Standard Operating Procedures for Dissolved Oxygen, Temperature, Turbidity, and pH Continuous Monitoring at the Jabez III Stream Restoration Project

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Department of Natural Resources
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1.0 Purpose

This document describes the standard procedures used by the Maryland Department of Natural Resources (MDNR), Resource Assessment Service (RAS), to collect water quality data- specifically dissolved oxygen, temperature, turbidity, and pH- from above, within, and below a stream restoration project on the Jabez III tributary in Anne Arundel County, Maryland. These data consist of 15-minute continuous water quality readings collected between March 1st and September 30th in the post-restoration period, as required under the current *Army Corps of Engineers and Maryland Department of the Environment Water and Science Administration Jabez III Restoration Project Monitoring and Adaptive Management Plan* (henceforth Adaptive Management Plan).

2.0 Background

Founded in 2007, the Chesapeake and Atlantic Coastal Bays Trust Fund is a program intended to accelerate restoration and improve water quality in the Chesapeake Bay, Maryland's Coastal Bays, and their tributaries. As a part of this effort, the Chesapeake and Atlantic Coastal Bays Trust Fund supports the project construction and select water quality monitoring for a restoration project on the Jabez III tributary.

Jabez III flows into Jabez Branch in Anne Arundel County, Maryland and has a watershed heavily impacted by impervious surface from development. Before restoration, the lower reaches of Jabez III were highly eroded with an incised channel, and were identified as contributing to sediment and nutrient loads in Severn Run and the Severn River tidal system downstream. To abate these impacts, the impaired reaches of Jabez III were targeted for restoration.

In 2024, a Regenerative Stormwater Conveyance (RSC) project was initiated on the lower reaches of Jabez III with the goal to improve the hydrologic, hydraulic, geomorphic, and physicochemical functions of the stream and surrounding wetlands. Approximately 2,100 linear feet of stream channel, located on both state and private property, underwent construction that involved filling the eroded streambed with native sediments, woodchips, and boulders to reduce erosion and enhance floodplain connectivity. In addition to amendments to the stream channel, this created approximately six acres of additional wetland habitat.

RAS has been tasked with conducting water quality monitoring following the construction of the Jabez III restoration project. Specifically, RAS has been asked to provide data from continuous 15-minute measurements of dissolved oxygen, water temperature, turbidity, and pH at five locations above, within, and below the restoration reach, as well as one location adjacent to it, between March 1st and September 30th annually (Figure 1). This document describes the standard operating procedures employed for this effort.

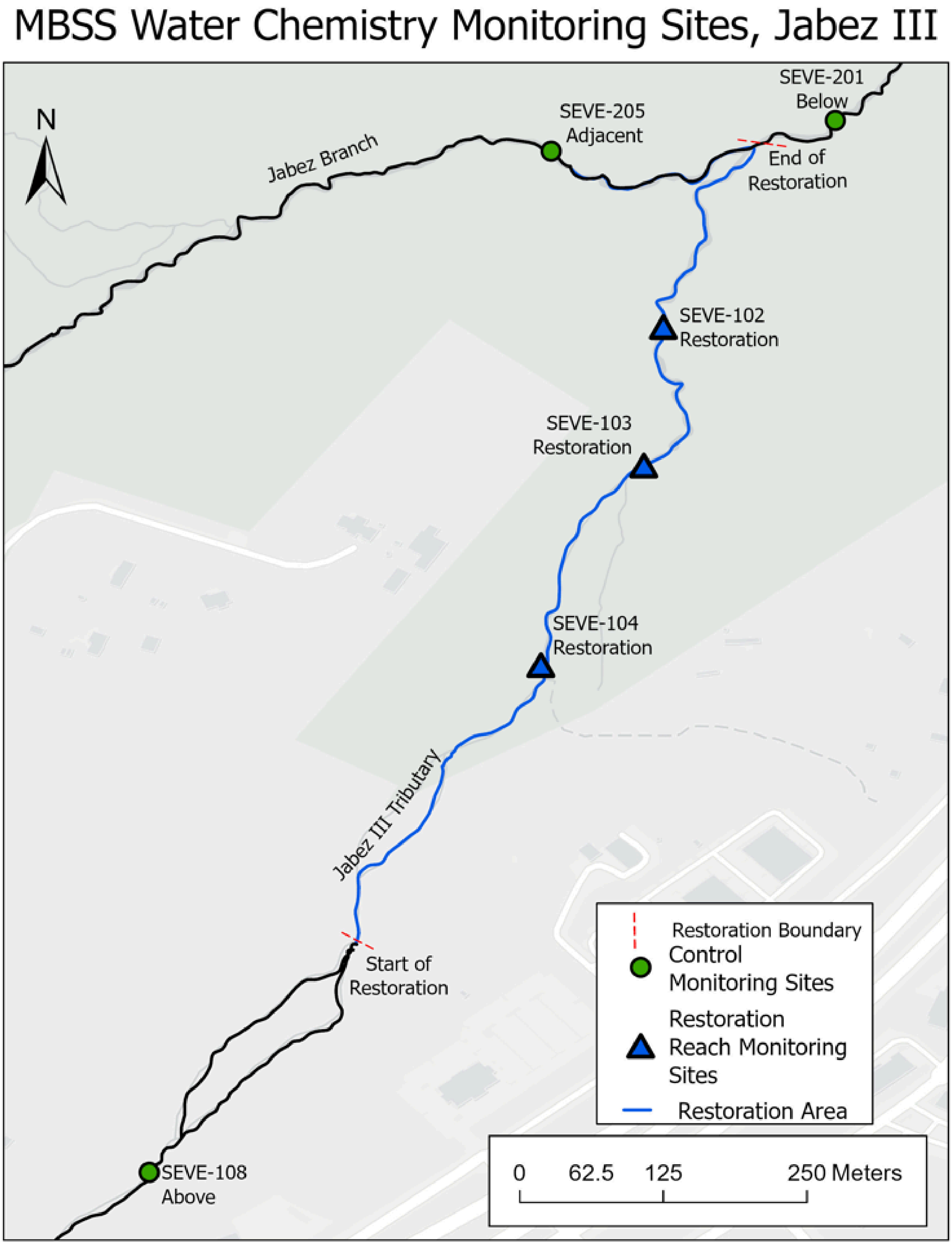

Figure 1. Jabez III water quality monitoring stations.

Table 1. Continuous water quality monitoring stations associated with the Jabez III stream restoration project. At each station, dissolved oxygen, water temperature, turbidity, and pH readings were collected in 15-minute intervals between March 1st and September 30th. The adjacent control station, SEVE-205, is not a requirement in the Adaptive Management Plan, but was added as an additional control site and denoted with an asterisk.

Site Type	Site	Stream	County	Latitude	Longitude	Monitoring Interval
Above	SEVE - 108	Jabez III	Anne Arundel	39.07262	-76.63666	15 minutes
Restoration	SEVE - 104	Jabez III	Anne Arundel	39.07647	-76.63377	15 minutes
Restoration	SEVE - 103	Jabez III	Anne Arundel	39.07809	-76.63299	15 minutes
Restoration	SEVE - 102	Jabez III	Anne Arundel	39.07931	-76.63289	15 minutes
Below	SEVE - 201	Jabez Branch	Anne Arundel	39.08086	-76.63324	15 minutes
Adjacent*	SEVE - 205*	Jabez Branch	Anne Arundel	39.08047	-76.63324	15 minutes

3.0 Methods

Six water quality monitoring stations were selected at locations above, within, below, and adjacent to the Jabez III stream restoration reach (Table 1). Five of these stations (those situated above, within, and below the restoration reach) are mandated by the Adaptive Management Plan. A sixth station, situated on the mainstem of Jabez Branch upstream of its confluence with the Jabez III tributary, was added as an adjacent control site to detect potential water quality impacts from sources further upstream on Jabez Branch, that are independent of restoration influence (Figure 1). At each station, a YSI EXO3 Multiparameter Sonde (henceforth "sonde") was installed and equipped with dissolved oxygen, temperature, turbidity, and pH probes. The sondes were oriented horizontally in the water column with probes pointing downstream. This allows them to remain submerged throughout the monitoring period and helps to protect the sensors from debris. Dissolved oxygen, temperature, turbidity, and pH readings were collected at 15-minute intervals. Sondes were deployed prior to March 1st and removed from the stream system after September 30th annually to ensure a full 24-hour dataset is available on the first and last days of the required monitoring period. Sondes were not deployed between October and February to extend their longevity and because water quality monitoring during these months is not required in the Adaptive Management Plan.

MDNR procedures for sonde installations, data downloads, and data Quality Assurance/Quality Control (henceforth "QA/QC") conducted as part of Jabez restoration monitoring undergo scrutiny from an independent observer. This individual has extensive experience and expertise in water quality sampling, stream data QA/QC, and data analysis. The independent observer was commissioned to help ensure the efficacy of the methodologies and accuracy of the data collected during post-restoration monitoring. The independent observer provides an annual summary of QA/QC observations that is made available each year on MDNR's Eyes on Jabez website (see Section 5.0 for website description).

3.1 Site Selection and Station Installation

The locations for sonde deployment within each monitoring station were selected based on water depth and velocity. Potential sonde deployment locations were flagged at each station during restoration construction and then evaluated for several weeks to ensure that deployments would occur in areas with stable conditions. Deployment locations were originally selected in areas with the greatest water depth, but analyses of biofouling accumulation on the sensor probes indicated that deployments in areas with higher water velocities experienced less fouling and provided more reliable data over a longer period. Based on these analyses, each monitoring station's sonde was deployed in an area that had a high water velocity while maintaining or exceeding the minimum depth for sonde operation throughout the monitoring period. A PVC housing suspended between two steel signposts was used for each deployment to protect the sonde and keep instrumentation off the stream bottom (Figure 2).

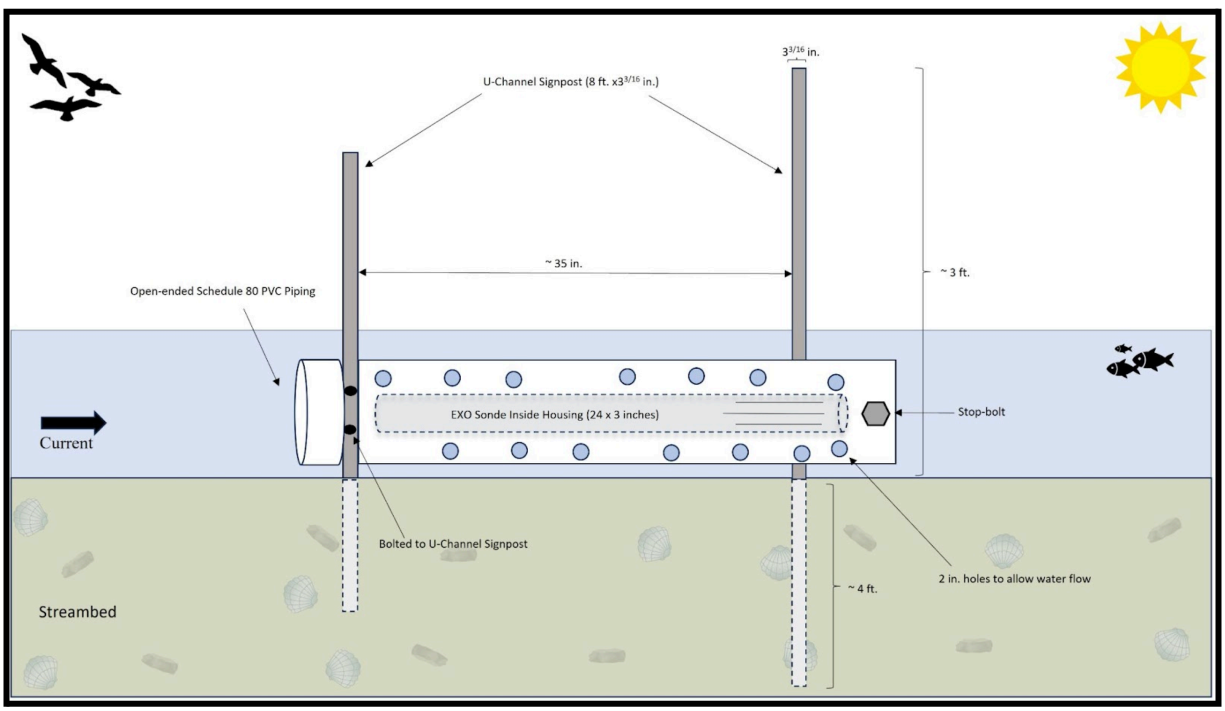

Figure 2. Schematic depicting approximate dimensions and configuration of a singular water quality monitoring station within the Jabez III project area.

3.2 Sonde Calibration

Sondes are calibrated prior to deployment, and following retrieval for data downloads and/or maintenance, a post-calibration test is performed. Post-calibrations ensure the sondes' probes are performing within range and functioning normally. Units that do not pass initial calibration are not used and are repaired or replaced. Data downloaded from sondes that do not pass post-calibration tests are carefully evaluated in additional QA/QC steps (see Section 4.0). The EXO family of sondes can warn users of calibration errors when sensors are unable to be calibrated correctly (due to age, fouling, damage, etc.), utilizing an embedded microprocessor and calibration data. Additionally, EXO sondes use SmartQC (YSI SmartQC User Guide) which is a built-in mechanism to normalize different sensors attached to a sonde and to assess the current state of each sensor's performance relative to factory-defined performance parameters. The SmartQC mechanism is used for interpreting all calibration data.

All calibrations are performed using the proprietary YSI KOR software following standard YSI calibration procedures outlined in the EXO User Manual (Revision L). Prior to calibration, the user selects and turns on the desired parameters within the calibration software and ensures that the sensors, sensor guard, and the calibration cup are clean. Calibrations are performed using dedicated calibration cups and guards for each sonde, which are used solely for calibration.

A zero oxygen check is conducted in addition to the YSI standard calibrations following procedures outlined in the EXO User Manual (Revision L). This is done to determine the ability of sondes and oxygen probes to achieve zero oxygen readings but is only a check- per manufacturer recommendations - units are not calibrated to zero. If a probe takes more than 15 minutes to achieve a zero oxygen reading during a check, the probe is not used in any deployments. If a deployed probe does not pass a post-hoc zero oxygen check, dissolved oxygen data are carefully evaluated in additional QA/QC steps (see Section 4.0).

3.3 Sonde Maintenance and Data Downloads

To prevent stream disturbance and/or human-induced alteration of ambient water quality, staff avoid entering the stream channel when removing and installing sonde equipment to the best extent possible. If entering the stream is unavoidable, staff try to remain downstream of the water quality monitoring station when retrieving sondes. During sonde retrievals, a handheld YSI EXO multiparameter water quality meter is placed into the water column to record *in situ* water quality readings that are compared with continuous data (see Section 4.0). This handheld meter undergoes the same calibration methodologies as the continuously-deployed sondes used at the water quality monitoring stations.

Sondes are retrieved from the stream on approximately two-week intervals and returned to the laboratory for maintenance, data downloads, and post-calibration checks. Zero oxygen checks are conducted monthly. Occasionally, sondes may be deployed for more than two weeks due to weather anomalies or scheduling difficulties. After maintenance and cleaning, probes are checked for indications of wear and/or failure and replaced as needed, then data is downloaded and saved on a DNR shared network drive for future QA/QC and dissemination on MDNR's Eyes on Jabez website.

Within approximately three business days of retrieval, post-calibration, data download, and cleaning, sondes are recalibrated prior to redeployment. If they pass calibration, they are returned to their original deployment locations within each monitoring station for another two-week monitoring period. It is important to note that there are currently no extra sondes available for this project, and it is thus not possible to exchange units with an identical replacement when they are retrieved. As such, there will typically be a gap of at least a few days in the monitoring data between deployments for each sonde.

3.4 Handling and Storage

When conducting routine fieldwork and in laboratory settings, it is important to protect the EXO housing and associated probes to avoid unnecessary damage to instrumentation. Any storage less than four weeks is considered *short-term storage,* and it is recommended by YSI to keep the sponge moist in the sensor cap during this period. For periods longer than four weeks, it is important to remove the pH and dissolved oxygen sensors, as these have special long-term storage instructions. After long-term storage, the user inspects for damaged o-rings and ensures ports and connectors are properly lubricated, as described in the EXO User Manual (Revision L).

4.0 Quality Assurance/Quality Control

4.1 Overview of QA/QC Procedures

Water quality data must undergo QA/QC before data analysis and subsequent dissemination. QA/QC processes are conducted by at least two RAS staff to ensure thorough review and assessment of all continuous water quality data. As of November 2025, MDNR is not able to compute data corrections related to fouling using a method that accounts for potential changes in environmental conditions during sonde servicing as described in USGS protocols (Wagner et al. 2006, Bennett et al. 2014). Furthermore, these QA/QC processes could be refined as experience with project conditions increases.

4.2 Data Flagging

Sonde measurements could potentially be influenced by instrumentation calibration drift and/or fouling (from sediment, algae, flocculant, etc.), which can result in inaccurate readings. These data must be carefully assessed against known values to help determine whether drift and/or fouling may have occurred.

Following removal from the stream, a sonde's last readings for each parameter are compared with a set of concurrent *in situ* readings recorded with a YSI EXO handheld meter. There is a high degree of confidence in the accuracy of the handheld meters, which are calibrated within one week of taking readings. The difference between handheld meter readings and deployed sonde readings may indicate a change in the ability of the sonde (and/or individual probes) to take accurate readings over the deployment period.

Post-calibration test readings are also important indicators that a sonde may be collecting inaccurate measurements by the end of its deployment. Data in a collection period for a given parameter is flagged when post-calibration values exceed the limits stated in the July 2023 iteration of the Quality Assurance Project Plan for the Maryland Department of Natural Resources Chesapeake Bay Shallow Water Quality Monitoring Program, which is outlined in Table 2. Out-of-range post-calibration results observed from the EXO3 sondes appear to be frequently associated with fouling, rather than instrumentation drift. The extent of flagging based on these post-calibration results varies depending on the presence of corroborating evidence of potentially inaccurate measurements. Any exceedances of the limits for a given parameter are noted with all readings in that collection period; however, the related Flag column(s) should be referenced as some data might pass QC if no impact is evident.

Table 2. Acceptable drift tolerances for YSI EXO3 sondes during post-calibration checks.

Parameter	Value
Dissolved Oxygen	±0.5 mg/L
Temperature	±0.2°C
Turbidity	±5% of true value or 5.0 NTU, whichever is greater. *Note: MD DNR turbidity measurements were taken in FNU, which are comparable to measurements in NTU when collected with a YSI instrument.*
pH	±0.2 pH units

A central wiper is used on all deployed sondes to reduce the potential for fouling on probes that can cause unreliable readings. The automatic wiper on the YSI EXO3 sondes cleans the probes every 15-minutes, prior to each reading. Based on comparative analysis of sondes with and without wipers during the construction period, measurements with wipers appeared to more closely align with *in situ* readings.

QA/QC procedures rely in part on a trail camera (Spypoint Flex G-36) installed at each water quality monitoring station and programmed to continuously photograph the monitoring station (including the sonde) at one-hour intervals. The cameras are used to observe the monitoring stations during storm events and to monitor the status of the sondes (Figure 3). This surveillance helps to mitigate possible equipment damage and, when images are available, inform post-hoc interpretation of data validity (e.g., confirm instrument burial, fouling, dewatering, stochastic events; Figure 4).

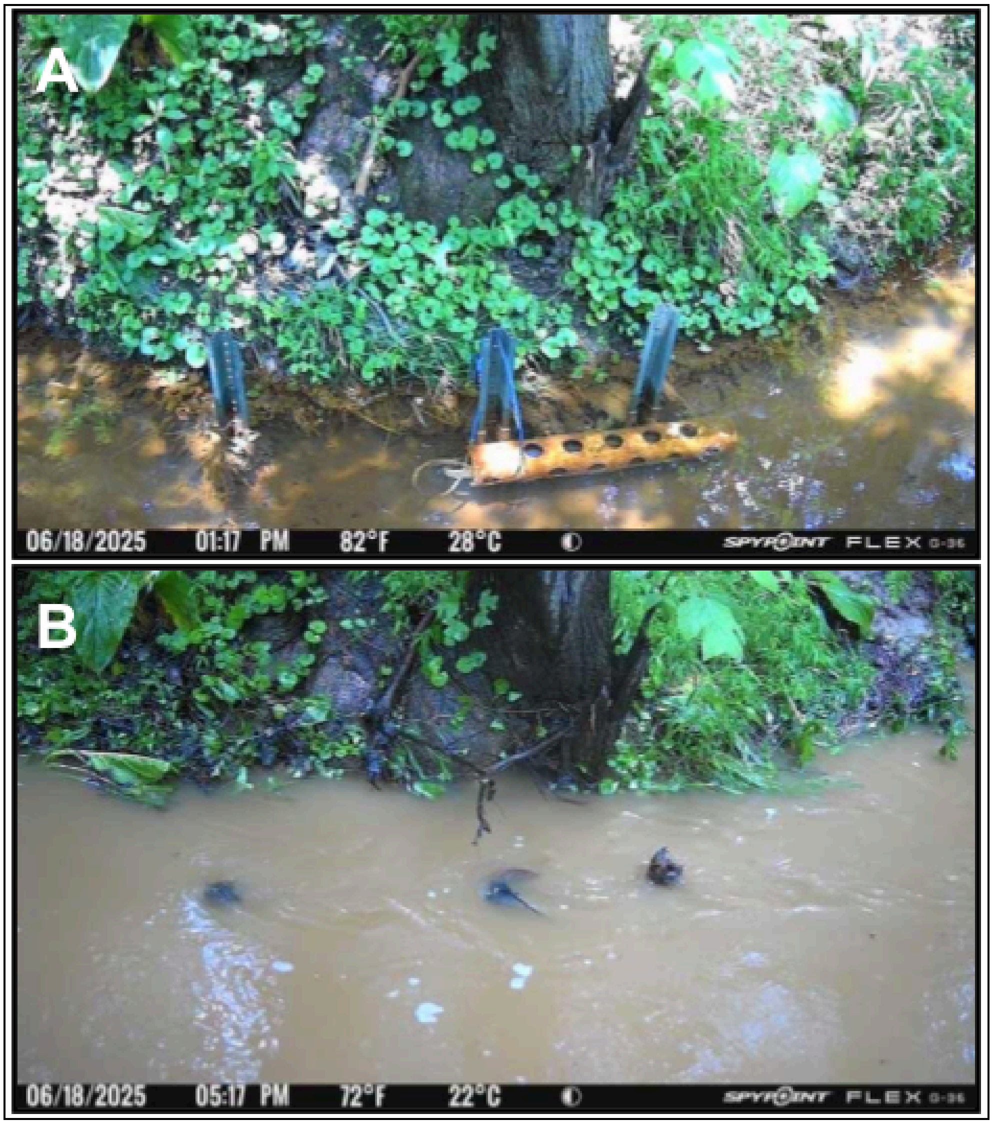

Figure 3**.** Examples of low water conditions (A) and high water conditions (B) captured at the same water quality monitoring site via a remote access trail camera.

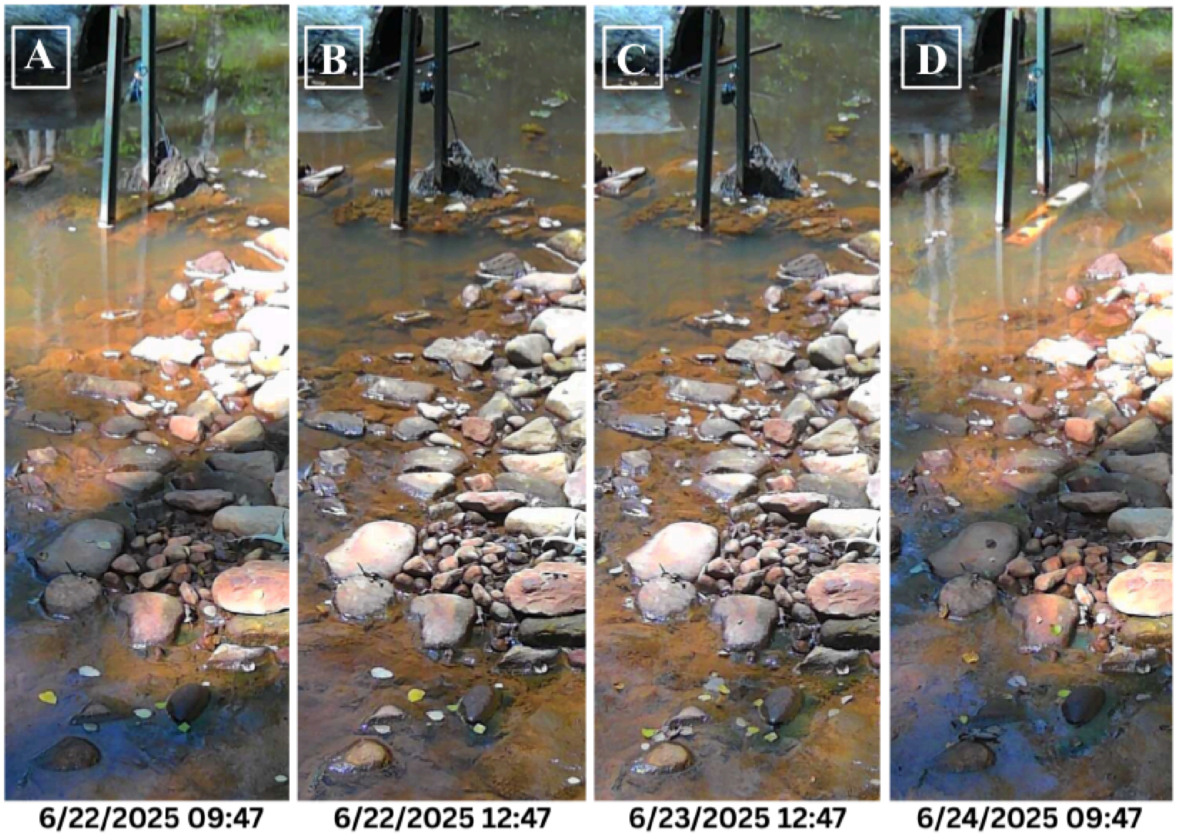

Figure 4. Trail camera images show iron flocculant collecting around the sonde housing on 6/22/2025 in stagnant conditions at restoration site SEVE-103-X over the course of a few hours (A-B) and remaining after another 24 hours (C). The accumulated iron flocculant was cleared from the sonde housing by field staff the following day (6/24/2025; D).

Flagging decisions are also informed by notes taken by field staff during sonde deployments and retrievals, which include field observations of fouling or burial of the sondes, significant changes in environmental conditions, sensor caps in need of replacement, and sondes with dead batteries.

In addition to the evaluation of trail camera photos and field notes, precipitation and discharge data are used to inform flagging decisions. The occurrence of rain events that could impact sonde measurements is determined using precipitation data from an on-site weather station operated by Underwood & Associates and discharge data from a USGS gage on South Fork Jabez Branch (USGS gage number 01589795). Given precipitation can cause natural variations in measurements compared to baseflow conditions, data collected during a rain event are not flagged unless there is a physical impact to the sonde (e.g., burial in sediment or an accumulation of debris and other materials on and around a sonde housing which could lead to fouling).

Measurements taken while a sensor was still acclimating to stream conditions early in its deployment are also flagged. This issue is most frequently observed with pH readings. Acclimation periods are generally characterized by a small number of the earliest readings with relatively large increases or decreases during baseflow conditions, followed by readings that are more typical of the parameter.

All raw data are plotted using the statistical software R to visualize patterns, anomalies, and potential errors in each monitoring period. To better understand the potential impact of rain events, data are plotted with precipitation data collected by the on-site weather station. Plots are used to aid in comparisons of concurrent measurements and patterns at other monitoring stations.

Dissolved oxygen and temperature data are assessed in part using methods outlined in MDNR's Quality Assurance Document for Temperature Monitoring. DO concentrations and temperature are each graphed by monitoring period to view potential changes in daily patterns that could indicate fouling or burial of the sonde (Figure 5, Figure 6). Water temperature from each site is plotted with air temperature data from the on-site weather station to check for potential burial and/or dewatering of the sonde.

Fouling is most frequently observed in DO and turbidity data. These two parameters are often plotted together to help determine potential concurrent abnormalities that could provide stronger evidence for fouling or burial of the sonde (Figure 7).

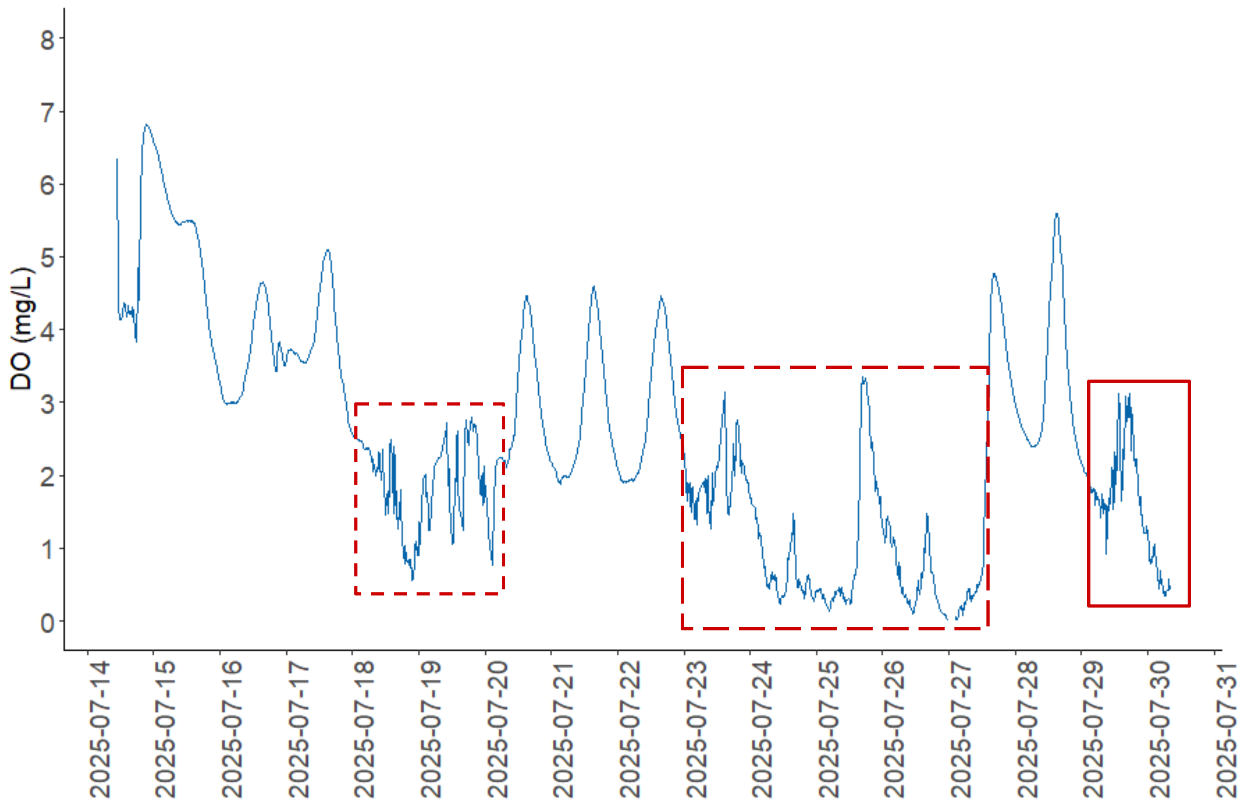

Figure 5. Dissolved oxygen data from SEVE-103 including irregular DO readings (highlighted in red box with solid red line) collected toward the end of the monitoring period when trail camera images showed that debris and iron flocculant had accumulated on and around the sonde housing. Additionally, a post-calibration test showed the sonde was not reading within an acceptable range of accuracy for DO by the end of the deployment period. Based on these multiple indicators, the DO sensor during this period may have been fouled and the data were flagged. Other series of unusual, erratic readings were observed rather than expected diel patterns (highlighted in red boxes with dotted red lines). There was insufficient evidence to support flagging data in these boxes; instead, comments described factors contributing to uncertainty about the data.

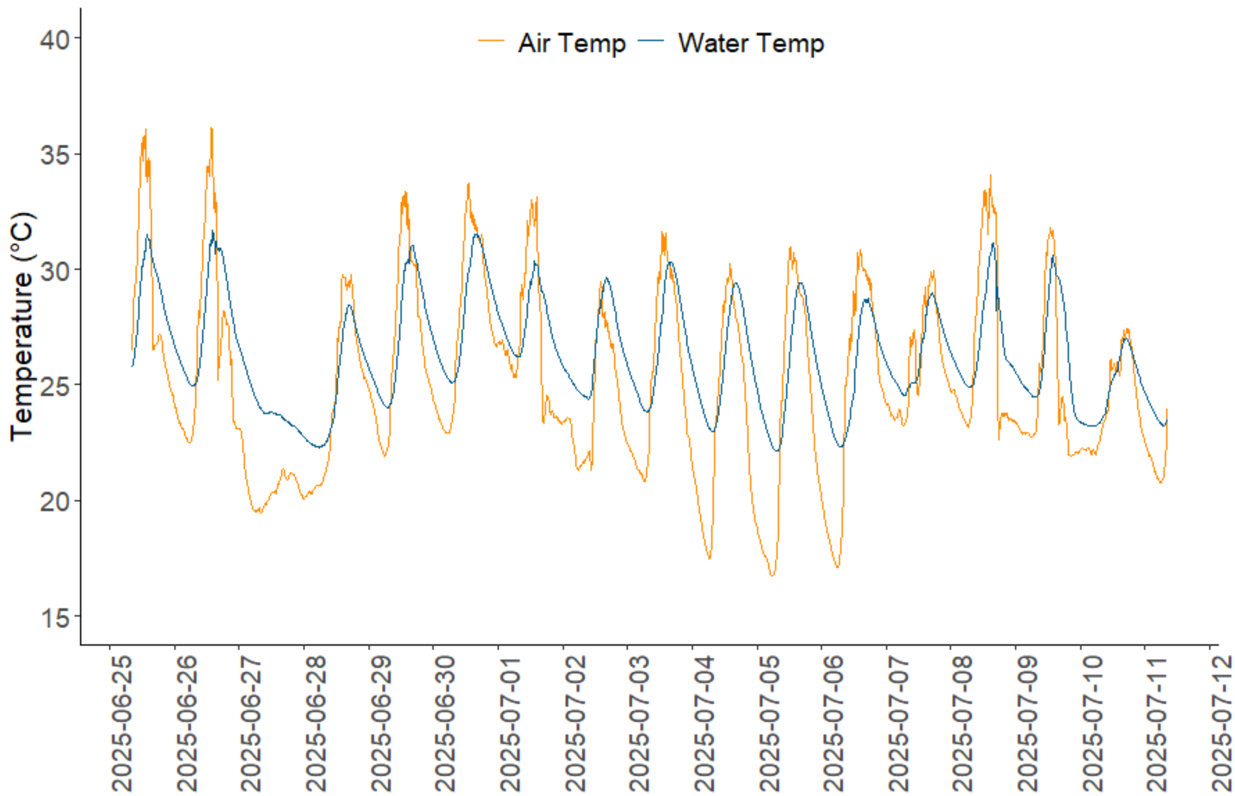

Figure 6. Water temperature data from SEVE-102-X in the restoration is evaluated in part by comparing readings with air temperature data from an on-site weather station. Examples of these comparisons demonstrating fluctuations in water temperature that required flagging due to burial and/or dewatering were not available from data collected at the monitoring stations in May-July 2025.

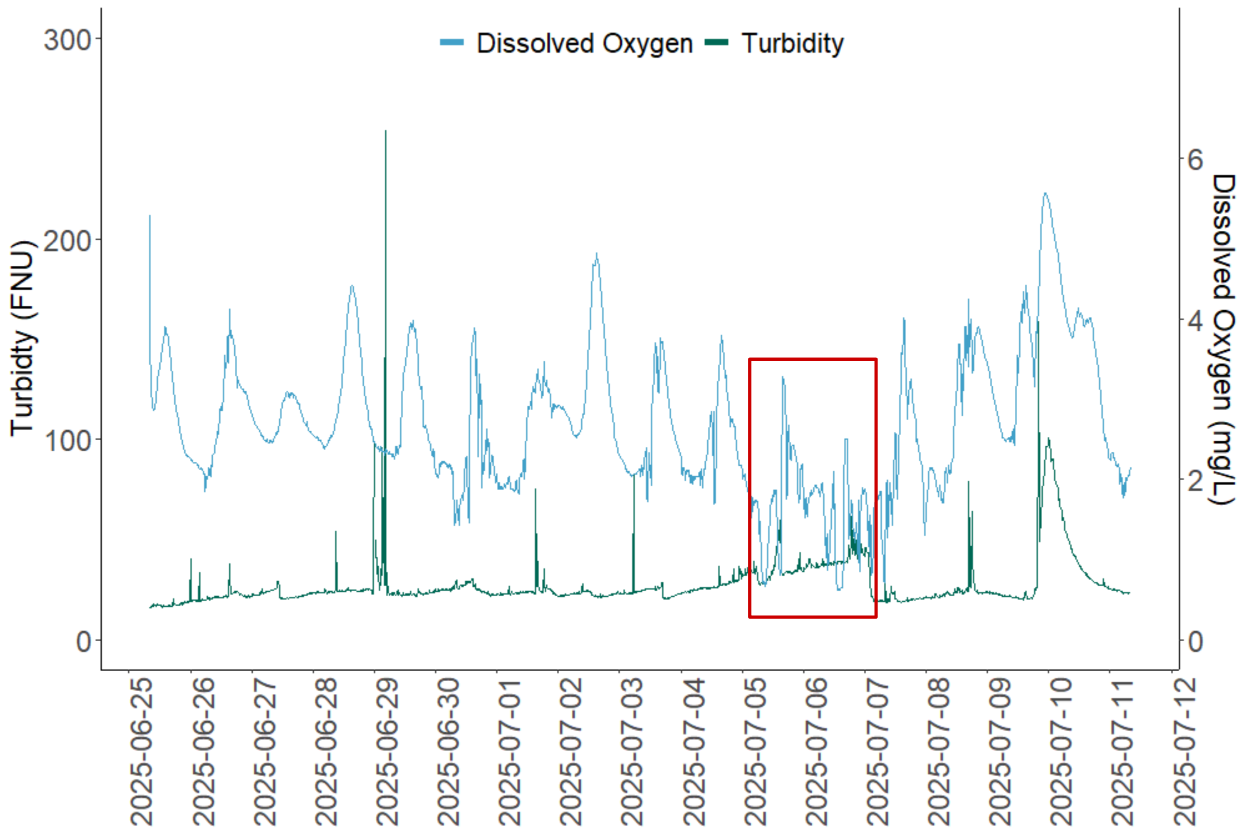

Figure 7. Dissolved oxygen and turbidity data from SEVE-103-X plotted together to identify periods of potential fouling. The red box contains a period in which DO readings did not follow an expected diel pattern at the same time a gradual rise in turbidity followed by a sudden drop was observed. The concurrent changes in these two parameters provides stronger evidence to support flagging for possible fouling.

Potentially inaccurate anomalies in turbidity readings are identified in part using a set threshold for spikes observed in the data. Spikes that occur in isolation or clusters could be artificially high readings produced by temporary fouling of the probe, or nearby lingering material recently removed from the sensor by the wiper. Turbidity readings that were more than 5 times greater than the previous reading and were not on trend with other measurements were marked as likely impacted by fouling and carefully reviewed in subsequent QA/QC steps (Figure 8). This threshold was adapted from a QC method used by MDNR’s Continuous Monitoring Program, which evaluates turbidity measurements that are 3 times greater than the previous reading. A higher threshold was determined to be more effective for identifying potentially inaccurate spikes in the Jabez water quality data while minimizing the amount of legitimate data above the threshold. Chase (2010) describes a similar approach to address potential turbidity outliers during baseflow, focusing on isolated spikes and using a set threshold to identify readings that might be inaccurate. Additionally, gradual increases of turbidity measurements in a period with no or little precipitation followed by a sudden drop were subject to flagging due to possible fouling (Figure 9).

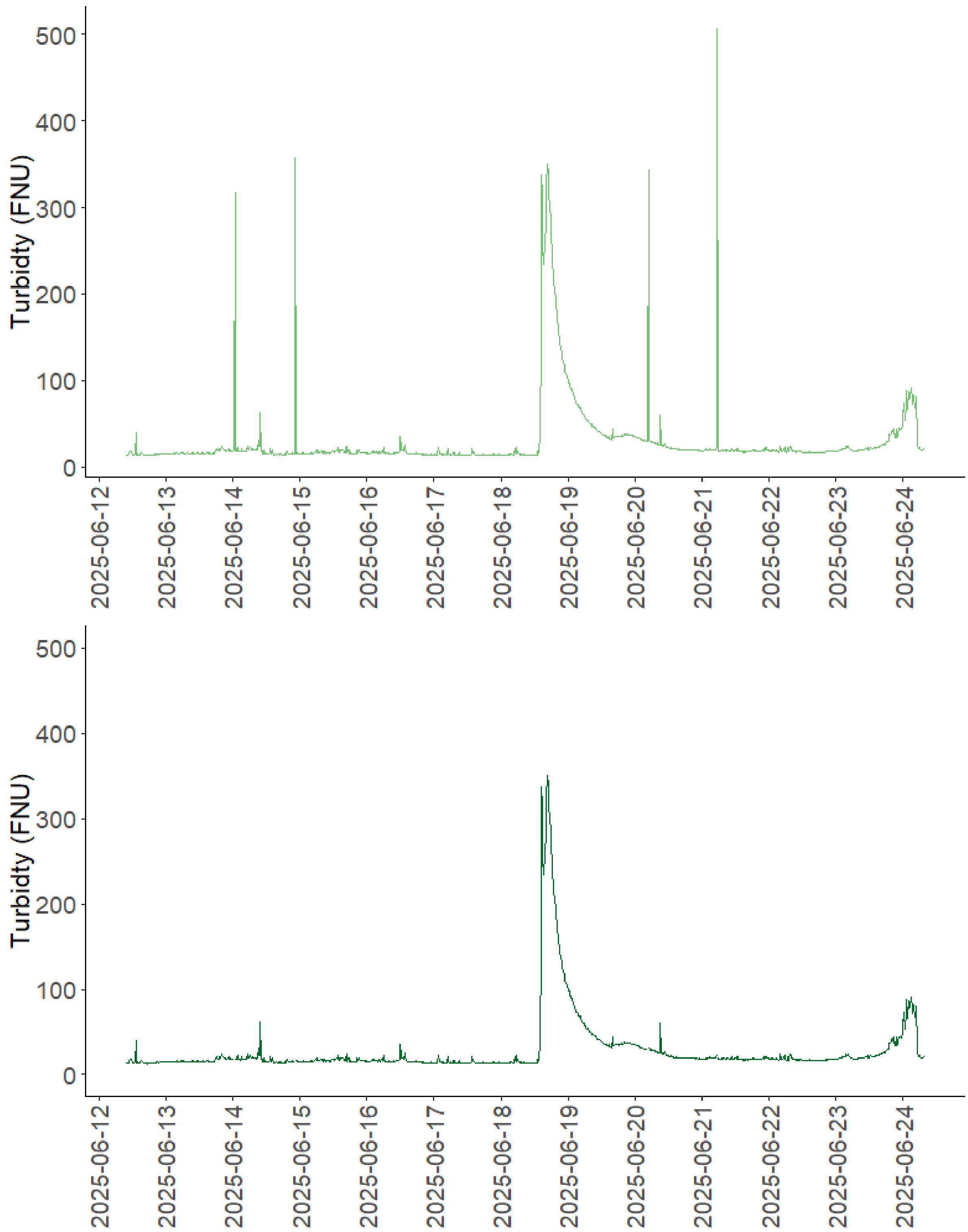

Figure 8. Turbidity measurements at SEVE-103 in the restoration before (top) and after (bottom) a filter was applied to the data that removed readings 5x greater than the previous measurement as a QA/QC step to identify spikes that might be the result of fouling.

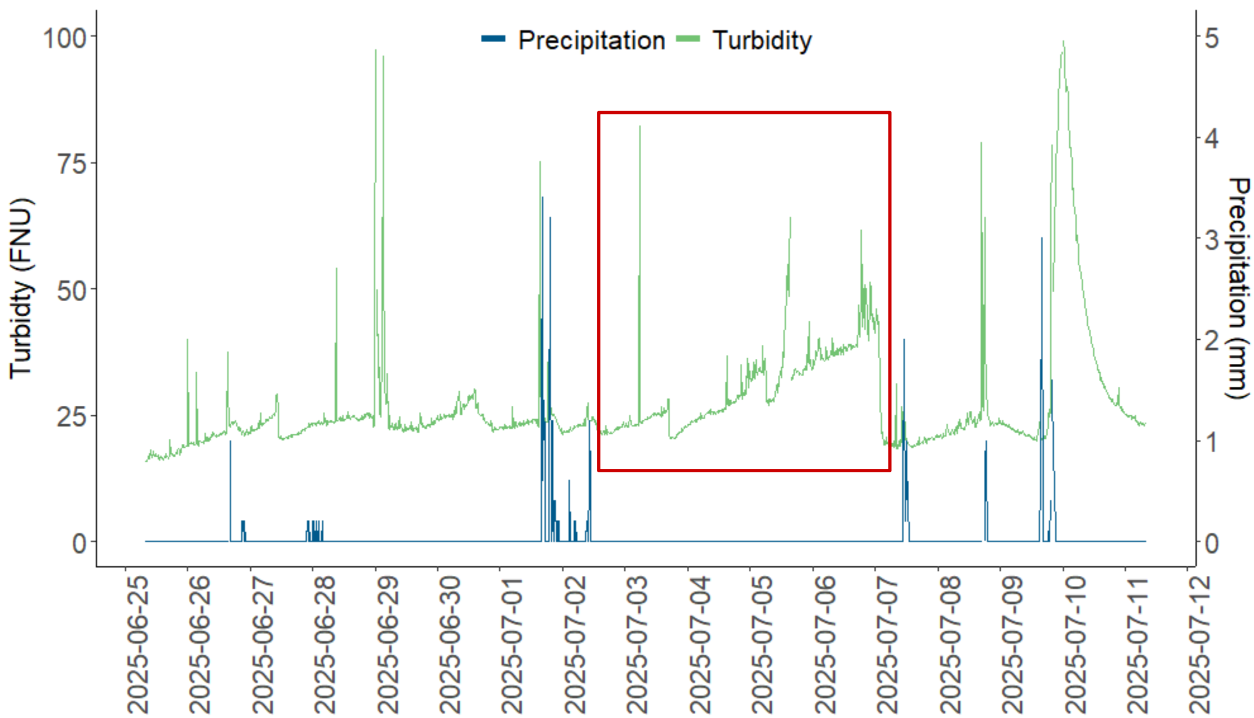

Figure 9. Turbidity readings from SEVE-103 show a repeated pattern of gradual increases followed by sudden drops during a period with no rain, indicating potential fouling of the sonde.

Because pH sensors occasionally require relatively long periods of time to acclimate to stream conditions (Figure 10), measurements taken during any ongoing acclimation period early in a sonde's deployment are flagged. Additionally, comments may be provided with pH data when readings are erratic, with unusual, relatively large differences between subsequent readings; however, these data are not flagged and excluded from success criteria calculations (Figure 10). Paired with post-calibration tests and field office notes, these erratic readings can indicate the sensor tip is in need of replacement and measurements may be inaccurate. In other cases, readings may fluctuate irregularly due to fouling. pH data is also subject to possible flagging when measurements at or near baseflow are outside the normal range observed at the site and concurrent with changes in other parameters.

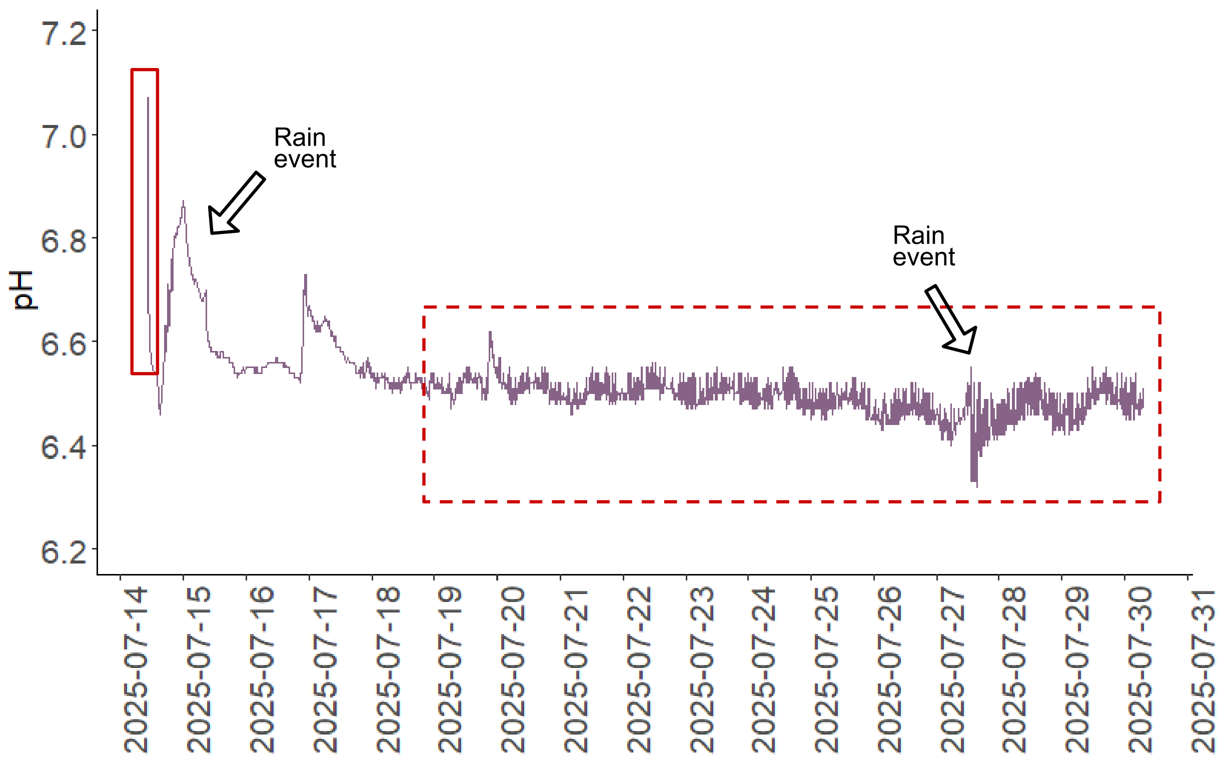

Figure 10. Early pH readings from SEVE-108 (upstream control) in the monitoring period were flagged because they indicated the sonde was still acclimating to stream conditions. pH measurements that became increasingly erratic (red box with dotted lines) were not flagged but accompanying comments noted the sensor tip was showing signs of wear. MD DNR field office staff replaced the pH probe on this sonde after this deployment.

Data determined to be unreliable during QA/QC checks are flagged with accompanying comments. In some cases, partial or suspected fouling may introduce uncertainty without providing sufficient evidence to warrant flagging or exclusion from success criteria calculations. These data are not flagged but include a note in the *Comments* section (see Section 4.3) indicating the associated uncertainty.

All raw data, including those with flags and/or comments, are permanently retained and accessible through [MDNR's Eyes on Jabez website] for ongoing assessment and future re-evaluation. Future advances in analytical techniques or technologies may allow the use of data previously deemed unreliable.

Despite strict adherence to QA/QC procedures for this project, some level of subjectivity in flagging data is unavoidable and may lead to occasional discrepancies among data assessors. MDNR employs a weight-of-evidence approach combined with the best professional judgement when flagging data, which may be refined over time with more experience in assessing water quality data at the Jabez III monitoring sites.

4.3 Success Criteria Calculations

Grouped by month, data from the four parameters that have passed the previous QA/QC steps are compared against success criteria as defined in the Adaptive Management Plan (Table 3). Flagged data are excluded from success criteria analyses related to percentages of individual measurements, as well as, summary statistics calculated for each site.

Table 3. Success criteria for the four water quality parameters as defined in the Adaptive Management Plan. Success Criteria language is subject to change, pending approval from Maryland Department of the Environment.

Parameter	Success Criteria
Dissolved Oxygen	The restored DO is not less than 5 mg/L at any time and has a minimum daily average of not less than 6 mg/L.
Temperature	The restored water temperature has an average daily mean temperature of 22.5°C or ambient temperature, whichever is greater.
Turbidity	The restored turbidity is below a maximum value of 150 NTU or a monthly average less than 50 NTU. *Note: MD DNR turbidity measurements were taken in FNU, which are comparable to measurements in NTU when collected with a YSI instrument.*
pH	The restored pH meets baseline or falls within 6.5-7.2.

Summary statistics (daily mean, standard error, maximum, and minimum) of the four parameters are calculated for each month in the monitoring period. Following the flagging process, days with less than 100% data coverage are excluded from summary statistics calculations if they did not meet the following criteria: (1) 75% or more of the possible 96 daily observations were available, (2) the maximum value cannot be lower than the lowest maximum value observed on days with 100% data coverage, and the minimum value cannot be higher than the highest minimum value observed on days with 100% data coverage, and (3) the maximum and minimum values occurred at reasonable times depending on the parameter. This method is adapted from USGS protocols and recommendations provided by Bennett et al. (2014), and in Wagner et al. (2006), which state that the expected daily maximum and minimum values should be present when reporting daily summary statistics and less than 100% of data are available.

Fields included in completed data files, including raw data, flags, and certain success criteria results are described in Table 4.

Table 4. Descriptions of fields in data files that have completed QA/QC. Note: no SC_Temp column is provided because the success criterion for temperature does not focus on individual readings. * Indicates that pass/fail determinations for pH measurements are based on MD DNR's understanding of the success criteria as of November 2025.

Field	Description
Temp_C	Water temperature measured in degrees Celsius.
DO_sat	Dissolved oxygen saturation measured as a percent.
DO_conc	Dissolved oxygen concentration measured in mg/L.
pH	pH of the water.
Turbidity_FNU	The turbidity of the water measured in Formazin Nephelometric Units (FNU).
Flag_DO / Flag_Temp / Flag_Turb / Flag_pH	A "Y" indicates measurements determined to be, or likely to be, inaccurate, particularly due to fouling of the sensors by sediment, iron flocculant, and/or debris; or when the sonde is acclimating to the water conditions early in its deployment.
Comments	Context provided to accompany data flags.
Exceedances	Notes when a sonde reads outside an acceptable range for a given parameter during tests conducted after their deployment.
SC_DO	A "P" (pass) indicates a DO measurement was at or above 5.0 mg/L, based on the success criteria. An "F" (fail) indicates the measurement fell below the threshold, and a blank cell indicates the data was flagged.
SC_Turb	A "P" (pass) indicates a turbidity measurement is at or below 150 FNU, based on the success criteria. An "F" (fail) indicates the measurement exceeded the threshold, and a blank cell indicates the data was flagged.
SC_pH	A "P" (pass) indicates a pH measurement falls within 6.5-7.2, based on the success criteria.* An "F" (fail) indicates the measurement either fell below or exceeded the range, and a blank cell indicates the data was flagged.

5.0 Data Saving and Submission

Following similar methodologies of Nance and Cavileer (2019), data are downloaded from the sondes in CSV format utilizing KOR software and exported to a dedicated folder on the DNR shared network drive. Data files are coded *XXYY* (two-digit year code, two-digit week code). Calibration logs and field sheets are also uploaded into the network folder for repository and post-hoc analysis of data. After quality control checks are complete, data, including flags and explanations, as necessary, are uploaded to MDNR's Eyes on Jabez website.

The MDNR Eyes on Jabez website provides access to all data collected by MDNR related to the project, including continuous water quality data from the six monitoring stations. Users can view the most recent continuous data displayed on the website, and download all available data for the four parameters by month. Downloads include summary statistics and an overview of how each parameter did or did not meet success criteria.

6.0 References

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