OARS Dissolved Oxygen Monitoring
Talbot Mills Impoundment—2023

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OARS has been monitoring Dissolved Oxygen (DO) conditions in the Concord River in the impoundment created by the Talbot Mills Dam in Billerica. We anticipate that this dam will be removed in 2025/2026 and we are studying how the dissolved oxygen conditions in this section of the river will change with the removal—how conditions will differ between the current impounded state and the future free flowing state. In the summers of 2022 and 2023, we deployed a dissolved oxygen and temperature logger in the river 1.2 miles upstream from the dam (1/4 mile downstream from the Route 129 bridge, and 2/3 mile upstream from the Fordway Bar at Pollard Street). See the map of the deployment location in the appendix. The logger was deployed for five months in 2022 and four months in 2023, logging data every 15 minutes. A review of the 2022 data was published in August 2023[1]. This is a review of the full two-year data set considering new learnings from the data gathered in 2023. We are primarily interested in seeing how dissolved oxygen changes after dam removal, but to do that we need to first understand the baseline dynamics.

It was lucky that we continued the monitoring for two years because the two years demonstrated very different DO dynamics. The summer of 2022 was very dry with almost the second lowest amount of rainfall in more than 20 years. River flows were very low for most of the season, and the primary driver of DO in this location was in-stream photosynthesis from plant life. In contrast, the summer of 2023 was very wet with the highest amount of rainfall in more than 20 years. River flows were at flood level for most of the summer, and the primary driver of DO was flow. Photosynthesis was generally insignificant as a driver of DO in 2023. The extreme difference in dynamics between the two years is important to understand but it will make it hard to compare conditions before and after dam removal.

We would like to extend a special thank you to the Billerica Highway Department for allowing us to install and access the logger on their property.

Daily DO Cycle

Dissolved Oxygen in calm water bodies normally cycles diurnally. It is highly affected by photosynthesis, which is driven by sunlight. During summer months, DO concentrations generally reach the lowest point between 6 AM and 9 AM and peak between 5 PM and 7 PM. The following graph (Figure 1) shows 2022 mid-July DO and temperature cycles from the logger. It shows a typical DO cycle range of about 3 mg/L. This was the dominant dynamic in 2022 with the exception of a couple rain and flow pulses which resulted in short-term drops in the DO concentration lasting for a few days.

Dissolved oxygen dynamics in 2023 were completely different. River flow at the downstream USGS gauge exceeded 500 cfs (cubic feet per second) for the whole season and was above 1000 cfs for most of July, August, and September. In comparison, river flow in 2022 never exceeded 300 cfs. The high flow in 2023 almost completely washed out any effects of photosynthesis and significantly lowered DO concentrations. The second set of graphs below (Figure 2) show an hourly comparison between typical dynamics in 2022 and 2023. In the 2022 example there is a clear diurnal pattern with low DO between 06:00 and 09:00 and high DO between 17:00 and 19:00 while in 2023 there is no diurnal pattern. The graphs also show typical DO concentrations of 6–10 mg/L in 2022 and much lower concentrations of 2–4 mg/L in 2023. The 2023 example is color coded based on flow showing a clear decline in DO as flows declined.

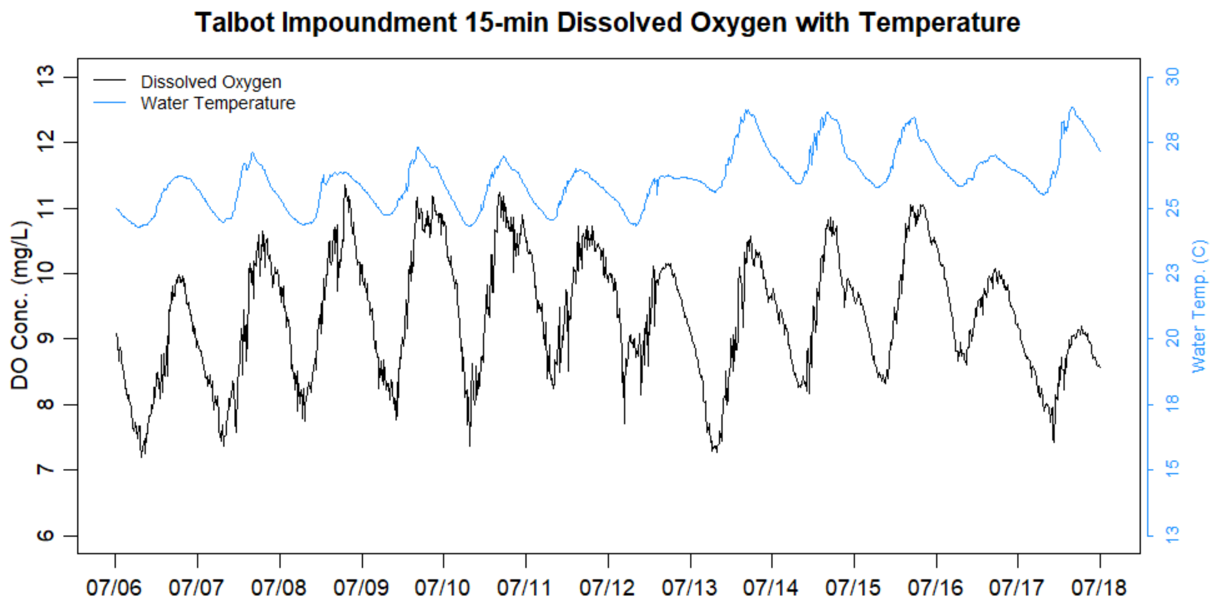


Figure 1: DO and temperature 15-min logger data from July 2022 showing typical calm water diurnal cycling.

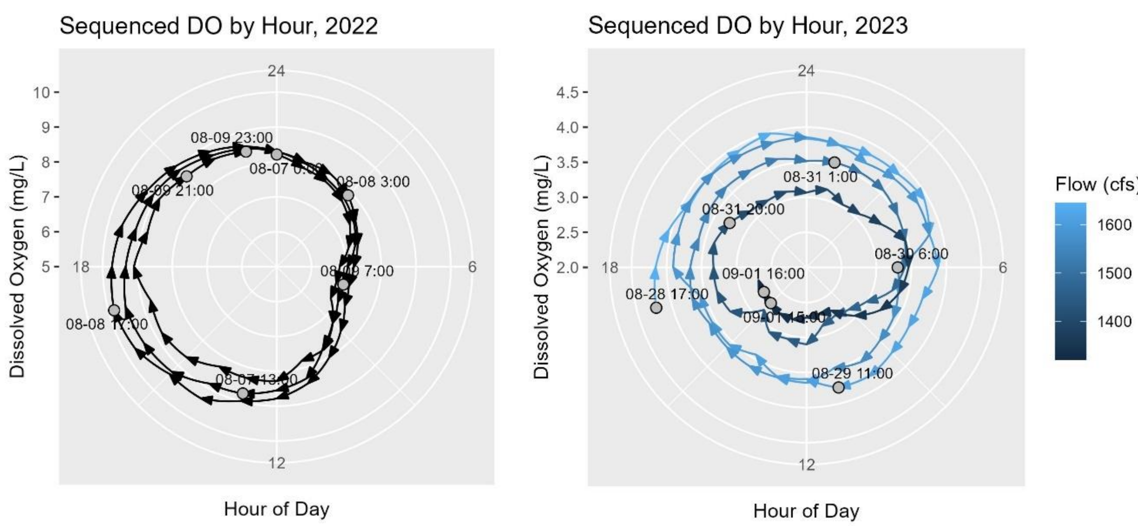


Figure 2: DO logger data graphed radially by hour. Hour is represented in a 24-hour dial and DO is graphed as distance outward from the center. Left graph: typical diurnal cycling in 2022. Right graph: typical dynamics in 2023 with very little daily pattern and DO driven by flow.

Long Term DO Drivers

In addition to daily oxygen cycling from photosynthesis, two other measurable conditions that can affect dissolved oxygen are temperature and river flow. Temperature controls the ability of water to hold oxygen. Cold water can hold more oxygen than warm water. River flow drives water circulation which could move oxygenated water spatially or could deliver oxygenation through turbulence. In 2023, river flow was the primary driver of dissolved oxygen concentrations in the study location. As mentioned above, and as demonstrated in the first graph below (Figure 3), flow dynamics and corresponding DO concentrations were completely different in 2022 and 2023. In 2023, flows were approaching flood conditions for most of the summer and DO concentrations were extremely low. The Mass DEP Class B water quality criterion[2] is 5 mg/L. In 2022 DO concentrations never fell below this criterion and we identified supersaturation (saturation > 150% of equilibrium conditions) as a concern in our 2022 analysis, but in 2023 DO concentrations were below 5 mg/L for almost all of the summer. Our hypothesis is that high water levels in 2023 overtopped the river banks and decomposition of organic matter from the flood plains consumed all available dissolved oxygen. This dynamic completely outweighed the effects of photosynthesis and temperature on 2023 DO concentrations.

The time-series graph below of daily dissolved oxygen compared with flow and temperature (Figure 4) shows striking alignment of changes in flow to changes in dissolved oxygen. Major flow increases in the beginning of July drove DO concentrations well below 5 mg/L and continuous extreme flows kept DO low until mid-September. The dominant pattern that can be seen (which we also noticed to a lesser extent in the 2022 data) is that high flow pulses cause an initial jump in DO concentrations but as soon as flow stabilizes DO plummets and continues to fall as the flow subsides. This can be visualized in the two example graphs below comparing sequenced DO with flow (Figure 5). High stable flows correspond with dramatic reductions in DO. Increases in flow bring fresh oxygenated water, but as soon as flow stabilizes and starts to fall the oxygen is quickly consumed by decomposing matter washed into the river from the floodplains.

With such widely varying conditions, it is hard to establish a pre-dam removal baseline that can be compared to conditions after dam removal. However, it may be possible to consider the general trend in the relationship between DO and flow as shown by the trendline in Figure 3. This trendline is not a good predictor of the high variability of individual DO and flow measurements (residual standard error = 1.6 mg/L), but it could be expected that large data sets collected with a logger during the same seasonal time window would be centered around this trendline as long as the dam and conditions in the impoundment are unchanged. After the dam is removed, a trendline with a lower slope and higher average would indicate improved overall conditions in the impoundment—reduction in supersaturation events during low flows and increased DO concentrations during high flows. Given the experience of 2022 and 2023, after dam removal it will be important to again collect data over multiple years to measure different annual flow regimes.

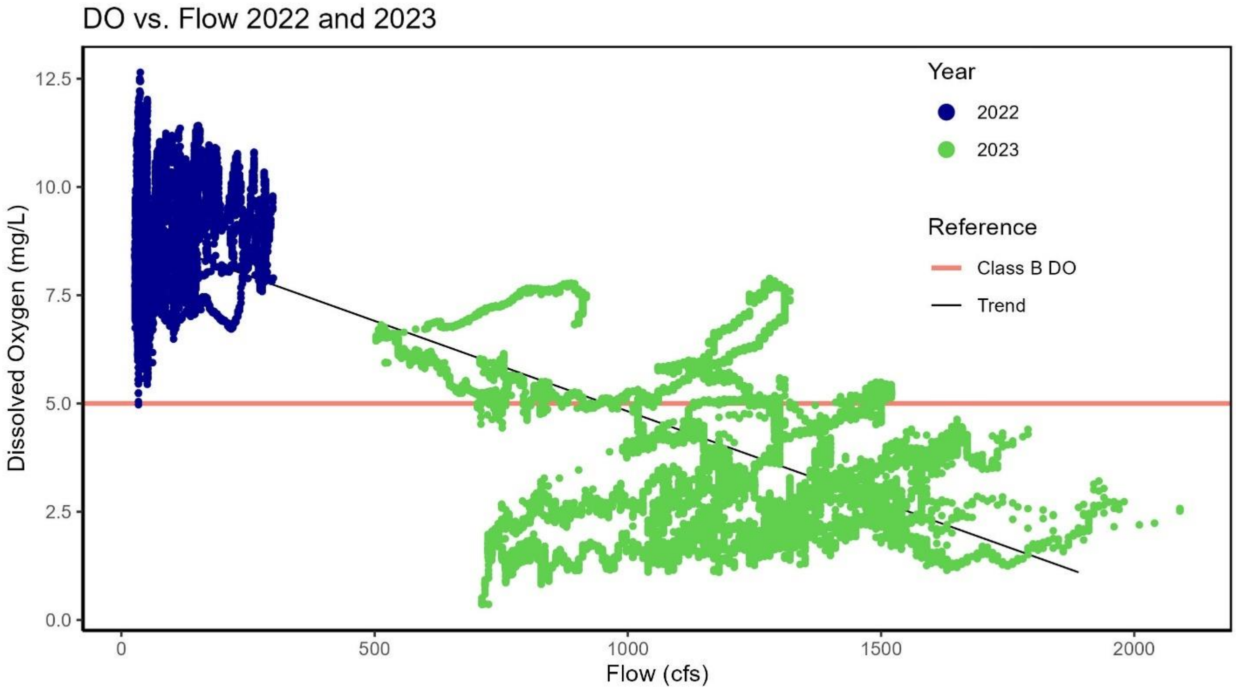


Figure 3: DO vs. Flow in 2022 and 2023. The trendline depicted is for visualization purposes only and does not reflect the very high variability in the DO vs flow relationship (Residual Standard Error=1.6 mg/L, R^2=0.69).

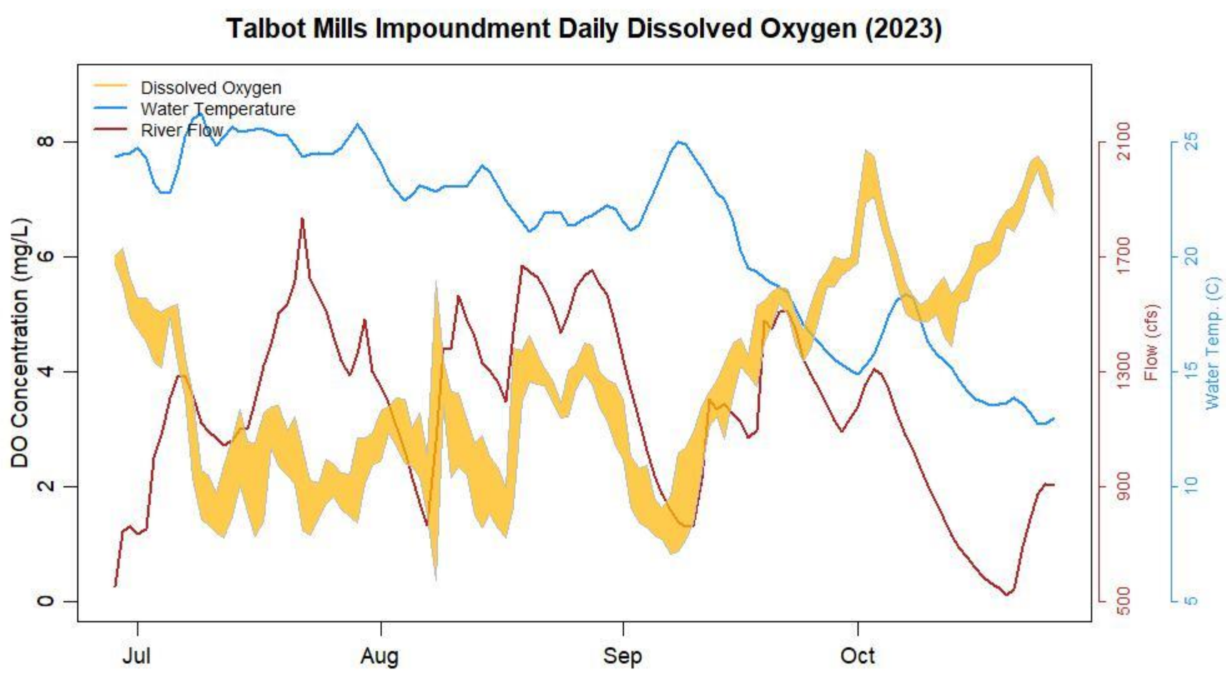
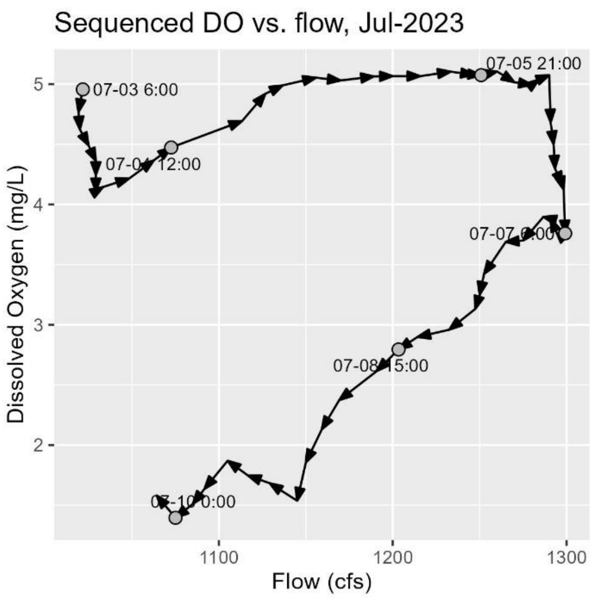


Figure 4: Daily DO min/max concentration (in yellow) graphed with daily mean water temperature and river flow.



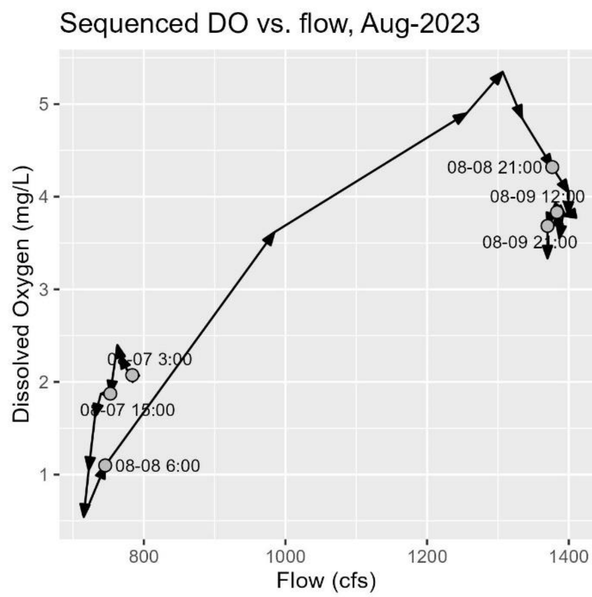


Figure 5: Relative changes in dissolved oxygen and flow. DO increases with increasing flow but quickly drops when flows stabilize and decline. The two graphs show two different selected time periods spanning new flow pulses and subsidence.

Logger Cleaning Schedule and Data Quality

The dissolved oxygen logger is highly affected by bio-fouling, which is a term for the constant growth of algae or scum that accumulates on objects that are left in the water. Therefore, it is necessary to adjust the data after retrieval to correct for sensor drift that occurs as a result of bio-fouling. Thanks to volunteers Len Rappoli and Amanda Brandt, we tried to clean the logger every two weeks to reduce fouling. The data prior to each cleaning were adjusted up to fit the readings post cleaning. In 2023, due to the dangerously high river flows, there were two four-week windows in July and September when we were not able to access the logger. This was unfortunate, but we believe the data are still usable. We also calibrated logger readings to real-time handheld readings at the beginning and end of the deployment and made a second adjustment of the data to correct for long-term sensor drift. The following graph (Figure 6) shows the adjusted data with cleaning dates highlighted. This is provided to demonstrate that the sudden changes in DO that sometimes occurred were not a result of sensor cleaning. In most cases, sudden shifts in DO happened independently of cleanings.

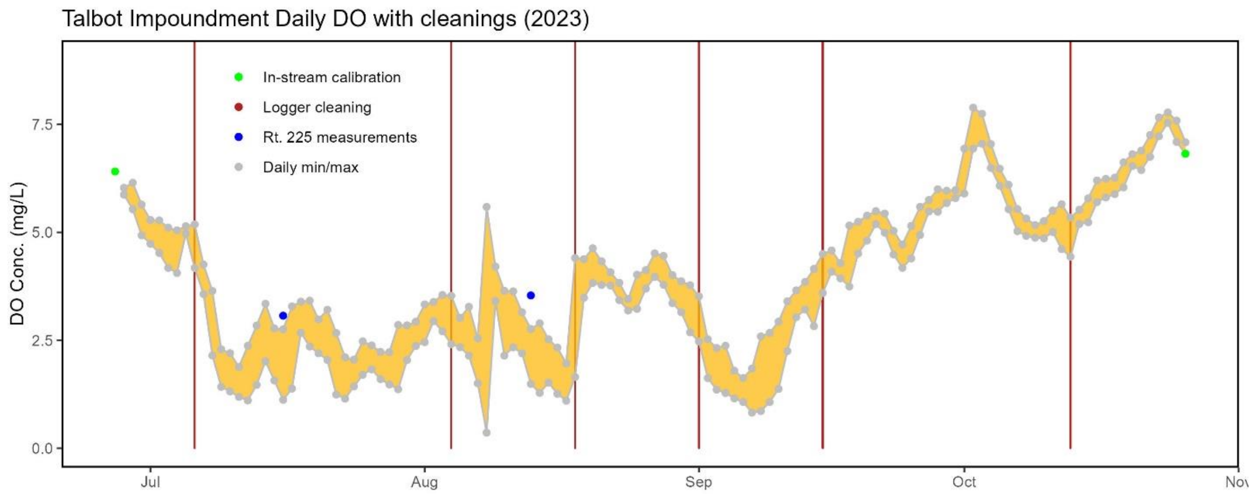


Figure 6: Logger cleaning schedule. Red lines represent dates the logger was cleaned. In-stream calibration was conducted at the beginning and end of the deployment. Route 225 measurements were taken 5.3 miles upstream during scheduled Water Quality monitoring.

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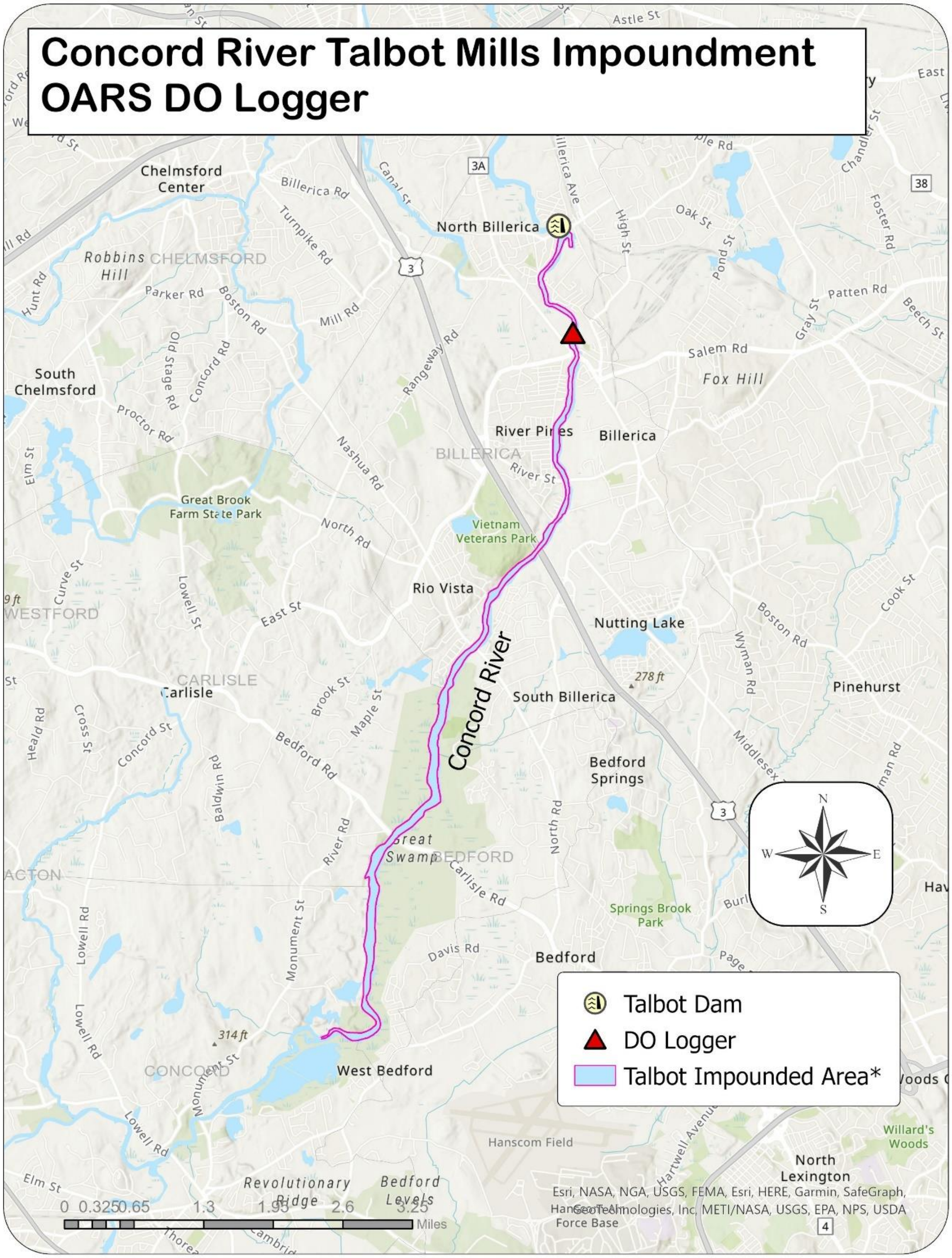
[1] "OARS Dissolved Oxygen Monitoring Talbot Mills Impoundment – 2022", August 3, 2023.
[2] "3.14 CMR 4.00 Massachusetts Surface Water Quality Standards", Massachusetts Department of Environmental Protection, Division of Water Pollution Control, November 2021, corrected January 2022.

Appendix: Map of Talbot Impoundment



*The extent of the Talbot impounded area was derived from the USGS 100K Ponds and Lakes GIS data layer. The actual hydraulic influence of the dam can extend further into the Assabet and Sudbury rivers depending on flow.