetation, and mixed shoreline pixels could cause significant spectral contamination.

Radiometric scaling was applied to convert integer digital number (DN) values to unitless surface reflectance prior to any spectral computation:

$$\rho = DN * 0.0001 \quad (6)$$

where ρ represents surface reflectance (Google Earth Engine, 2025). This scaling was applied uniformly across all optical bands within GEE before index calculation, ensuring that all spectral

operations were performed on physically meaningful reflectance values consistent with the Sentinel-2 Level-2A product specification.

Chl-a concentration was assessed using the Normalized Difference Chlorophyll Index (NDCI), which exploits the characteristic absorption of Chl-a in the red wavelength and its enhanced reflectance in the red-edge region of the spectrum (Mishra & Mishra, 2012). The NDCI was computed as follows.

$$NDCI = \frac{B5 - B4}{B5 + B4} \quad (7)$$

where B5 is the surface reflectance of the Sentinel-2 red-edge band (705 nm), and B4 is the surface reflectance of the red band (665 nm). The red-edge band at 705 nm is particularly well-suited for Chl-a retrieval in inland waters because it directly captures the steep reflectance increase at the Chl-a red-edge, providing greater sensitivity to phytoplankton biomass (Gitelson, 1992; Mishra & Mishra, 2012). The reliability of NDCI as a proxy for Chl-a concentration at Tappan Lake was assessed through linear regression against in-situ measurements collected during the summer 2024 field campaign across eleven monitoring stations distributed across the lake.

Spatio-Temporal Chl-a Mapping

To evaluate interannual changes in algal bloom conditions across the lake surface, annual summer NDCI composite maps were produced for the years 2020-2025 using Sentinel-2 SR Harmonized imagery in GEE. The summer window, defined as June 1 through August 31, was selected to capture the stratified period in which cyanobacterial bloom formation is most evident in shallow inland reservoirs due to high water temperatures, limited vertical mixing, and favorable nutrient availability conditions. Image collections were filtered to match the area of Tappan Lake and

limited to scenes with a cloudy pixel percentage below 30%. This stricter cloud cover limit, compared to the 50% threshold used in the point-based extraction process, was set to ensure that spatial composite maps were derived from high-quality, low-cloud acquisitions. This approach reduced the chance of leftover cloud artifacts affecting the median composite product.

For spatial analysis, Sentinel-2 imagery was refined through targeted cloud masking, open-water isolation, and seasonal compositing. Cloud-contaminated pixels were excluded using the QA60 band, and open-water areas were delineated with NDWI to improve water extraction under the shallow and turbid conditions of Tappan Lake. For each year, all valid summer observations were then composed using a per-pixel median to reduce the influence of residual atmospheric noise and short-term variability in individual scenes.

EFDC+ Model Background

The EFDC+ model for Tappan Lake was originally developed and calibrated in detail by (Paneru, 2025) as part of a comprehensive investigation into temperature and dissolved oxygen stratification and eutrophication dynamics in the reservoir. The model domain was constructed based on an orthogonal curvilinear grid with 963 active cells of different sizes varying between 50 and 200 meters horizontally, together with 10 stretched sigma layers vertically that allow for resolving thermal and chemical conditions in the water body column. Bathymetric data were sourced from USGS, the U.S. Army Corps of Engineers, and the Ohio Department of Natural Resources (ODNR). Hydrodynamic forcings included daily tributary discharge from USGS gauging stations and the Soil and Water Assessment Tool (SWAT) model outputs, alongside meteorological inputs such as wind speed and direction, relative humidity, air temperature, and

precipitation obtained from nearby monitoring stations and National Oceanic and Atmospheric Administration (NOAA) archives.

In the current study, the previously developed EFDC+ model was used to determine the characteristics of sediment resuspension and the spatial distribution of TSS within Tappan Lake. The model-generated TSS was verified using field-collected TSS data from 2022, which were not used in the original model development by (Paneru, 2025). Modeled TSS outputs were extracted at the corresponding spatial locations and compared against field observations. Model performance was evaluated using the coefficient of determination to quantify the agreement between simulated and observed TSS concentrations. The spatial distribution of modeled TSS across the lake was then analyzed to characterize zones of active sediment resuspension and deposition, providing a process-level understanding of internal sediment dynamics that complements the ADCP backscatter observations.

Results and Discussion

Trophic Classification and Chl-a Distribution

Sentinel-2 derived NDCI demonstrated a statistically significant positive correlation with measured Chl-a concentrations ($R^2=0.67$), supporting its application for spatio-temporal mapping of algal dynamics across the lake surface (Fig 2.2). This level of retrieval performance is consistent with values reported in prior satellite-based Chl-a studies conducted in optically complex small inland reservoirs, where mixed spectral signals, suspended sediments, and other optically active constituents can reduce retrieval accuracy compared to clearer and more homogeneous water bodies (Llodrà-Llabrés et al., 2026).

Application of the calibrated NDCI trophic classification of Tappan Lake during 2020-2025 (Figure 3) showed continued high levels of nutrients with NDCI values in the range of 0.008 to 0.316 in the lake as indicated by green pixels nearly throughout all years for the length of our observations, and elevated concentrations of Chl-a (8 - 25 $\mu\text{g/L}$) indicating the presence of excess phytoplankton (bloom) throughout the lake. No significant portion of the lake was ever in mesotrophic or oligotrophic condition. Phytoplankton bloom intensity showed moderate interannual variability, with the lake exhibiting moderate eutrophic conditions in 2020 and 2021, and peak hyper-eutrophic conditions in 2023, with Chl-a exceeding 25 $\mu\text{g/L}$. Although bloom intensity declined slightly in 2024 and 2025, eutrophic conditions persisted across the entire lake surface.

ADCP Velocity Profile and Spatial Distribution

The velocity data revealed a clear spatial differentiation between the deeper stations near the dam and the shallower stations toward the inlet (Table 2). Station 1 from the main impounded basin towards the dam recorded the lowest station-averaged speeds of 0.0412 m/s, consistent with the quiescent hydrodynamic conditions characteristic of deep reservoir basins, where flow energy is minimal, and the water column is largely sheltered from surface wind forcing (Morris & Fan, 1998a; Thornton et al., 1991a). Moving towards the transitional mid-lake zone, Stations 3 and 6 recorded depth-averaged speeds of 0.106 and 0.115 m/s, respectively, notably higher than the deep basin stations, reflecting the shallower bathymetry and greater wind-driven circulation energy in the mid-lake region (Zhang & Chen, 2023). Station 4, located immediately downstream of a hydraulic constriction, recorded the highest depth-averaged speed of 0.231 m/s, more than five times that of the deep basin stations. The elevated velocity at this station reflects the accelerated flow conditions characteristic of structural flow control rather than wind-driven circulation or

bathymetric channelization. Stations 7, 8, 9, and 10, located in the eastern arm of Tappan Lake, recorded low depth-averaged speeds ranging from 0.050 to 0.066 m/s. These stations are relatively shallow yet show slower flow compared to other shallow stations, likely because the eastern arm is narrow and oriented in a way that limits the distance over which wind can act on the water surface. As a result, wind-driven water movement in this part of the lake is weaker, producing calmer and slower flow conditions throughout the water column.

Acoustic Backscatter and Near-bed Sediment Dynamics

RBI Profiles computed from 1 MHz ADCP ensemble data (Table 3) showed that while surface and mid-column backscatter values were relatively consistent across stations, near-bed RBI values varied substantially, from 29.8 dB at Station 1 to 49.5 dB at Station 3, indicating that near-bed suspended particle dynamics differed markedly across the lake. The near-bed RBI enhancement index identified six stations (Station 2, 3, 5, 7, and 9) with near-bed suspended particle enrichment above the +2 dB threshold, with the strongest enhancement concentrated in the mid-lake transition zone at Stations 3 (+16.20 dB) and 6 (+13.34 dB). These enhancements indicate substantially elevated suspended particle concentrations in the near-bed zone relative to the overlying water column at both stations. Elevated near-bed suspended particle concentrations relative to the overlying water column are consistent with sediment resuspension driven by hydrodynamic bottom forcing, as wind-induced disturbance of the lakebed preferentially elevates sediment concentration in the near-bed zone before vertical mixing disperses particles upward through the water column (Jalil et al., 2019; Qin et al., 2004). This pattern is well documented in shallow eutrophic lakes where wind-driven turbulence periodically mobilizes fine bed sediment, particularly in zones of intermediate water depth where wind stress can reach the bed, yet sufficient depth exists for a near-bed concentration gradient to develop above the settled sediment layer

(Hamilton & Mitchell, 1996; Jalil et al., 2019). Stations 8 and 10 showed weak or negligible enhancement, suggesting no consistent near-bed particle enhancement at these eastern arm stations.

EFDC+ Model Verification

(Paneru, 2025) successfully calibrated and validated the model for water temperature ($R^2 = 0.905$, $NSE=0.853$) and dissolved oxygen ($R^2=0.512$, $NSE=0.457$), and subsequently extended the model to simulate nutrient cycling, algal dynamics, and sediment transport processes relevant to eutrophication. The performance of the EFDC+ sediment transport model results was assessed based on the comparison of simulated and measured depth-averaged total suspended solids (TSS) concentrations at eight locations throughout Tappan Lake obtained from August 2022 measurements. The correlation analysis showed $R^2=0.43$, signifying a weak but positive relationship between the spatial distribution of simulated and measured TSS concentrations. This result was anticipated since the EFDC+ model utilized in this study had been designed for hydrodynamic, temperature, and dissolved oxygen processes by Paneru (2025). Despite these quantitative limitations, the model correctly reproduces the directional spatial gradient in TSS, with the lowest concentrations in the deep western basin and the highest values toward the eastern tributary inlets, which is consistent with field observations.

Spatial TSS Distribution

The simulation of the longitudinal gradient of suspended sediments on the TSS map based on the data collected on August 17, 2022 (Fig. 2 .9) generated by the EFDC+ model shows that TSS was higher in the eastern arm of the lake (~ 18 mg/L) and decreased gradually to approach almost zero concentrations in the deeper main body close to the dam of the reservoir (Table 6). This behavior

is typical for the classic trap efficiency of a reservoir, where the flows bringing sediment particles into the reservoir have their transport efficiency reduced due to the gradual decrease in the speed of flowing waters with water depth and fetch, resulting in the deposition of suspended particles along the longitudinal profile of the reservoir (Brune, 1953; Morris & Fan, 1998b). The eastern arms, characterized by shallower depths, sustain sediment in suspension, while the broader lacustrine area towards the west, closer to the dam, acts as a depositional sink. This longitudinal sediment distribution is consistent with the field-measured TSS values, which were highest at the eastern station 7 (14.5 mg/l) and station 8 (14.0 mg/L) and lowest at the western stations 1(7 mg/l) and station 2 (6.0 mg/L), supporting the model's representation of the dominant sediment transport pathway in Tappan Lake.

Sediment Dynamics and Algal Bloom Distribution

The three independent lines of evidence presented in this study, satellite-derived Chl-a distribution, ADCP velocity and acoustic backscatter measurements, and EFDC+ sediment transport modeling, collectively provided a coherent picture of the physical and biogeochemical processes that cause the blooms in Tappan Lake.

The EFDC+ model established the overarching sediment transport framework for Tappan Lake, simulating peak TSS concentration near the Clear Fork tributary and follows the similar pattern of high TSS concentration near the other three tributary inflows, including Beaverdam Run, Eddington Run, and Willis Run (Figure 11). The TSS Concentrations decline progressively westward toward the Stillwater Creek outflow as flow velocity diminished and particle settling dominated. This longitudinal depositional gradient is consistent with classical reservoir trap

efficiency behavior (Brune, 1953; Morris & Fan, 1998b) provided the spatial foundation upon which the ADCP and remote sensing findings are interpreted.

Taken together, the three methods converge on a consistent spatial narrative that reveals the coupled physical and biogeochemical mechanisms sustaining algal bloom conditions in Tappan Lake. ADCP measurements revealed elevated flow velocities and substantial near-bed RBI enhancement at stations 3, 5, 6, and 7, identifying these locations as active sediment resuspension hotspots within the central zone of Tappan Lake (Table 2 & 4). This central corridor, comparatively narrow relative to the wide main basin near the dam, channels tributary-driven flow through a reduced cross-section, generating near-bed shear stress sufficient to periodically mobilize bottom sediments back into the water column. In contrast, the broad western basin near the Stillwater Creek outflow functions as the primary depositional sink, where reduced flow velocities and greater water depth promote particle settling and maintain a comparatively clear water column. Similar longitudinal patterns of sediment resuspension in transitional mid-lake zones and progressive deposition toward dam outlets have been documented in comparable reservoirs, where similar morphology and tributary-driven hydraulic energy create persistent resuspension corridors that contrast sharply with the calmer depositional conditions of the main basin (Keith & Stratton, 2019; Morris & Fan, 2005; Thornton et al., 1991b). The 2022 NDCI-derived Chl-a map reveals lake-wide elevated phytoplankton biomass, a spatial pattern that reflects the downstream transport of nutrients released from resuspending sediments in the mid-zone, fueling algal growth under the stable thermal stratification and low-oxygen hypolimnetic conditions documented for Tappan Lake by Paneru (2025).

Conclusion

This study used a combined approach of satellite remote sensing, field-based ADCP measurements, and EFDC+ hydrodynamic modeling to evaluate the role of sediment resuspension and internal nutrient loading in sustaining recurring algal blooms in Tappan Lake, Ohio. NDCI-derived Chl-a from Sentinel-2 imagery showed a strong relationship with measured Chl-a concentrations, confirming its useful application for lake-wide algal bloom monitoring. Analysis of annual summer composites from 2020 to 2025 revealed persistent eutrophic conditions throughout the lake, with elevated phytoplankton biomass observed in every year of the study period. Although Chl-a was consistently increasing and was covering the entire lake, no substantial portions of the reservoir consistently exhibited mesotrophic or oligotrophic conditions. This indicates that eutrophication has become a chronic characteristic of the lake rather than a series of isolated bloom events. This indicated surface signs of eutrophication and prompted a deeper investigation. Subsequent ADCP deployment across ten transects provided depth-resolved velocity profiles and RBI-based acoustic backscatter analysis, identifying the mid-lake zone as an active sediment resuspension area where near-bed RBI enhancement co-occurred with elevated flow velocities, indicating periodic mobilization of bottom sediments due to hydrodynamic forcing. This subsurface evidence was spatially corroborated by EFDC+ simulated TSS maps, which independently confirmed the mid-to-eastern zone as the primary resuspension source, with progressive sediment settling toward the near western outlet area.

The evidence from all three methods points to internal sediment resuspension in the mid-zone as the main factor maintaining nutrient availability in the lake, where bloom intensities are high. The persistent summer eutrophic conditions observed, combined with sediment resuspension and transport, suggest that legacy nutrients stored within bottom sediments continue to be recycled into

the water column and play an important role in sustaining algal growth. Consequently, reductions in external nutrient input alone may not be sufficient to achieve meaningful improvements in water quality. It suggests that blooms may continue even if nutrient inputs from tributaries are reduced (Smith et al., 1999; C. Sun et al., 2022). This physical-biogeochemical mechanism, where internal sediment resuspension keeps nutrients available regardless of external loading, presents a major management challenge for Tappan Lake, and future management efforts should therefore consider both watershed-based nutrient controls and strategies aimed at mitigating internal nutrient recycling. Overall, this study demonstrates the value of integrating remote sensing, acoustic monitoring, and numerical modeling to identify the mechanism driving eutrophication in inland reservoirs and provides a strong framework that can be applied to similar data-limited systems.

541 Table 1. Satellite image vs field sampling date, Tappan Lake (2024)

Field Date	Satellite Image Date	Date Gap (days)
April 23, 2024	April 20, 2024	3
May 21, 2024	May 20, 2024	1
June 28, 2024	June 24, 2024	4
July 18, 2024	July 19, 2024	-1
August 30, 2024	August 28, 2024	2
October 4, 2024	October 2, 2024	2

542 Table 2. Velocity data acquired through ADCP profiling at each measurement station

Station	Transect	No. Ensembles	Depth-Avg Speed (m/s)	Station Representative Speed (m/s)	Valid Depth Bins
1	L	1305	0.0412	0.0412	75
1	R	993	0.0645		51
2	L	873	0.0769		54
2	R	915	0.0669	0.0669	54
3	L	433	0.1056	0.1056	72
3	R	317	0.1418		32
4	L	176	0.2314	0.2314	40
5	L	424	0.1662	0.1662	28
6	L	737	0.1151	0.1151	37
6	R	781	0.0585		36

Station	Transect	No. Ensembles	Depth-Avg Speed (m/s)	Station Representative Speed (m/s)	Valid Depth Bins
7	L	333	0.0482		39
7	R	390	0.0503	0.0503	82
8	L	564	0.0660	0.0660	51
8	R	330	0.0354		47
9	L	504	0.0656		29
9	R	560	0.0581	0.0581	78
10	L	310	0.0609	0.0609	40
10	R	261	0.0771		27

543 *Note: Station 4 and 5 have only left transect data.*

544

545 Table 3. RBI calculated using 1 MHz SNR data acquired through ADCP profiling

Station	Transect	No. Ensembles	Mean Water Depth (m)	Sidelobe Cutoff (m)	Depth Bins	Mean RBI (dB)	Max RBI (dB)
Site 1	L	1305	7.41	6.97	72	26.77	33.31
Site 1	R	993	8.06	7.58	71	30.91	41.92
Site 2	L	873	6.26	5.88	55	33.36	47.75
Site 2	R	915	6.61	6.21	48	32.37	39.39
Site 3	L	433	4.24	3.99	29	35.06	56.58
Site 3	R	317	4.91	4.62	21	35.35	60.42
Site 4	L	176	3.23	3.04	49	34.22	45.91

Station	Transect	No. Ensembles	Mean Water Depth (m)	Sidelobe Cutoff (m)	Depth Bins	Mean RBI (dB)	Max RBI (dB)
Site 5	L	424	4.01	3.77	39	33.86	46.2
Site 6	L	737	5.02	4.72	36	30.17	53
Site 6	R	781	5.03	4.73	44	38.47	49.35
Site 7	L	333	4.01	3.77	46	35.58	48.54
Site 7	R	390	4.18	3.93	65	28.98	31.26
Site 8	L	564	3.95	3.71	60	30.74	42.23
Site 8	R	330	3.99	3.75	53	28.98	32.81
Site 9	L	504	3.95	3.71	42	37.94	45.45
Site 9	R	560	4.06	3.82	63	31.73	46.58
Site 10	L	310	2.89	2.72	35	31.92	35.47
Site 10	R	261	2.85	2.68	32	37.73	41.7

Note: Sidelobe cutoff = 94% of mean water depth, depth bins = number of valid measurement cells retained after filtering, and mean RBI and max RBI computed from 1 MHz ensembles only.

Table 4. Station-averaged RBI zonal analysis and near-bed enhancement from ADCP data

Station	Surface RBI (dB)	Mid-column RBI (dB)	Near-bed RBI (dB)	Enhancement (dB)
Site 1	25.16	30.54	29.82	-0.72
Site 2	30.58	31.29	39.98	+8.69
Site 3	28.63	33.25	49.45	+16.2
Site 4	31.32	38.2	32.51	-5.69
Site 5	28.28	34.02	40.65	+6.63
Site 6	32.19	31.08	44.42	+13.34
Site 7	31.14	31.67	35.78	+4.11
Site 8	31.04	29.21	30.41	+1.2
Site 9	34.38	32.9	39.9	+7
Site 10	37.7	33.71	33.71	0

Note: Station averages of left and right bank transect, enhancement = near-bed RBI – mid-column RBI, zones: surface = top 20%, mid-column = 30-70%, near-bed = bottom 20% of valid profile.

Table 5. Calibrating parameters to activate the sediment transport module to simulate TSS values in Tappan

Parameter	Range for Tappan Lake	Value Recommended
Cohesive Sediment Parameters		
IC WC Concentration (mg/L)	10 – 100	20 mg/L
IC Bed Mass (g/m ² per layer)	5,000 – 20,000	15,000 g/m ²
Specific Gravity	2.60 – 2.70	2.65

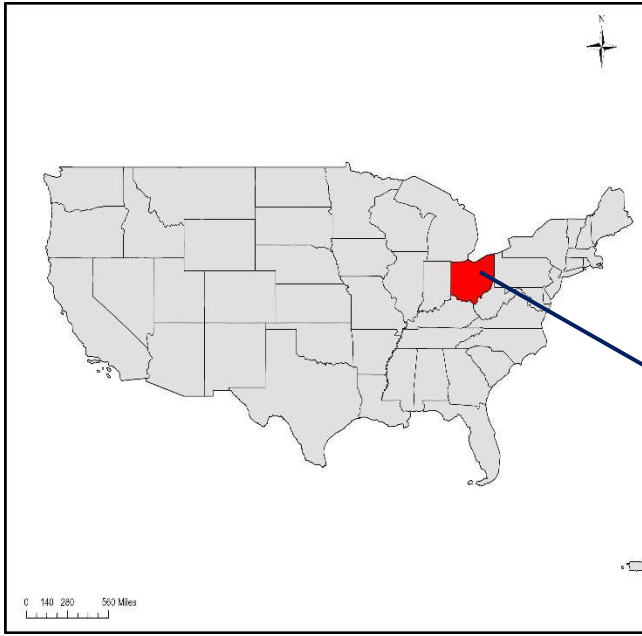
Settling Velocity (m/s)	0.0001 – 0.0005 or -1	-1
Tau Critical-Deposition (N/m ²)	0.05 – 0.10	0.08 N/m ²
Tau Critical-Erosion (N/m ²)	0.1 – 0.3	0.20 N/m ²
Reference Surface Erosion Rate (g/m ² /s)	1e-5 – 1e-3	0.0005 (5e-4) g/m ² /s
Erosion Exponent	1 – 2	1
Use Fluid Mud	Unchecked	Unchecked
Equilibrium Concentration Formula	Smith & McLean, van Rijn, etc.	Smith & McLean
Non-Cohesive Sediment Parameters		
Median Diameter (μ)	125 – 300	200 μ
Settling Velocity (m/s)	0.01 – 0.02 or -1	-1
Specific Gravity	2.65	2.65
Critical Shear Stress (N/m ²)	0.15 – 0.25 or -1	-1
Critical Shields Stress	0.02 – 0.06	0.03
IC WC Concentration (mg/L)	0 – 50	15 mg/L
IC Bed Mass (g/m ² per layer)	10,000 – 50,000	10,000 g/m ²
Bed Properties (Applied to all sediment layers)		
Max. Layer Thickness (m)	0.02 – 0.10	0.1 m
Deposition/Constant Porosity	0.40 – 0.60	0.6
Void Ratio of Depositing Cohesive	1.5 – 3.0	2

Minimum Void Ratio 0.3 – 0.6 0.43

Table 6. Qualitative assessment of EFDC+ model simulated, and field observed total suspended solids (TSS) at eight locations for instantaneous measurement during August 17, 22 and 29, 2022

Date	Day of Simulation	Observed TSS (mg/L)	Qualitative Comparison	Simulated TSS (mg/L)
8/17/2022	2580.42	7		0.1028
8/17/2022	2580.47	6	Low	0.026
8/17/2022	2580.53	9.5		0.6357
8/22/2022	2585.44	8.5		1.2452
8/22/2022	2585.51	9	Medium	4.825
8/22/2022	2585.48	7.5		2.0951
8/29/2022	2592.48	14.5		2.675
8/29/2022	2592.51	14	High	18.2430

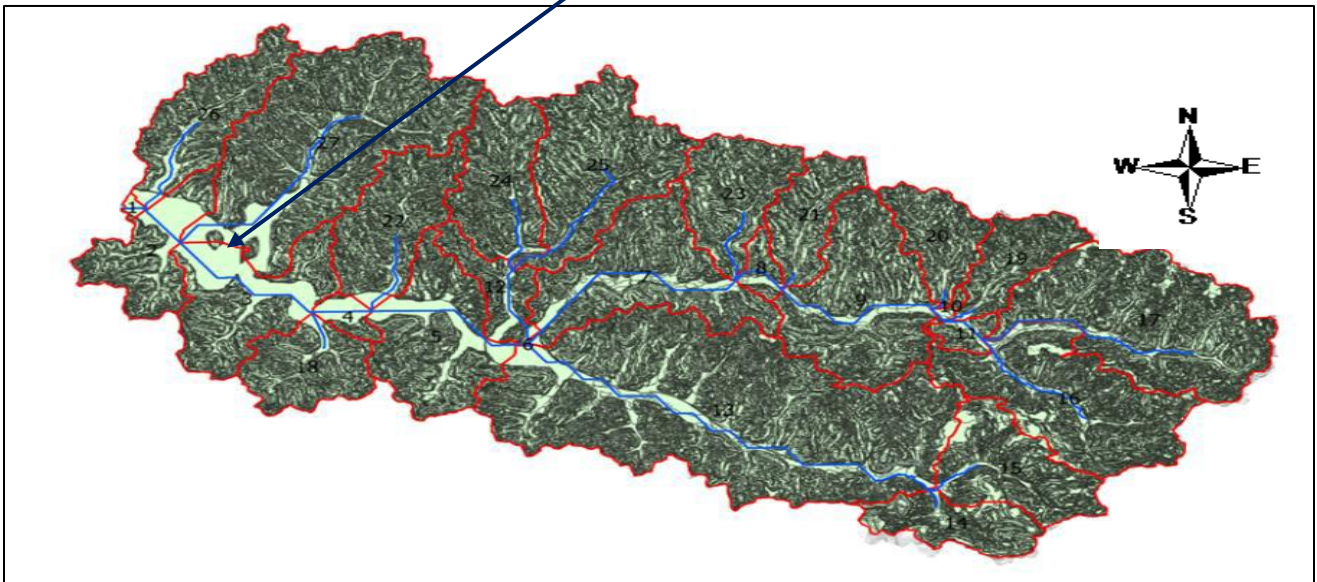
Note: TSS categories were defined based on the distinct hydrodynamic regimes observed across Tappan Lake's functional zones: Low (< 8 mg/L) corresponds to the deep, low-velocity western lacustrine basin near the dam; Medium (8 – 12 mg/L) represents the transitional mid-lake corridor; and High (> 12 mg/L) reflects shallow tributary inflows subject to active sediment resuspension and high bed shear stress.



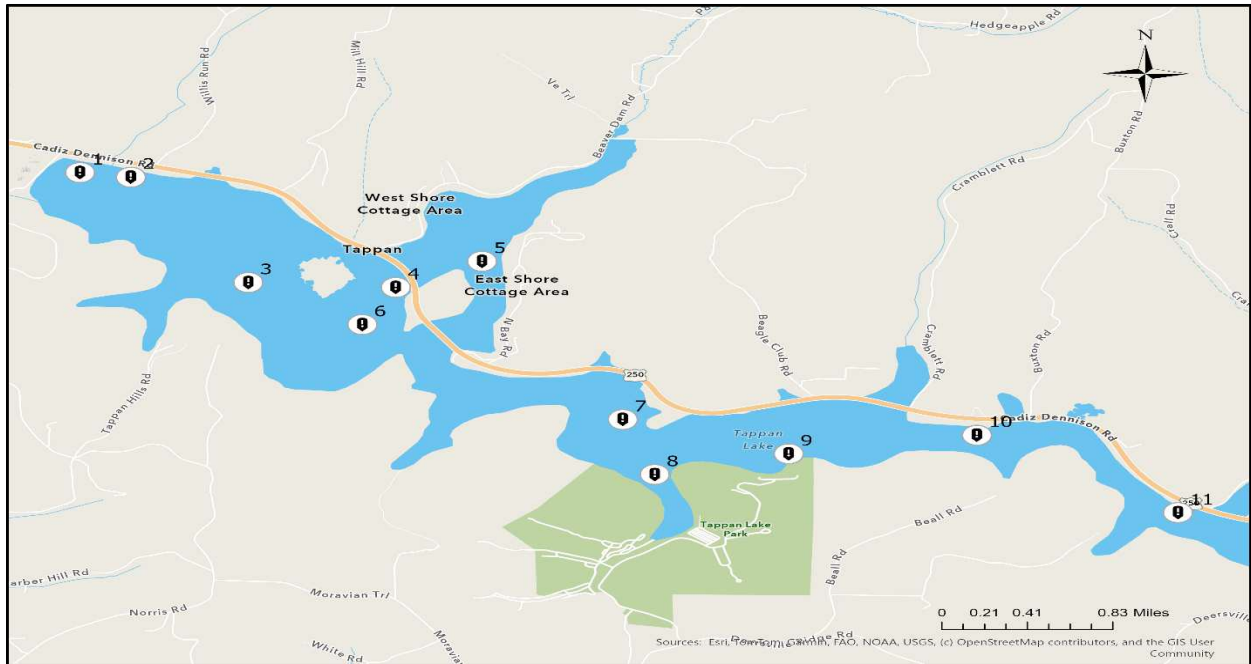
(a)



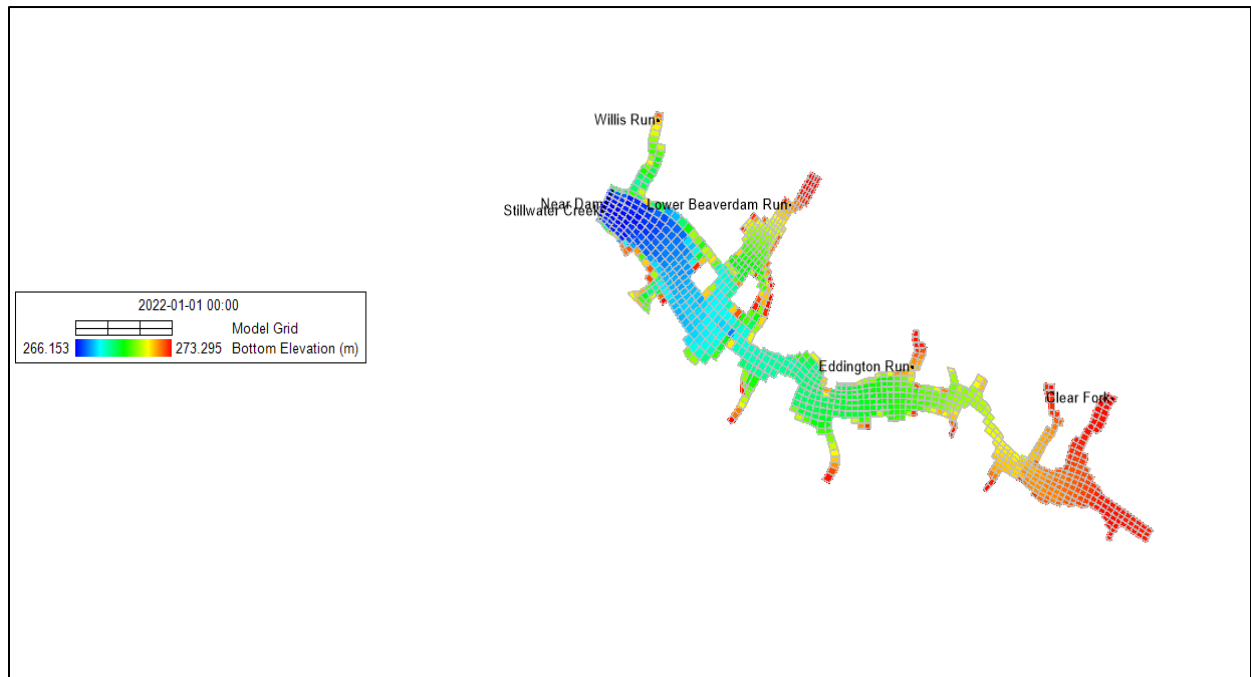
(b)



(c)



(d)



(e)

Figure 1. Location of the study area, progressively detailed: (a) Ohio within the United States; (b) Harrison County within Ohio; (c) the Tappan Lake watershed; (d) monitoring station locations at Tappan Lake; and (e) tributary inflows to Tappan Lake.

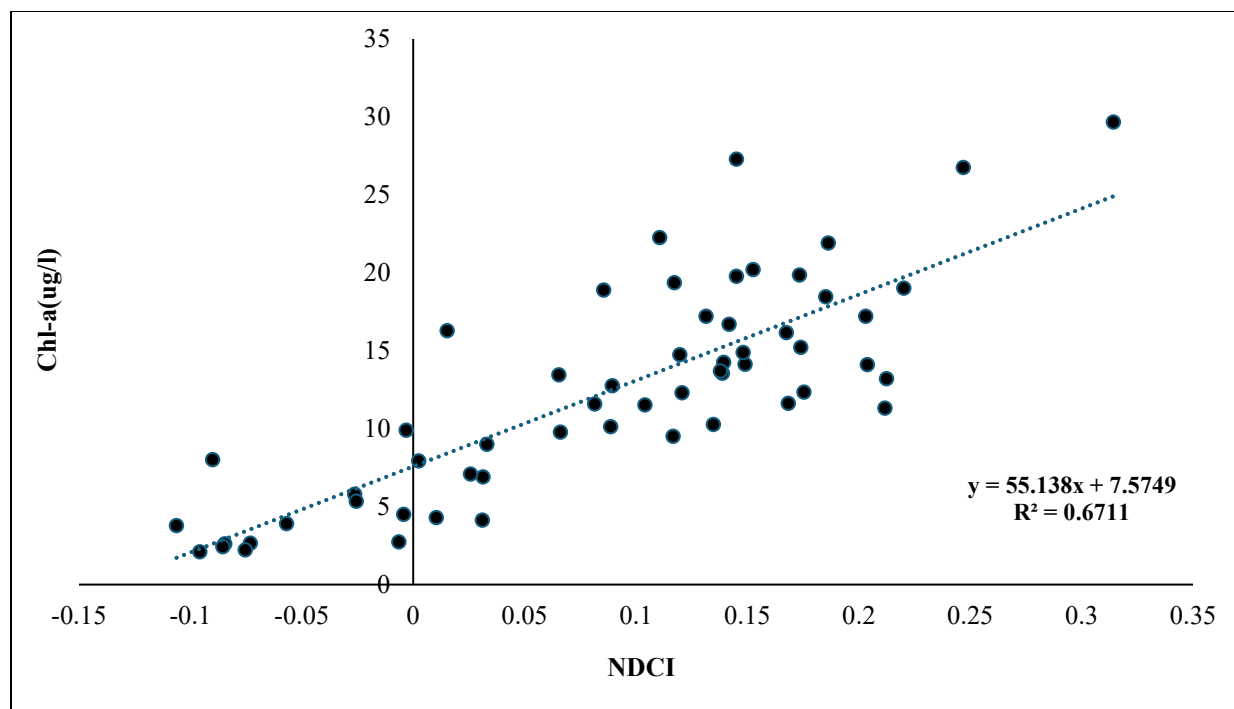
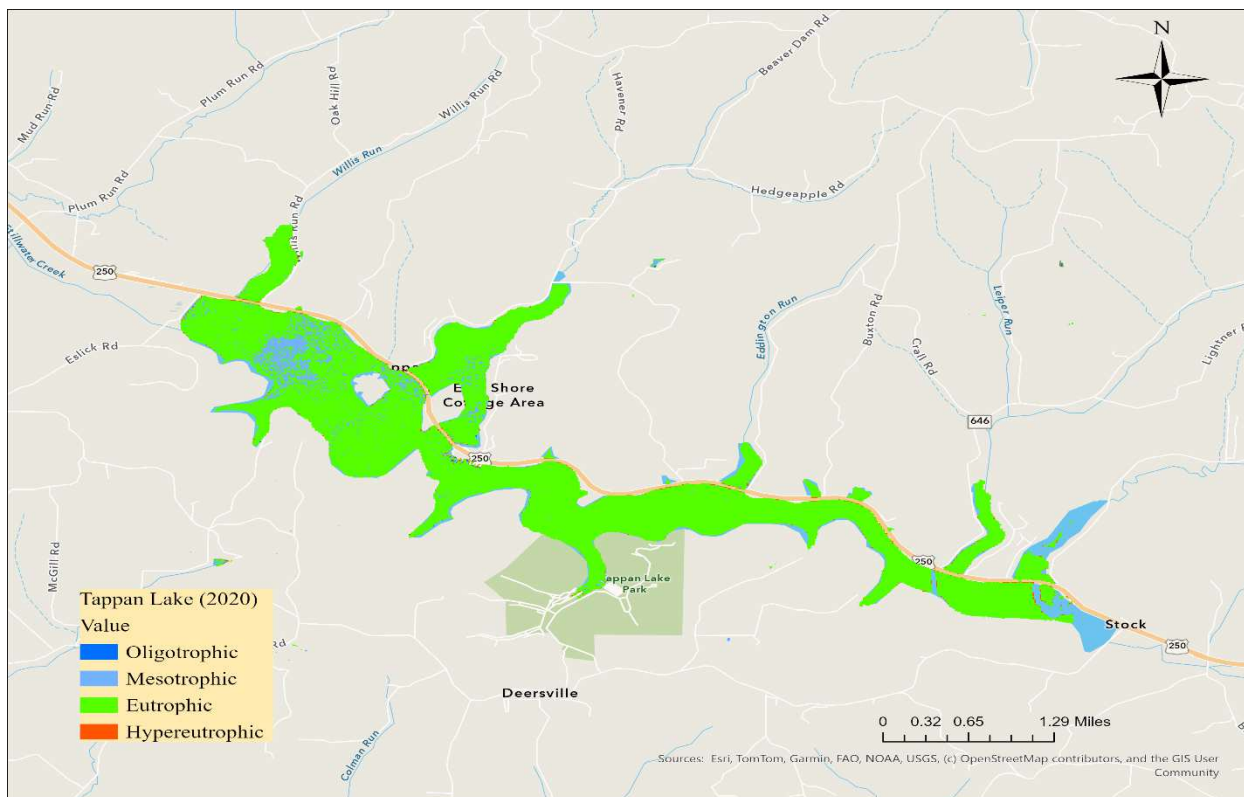
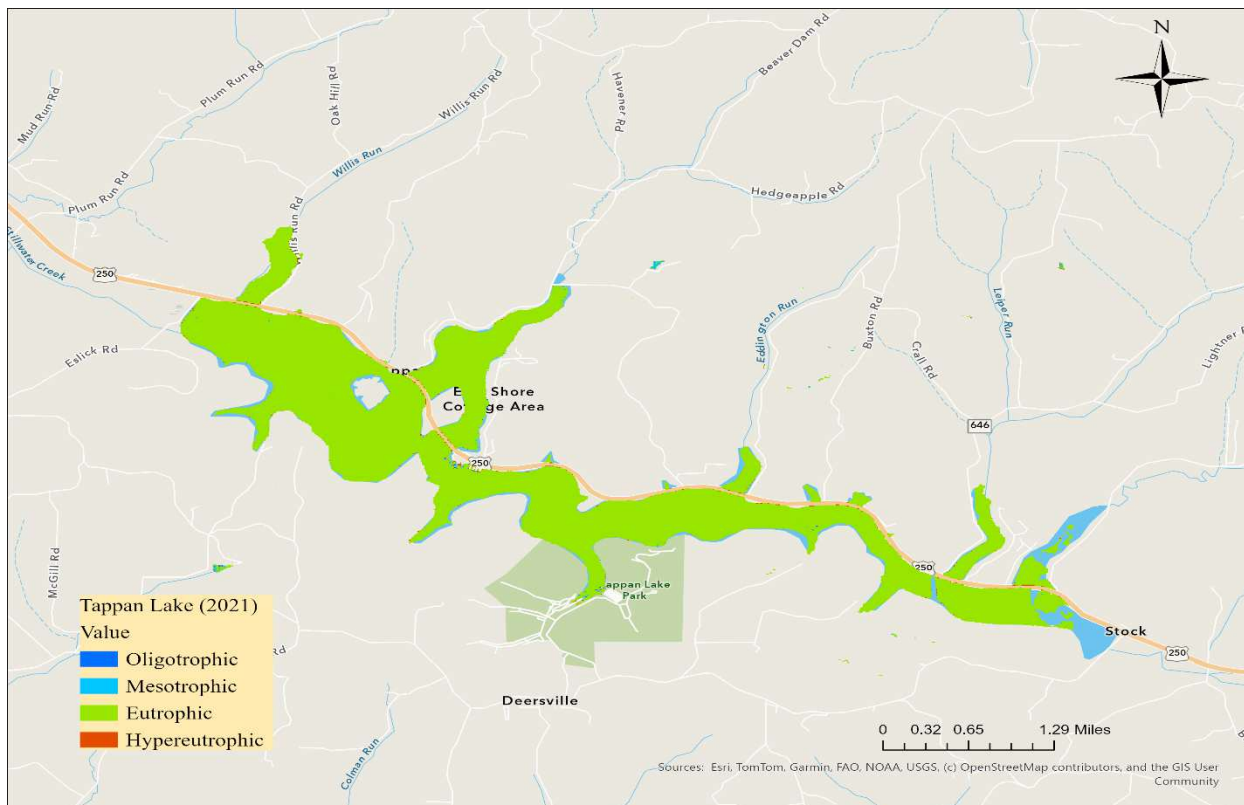


Figure 2. Linear regression relationship between Chl-a vs NDCI



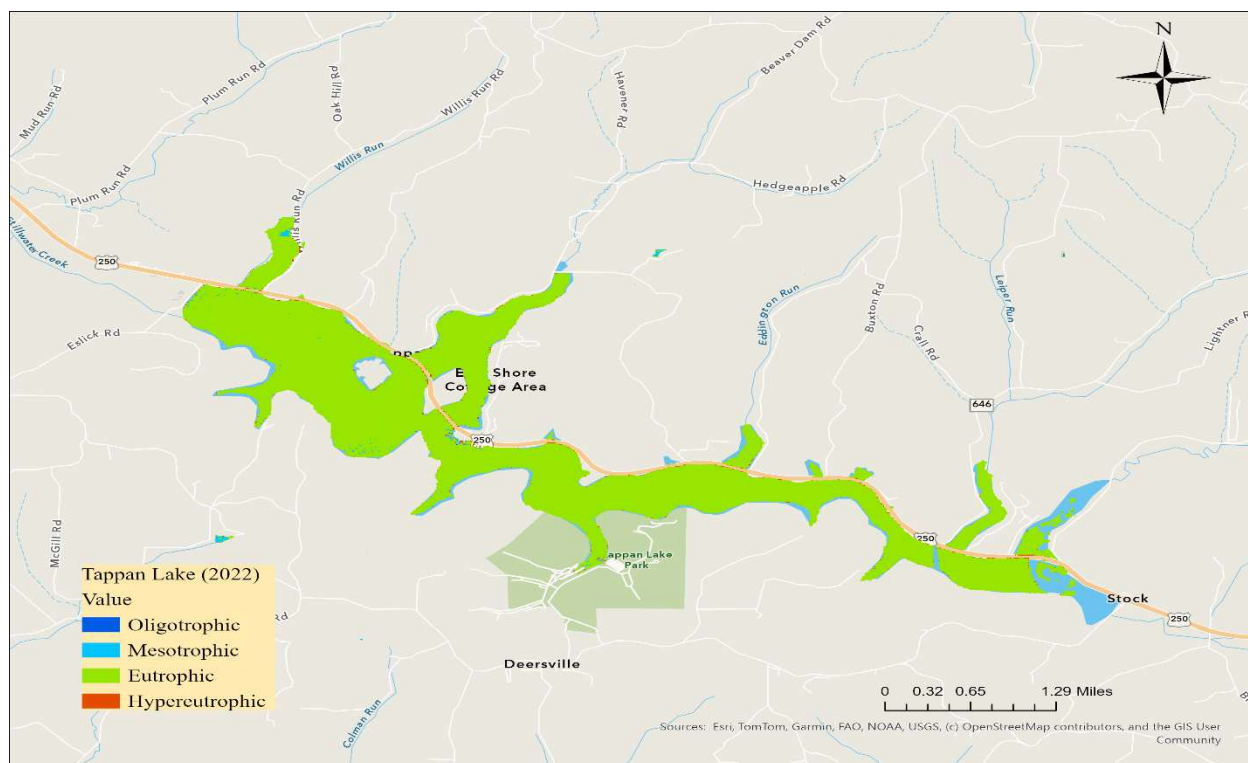
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(a) NDCI trophic classification of Tappan Lake, summer 2020

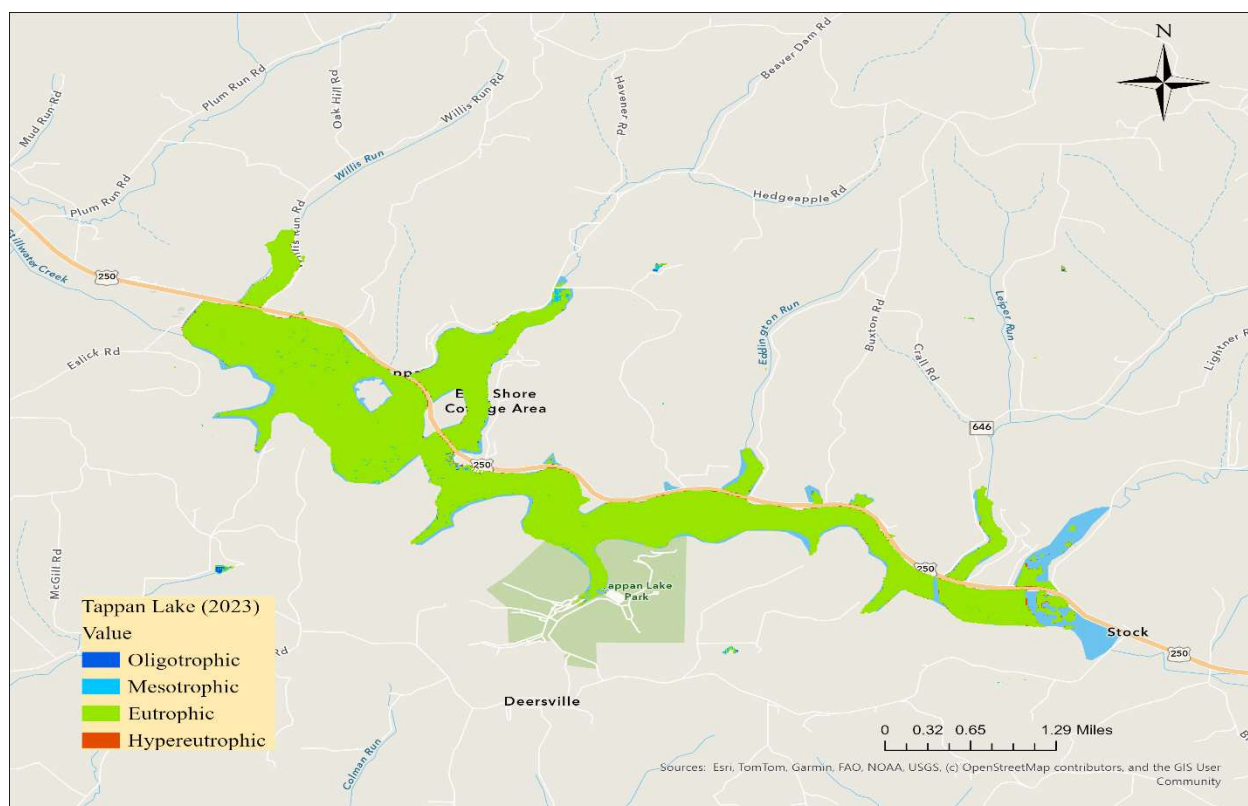


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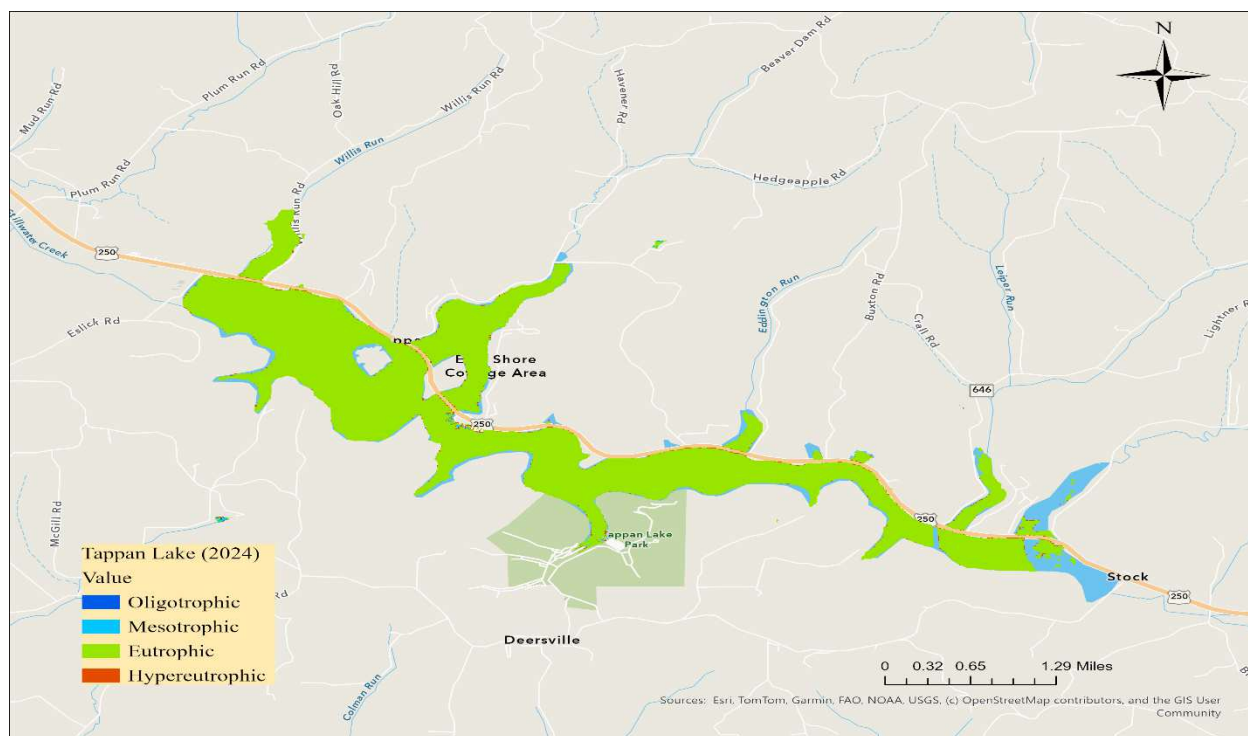
(b) NDCI trophic classification of Tappan Lake, summer 2021



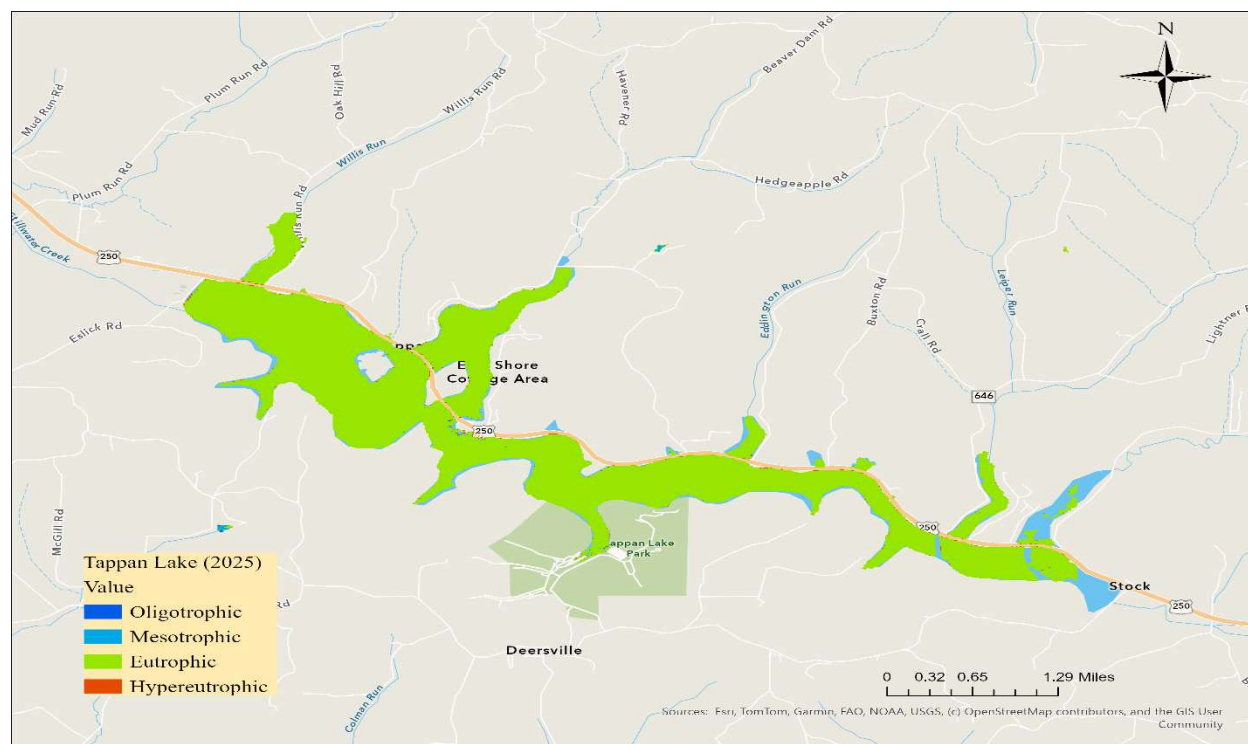
612 (c) NDCI trophic classification of Tappan Lake, summer 2022



613 (d) NDCI trophic classification of Tappan Lake, summer 2023



614 (e) NDCI trophic classification of Tappan Lake, summer 2024



615 (f) NDCI trophic classification of Tappan Lake, summer 2025

616 Figure 3. (a)-(f) Spatio-temporal distribution of NDCI-derived trophic status at Tappan Lake,
617 Ohio (2020–2025)

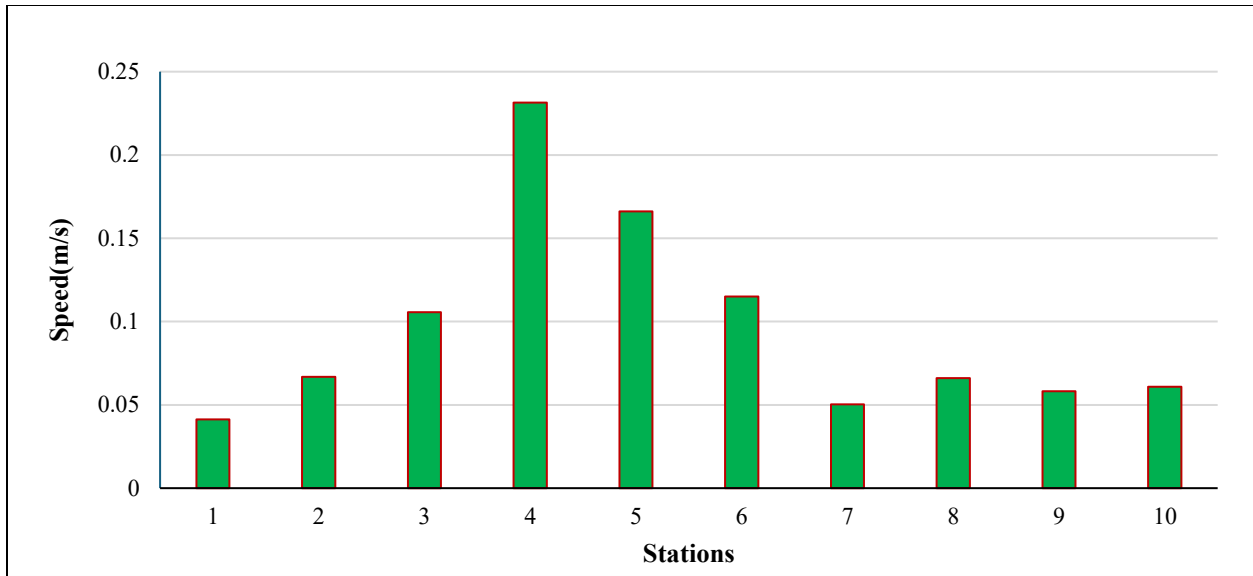


Figure 4. Mean flow velocity at each monitoring station at Tappan Lake, obtained by averaging ADCP-measured velocity data, illustrating spatial variation in average current strength across the monitoring network.

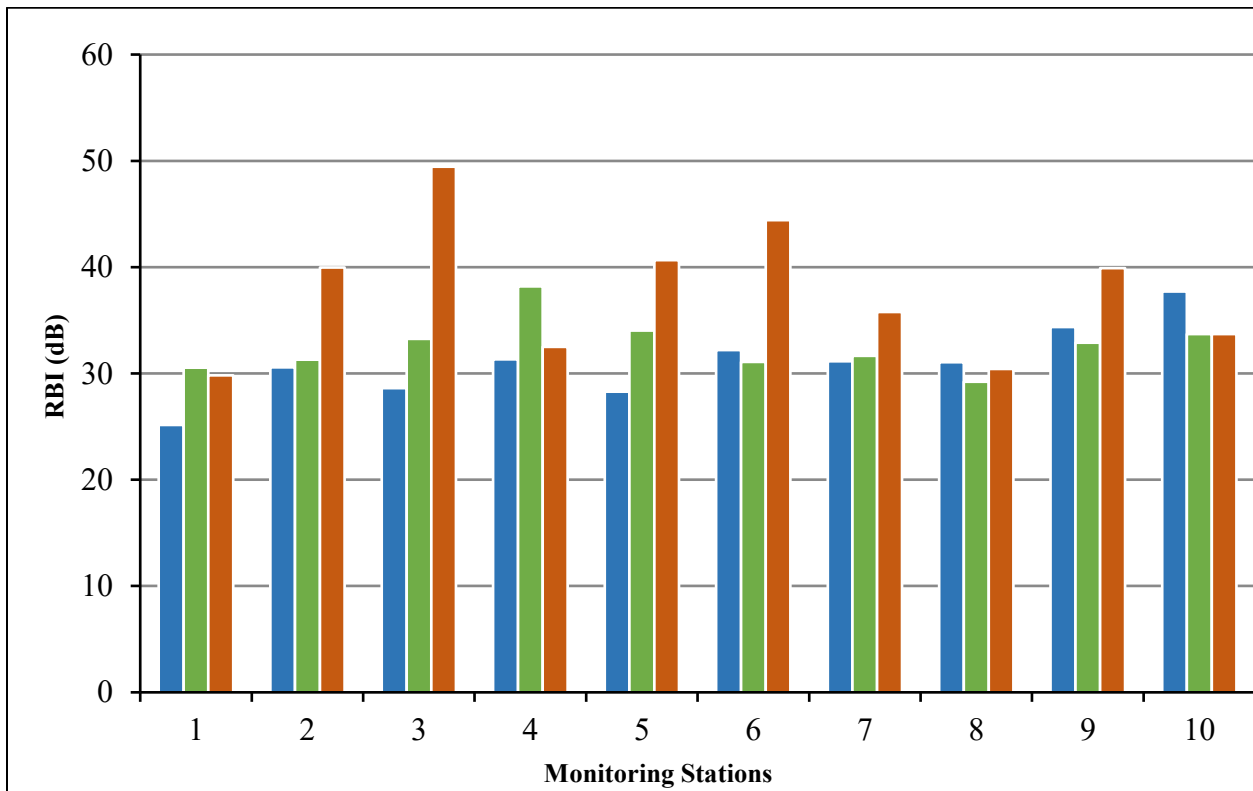


Figure 5. Station-wise comparison of surface, mid-column, and near-bed RBI (dB) across the monitoring network at Tappan Lake, illustrating the vertical backscatter structure and near-bed enhancement at each station

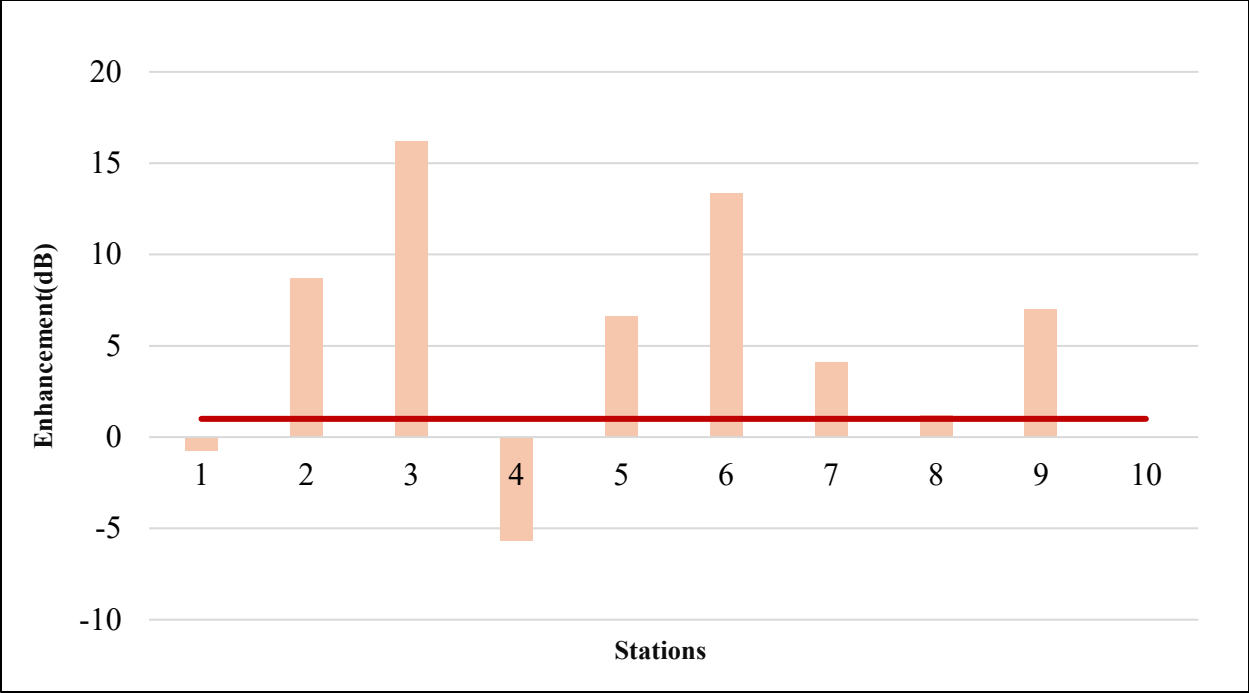
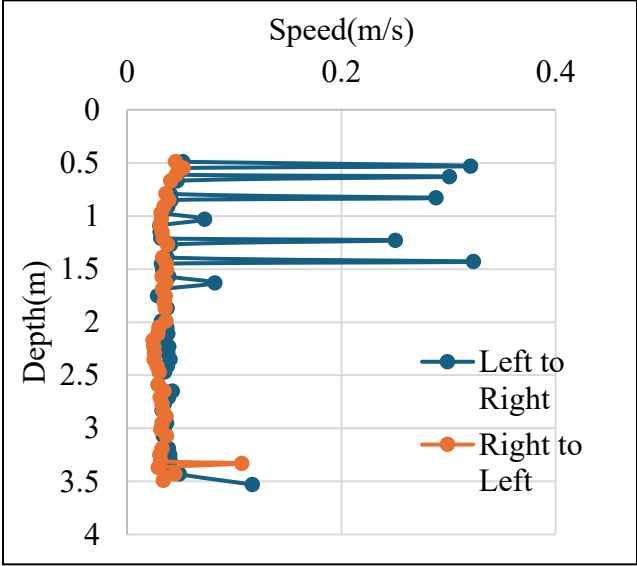
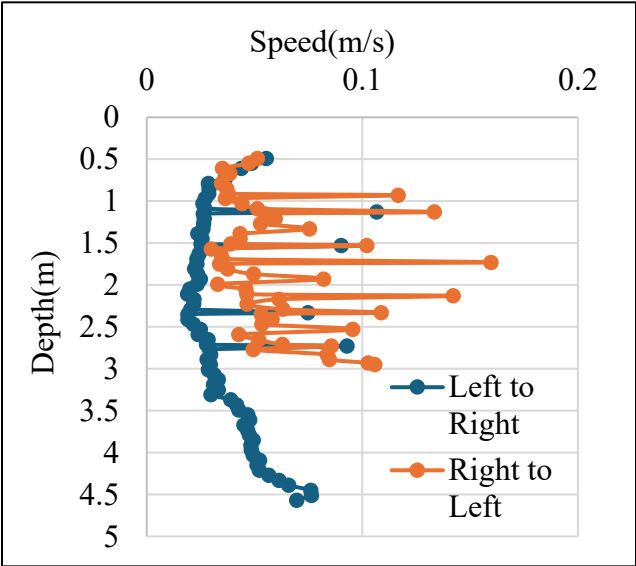
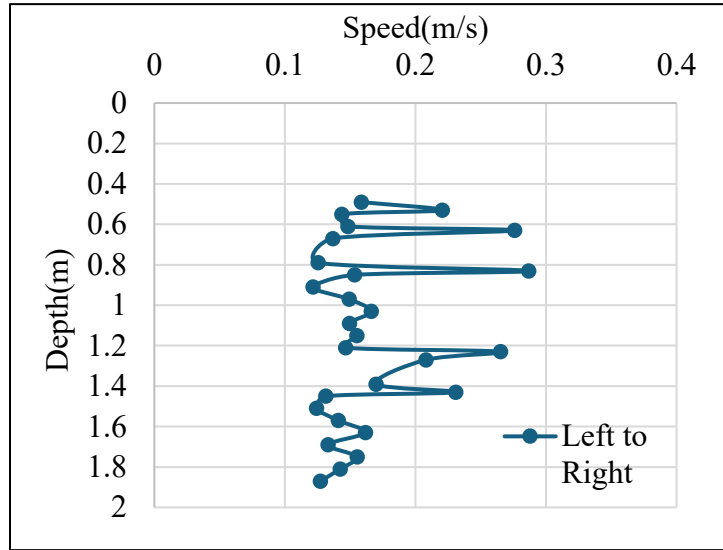


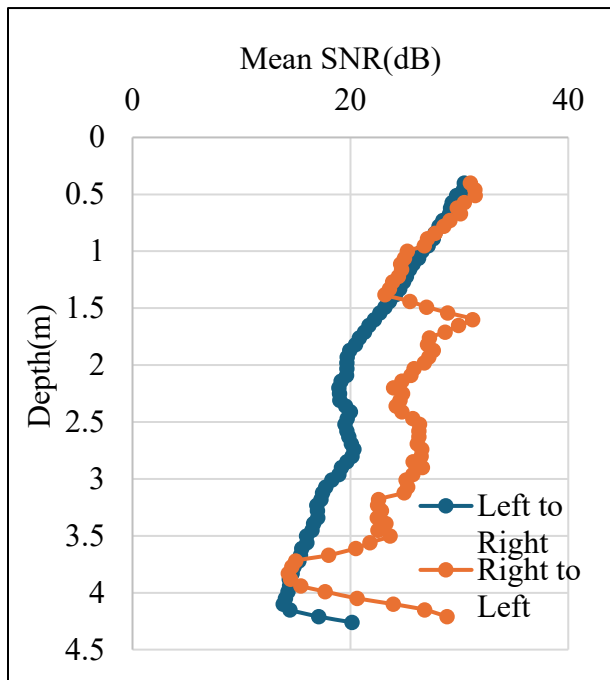
Figure 6. Variation of near-bed RBI enhancement across the monitoring stations at Tappan Lake, calculated as the difference between near-bed and mid-column RBI (dB)



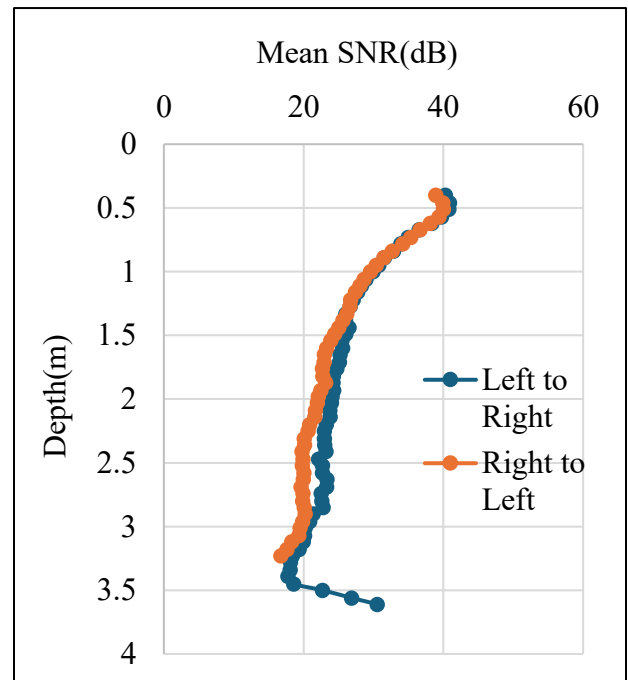


(c)

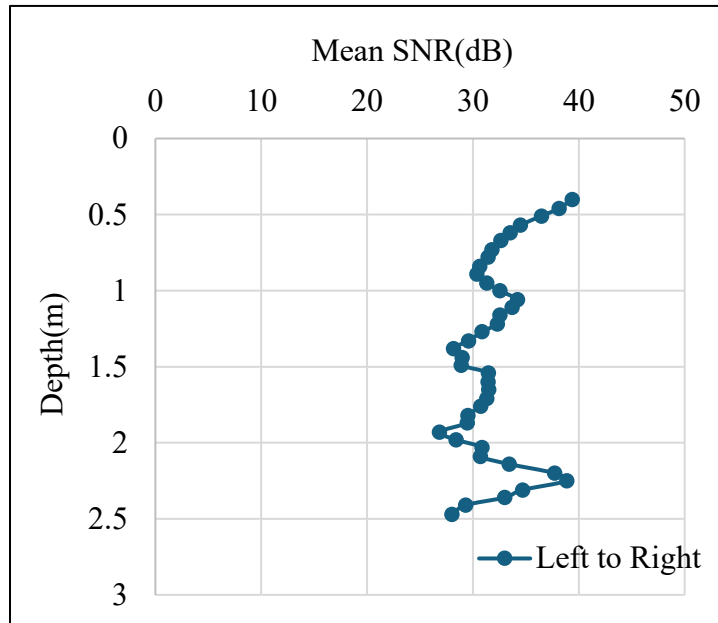
Figure 7. Depth-averaged velocity profile from available transect near outlet(a), inlet(b), and mid-lake(c) zone



(a)

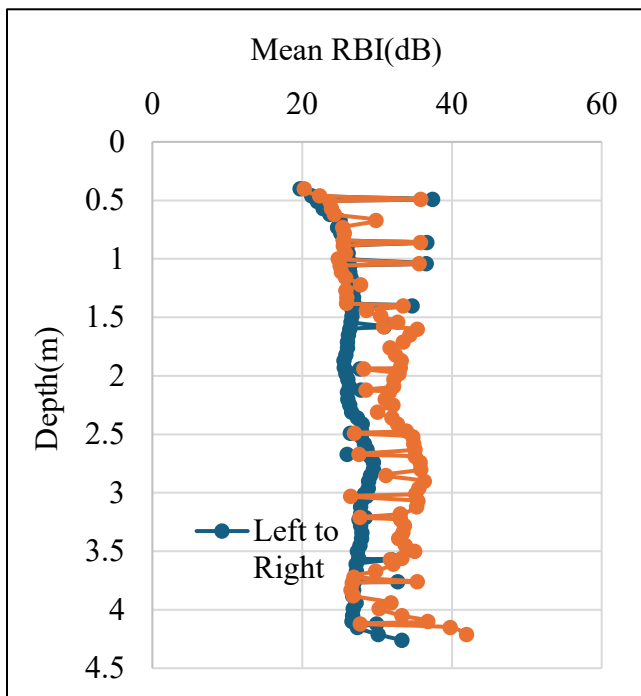


(b)

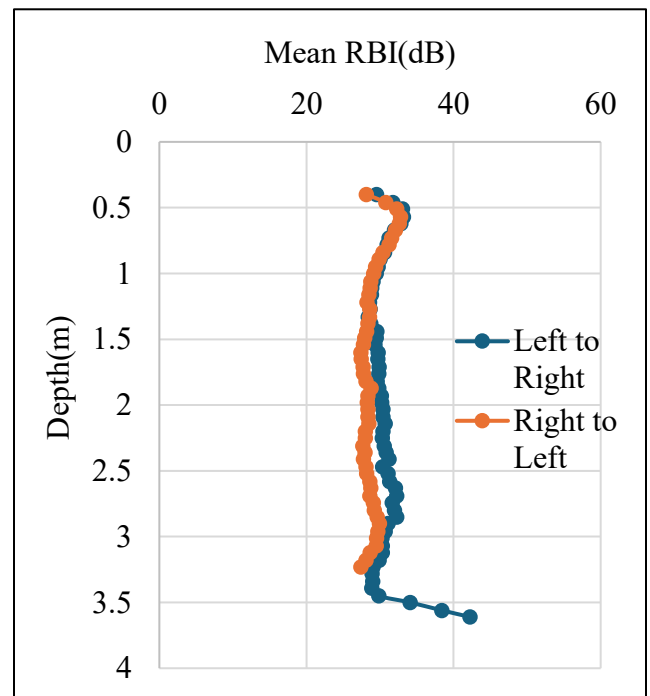


(c)

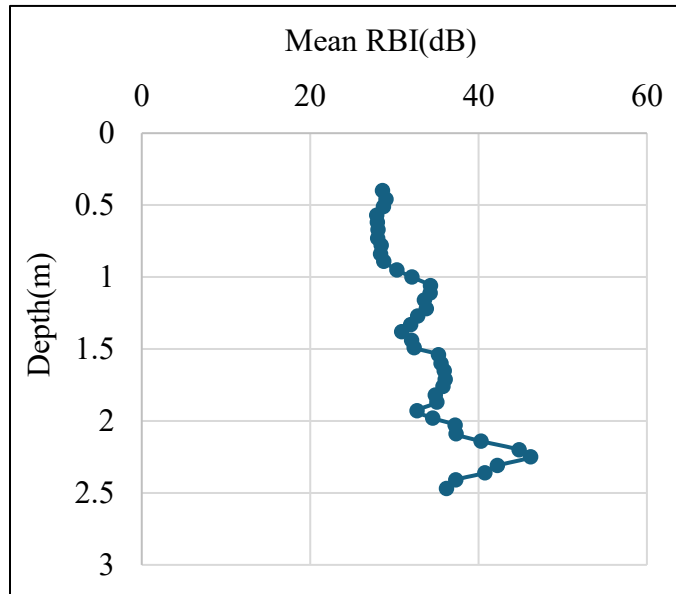
Figure 8. Depth-averaged SNR profile from available transect near outlet (a), inlet(b), and mid-lake(c) zone



(a)



(b)



(c)

Figure 9. Depth-averaged RBI profile from available transect near outlet (a), inlet(b), and mid-lake(c) zone

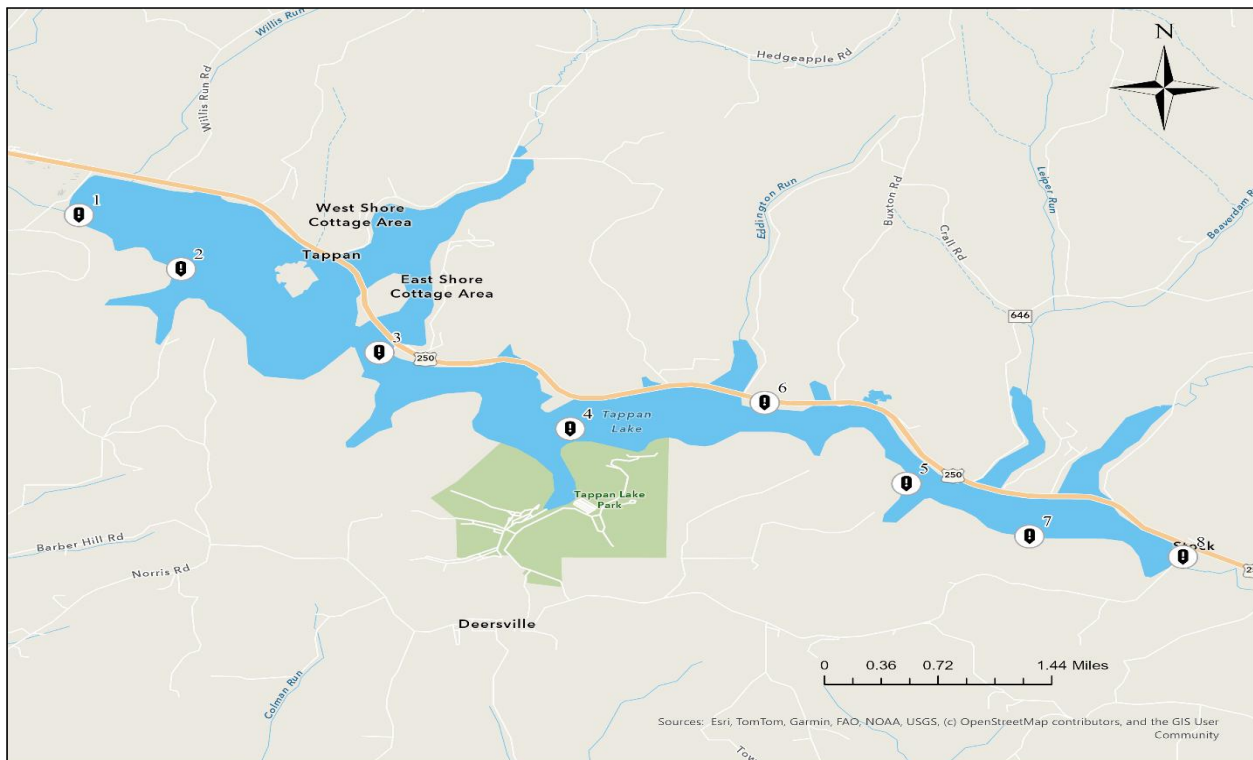


Figure 10. Spatial distribution of the eight monitoring locations at Tappan Lake selected for comparison of EFDC-simulated versus field-observed total suspended solids (TSS) concentrations

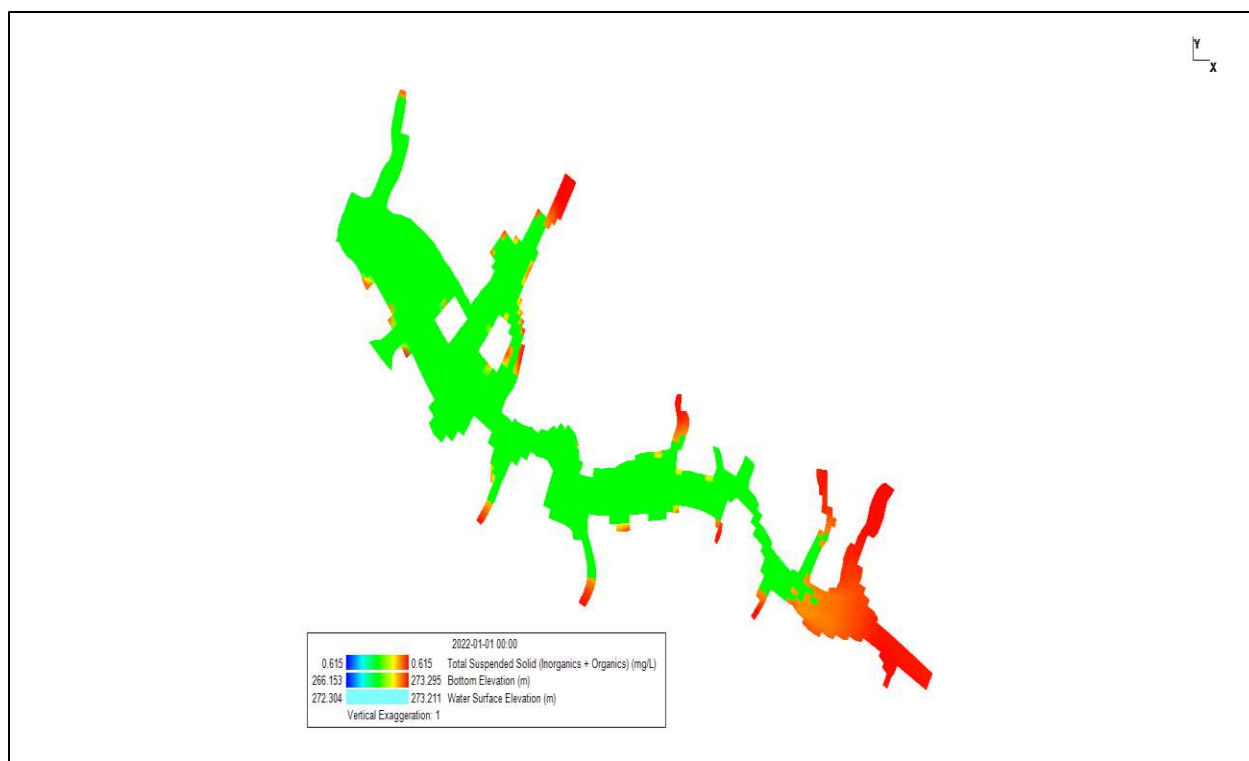


Figure 11. EFDC+ model-simulated spatial distribution of total suspended solids (TSS, mg/L) across Tappan Lake for 2022, illustrating the variation in suspended sediment concentrations throughout the lake domain

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