

Project ID: 18-0221

Quality Assurance Project Plan

Evaluation of Low-Cost Sensors for Continuous Remote Water Quality Monitoring

**North Oconee River – Athens, GA
Middle Oconee River – Athens, GA
Vickery Creek – Roswell, GA**

Project Date(s): March – June, 2018

Final QAPP Approval Date: March 19, 2018

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The activities depicted in this QAPP are accredited under the US EPA Region 4 Science and Ecosystem Support Division ISO/IEC 17025 accreditation issued by the ANSI-ASQ National Accreditation Board. Refer to certificate and scope of accreditation AT-1644.

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Evaluation of Low-Cost Sensors for Continuous Water Quality Monitoring

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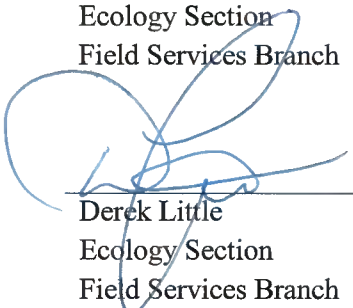
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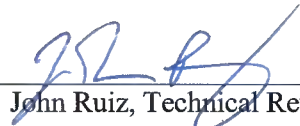
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*This quality assurance project plan (QAPP) has been prepared according to:
EPA Requirements for Quality Assurance Project Plans (EPA QA/R5 EPA/240/B-01/003, U.S. Environmental Protection
Agency, Office of Environmental Information, Washington, DC, March 2001 (USEPA, 2001).
This document will be used to ensure that environmental and related data collected, compiled, and/or generated for this
project are of the type, quantity, and quality required for their intended purposes within the limitations of available
resources.*

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1.0 QAPP Distribution

Recipient	Organization	Telephone Number	Address/Email
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2.0 Project Organization

Requesting Program: U.S. EPA Office of Research and Development (ORD) Innovations Team
– Regional/State Innovations Initiative

Principal Data User(s): U.S. EPA Science and Ecosystem Support Division scientists
U.S. EPA Office of Research and Development Innovations Team

Project Co-Leaders: Nathan Barlet, Environmental Engineer
Derek Little, Environmental Engineer
U.S. EPA, Science and Ecosystem Support Division (SESD), Field Services Branch (FSB)

Responsibilities: The project co-leaders are responsible for planning and implementing the field study to meet the data quality objectives. The project co-leaders are responsible for:

- Quality Assurance Project Plan (QAPP) preparation
- Ensuring QAPP is implemented as written
- All data collection activities for the duration of this study
- Final report preparation

Table 1: Project Participants

Team Members*	Organization	Responsibilities	Contact
Nathan Barlet	SESD/Ecology Section	Project Co-Leader/Logbook/ <i>In-situ</i> Water Quality Data Collection/Instrument Calibration and Maintenance	(706) 355-8617
Derek Little	SESD/Ecology Section	Project Co-Leader/Logbook/ <i>In-situ</i> Water Quality Data Collection/Instrument Calibration and Maintenance	(706) 355-8717
Jerry Ackerman	SESD/Ecology Section	<i>In-situ</i> Water Quality Data Collection/Instrument Calibration and Maintenance	(706) 355-8721
Greg White	SESD/Ecology Section	<i>In-situ</i> Water Quality Data Collection/Instrument Calibration and Maintenance	(706) 355-8705

*Project team members may change due to conflicting work assignments or personal schedules.

Data Reviewers: Internal technical reviews will be conducted by U.S. EPA SEDS scientists. The draft report will also be reviewed by members of the U.S. EPA ORD Innovation Team.

Responsibilities: Copies of the draft report will be provided to U.S. EPA SEDS scientists and the U.S. EPA ORD Innovations Team for review. Resulting comments will be addressed before the final report is distributed.

3.0 Project Management

3.1 Site Description

The main objective of this study is to evaluate the performance of low-cost water quality sensors relative to industry standard equipment (multi-parameter sondes). Site selection was performed on the basis of reasonable equipment accessibility and security. Continuous *in-situ* water quality monitoring stations will be established on the North Oconee River and Middle Oconee River in Athens, Georgia, as well as Vickery Creek in Roswell, Georgia. Specific site locations are outlined in Section 4.1 and Appendix A of this Quality Assurance Project Plan (QAPP).

The North Oconee River and Middle Oconee River are major tributaries of the Upper Oconee watershed that converge in Athens, Georgia, flowing into the larger Oconee River Basin. Upper reaches of both rivers are characteristic of rural watersheds with mixed forest/agriculture landscapes before flowing through the city of Athens. One continuous water quality monitoring station will be established on the North Oconee River due to its close proximity to EPA Region 4's Science and Ecosystem Support Division (SESD) laboratory. Two additional monitoring stations will be installed on the Middle Oconee River upstream and downstream of White Dam in Whitehall Forest at the University of Georgia's Warnell School of Forestry. Both of the low-cost sensor monitoring stations installed on the Middle Oconee River

will be collocated with existing water quality monitoring stations that have been previously established as part of the White Dam Removal Study (SESD Project ID: 17-0038).

A fourth water quality monitoring station will be installed on Vickery Creek, also known as Big Creek, in the Chattahoochee River National Recreation Area upstream of the bridge crossing at Riverside Road in Roswell, Georgia. Vickery Creek passes through a semi-urban/urban watershed before flowing into the Chattahoochee River.

3.2 Problem Definition

Quantifying the cumulative water quality impacts on our watersheds remains both a regional and national science priority and remains a top research priority for many of the states as summarized in a 2016 survey conducted by the Environmental Research Institute of the States (ERIS). Collecting *in-situ* measurements of water quality via traditional instantaneous measurements is often inefficient and ineffective at observing natural patterns, trends, and assessing overall ecological health in extremely dynamic systems. Furthermore, collecting data during storm events can also be difficult and dangerous using traditional means. Advancements in monitoring technologies have made “real-time” continuous monitoring of water quality possible. However, much of the technology currently available is still cost prohibitive for establishing robust monitoring networks at the federal, state/tribe, and community levels.

Non-point source monitoring programs such as Georgia Environmental Protection Division’s (GAEPD’s) Georgia-Adopt-A-Stream (GA-AAS) that utilize citizen science data collected through volunteer monitoring efforts at the community level are vital to understanding base-line water quality conditions and the state of our nations waters. In recent years a rapid expansion of open source resources and support have made the design and deployment of low-cost water quality sensors accessible to watershed monitoring organizations, researchers, students, and citizen scientists alike. The U.S. EPA currently maintains an Air Sensor Toolbox for citizen scientists with no analogous resource for low-cost water quality sensors. There is currently very limited information on the capabilities and quality of data collected by these emerging low-cost alternatives. The purpose of this study is to evaluate select low-cost water quality sensors in comparison to industry standard equipment as part of a regional innovations initiative supported by the U.S. EPA’s Office of Research and Development (ORD).

3.3 Project Description

This study is a component of the U.S. EPA Region 4 Regional Innovation Project titled “Low-cost sensors for real-time continuous water quality monitoring.” This project will conduct evaluations of select emerging low-cost water quality sensor technology relative to industry standard equipment. During this study SESD personnel will perform the following tasks:

- Establish monitoring sites for the collection of continuous *in-situ* measurements of pH, temperature, dissolved oxygen (DO), and specific conductance using open source sensor technology and traditional multi-parameter sondes over a 3-month period.

- Measure water depth at each monitoring site using deployable pressure transducers.
- Collect and record the GPS coordinates of established monitoring stations.
- Document site conditions via photographs and logbook notes.
- Compute and analyze errors associated with drift and fouling of the sensors.
- Compute and analyze the accuracy and precision of the low-cost water quality sensors with respect to the multi-parameter sondes.

3.4 Project Schedule

Project activities are outlined in Table 2. Field activities for sensor maintenance, calibration, and data retrieval will be conducted on a 2 – 4 week interval dependent on weather conditions, scheduling conflicts, and observed rates of sensor fouling and drift. Decisions regarding the rescheduling of field activities will be made by the project co-leaders in consultation with SESD Ecology Section management.

Table 2: Project Timeline

Date	Task
Week of March 19 th	Deploy low cost water quality sensors and multi-parameter sondes.
Week of April 2 nd – Week of May 28 th	Equipment maintenance, calibration, and data retrieval.
Week of June 11 th	Retrieval of low cost water quality sensors and multi-parameter sondes.
July 16 th	Data analysis and final report complete.

3.5 Quality Objectives and Criteria for Measurement Data

The main goal of this study is to evaluate the performance of low-cost water quality sensors relative to industry standard equipment. Low-cost sensor performance will be evaluated based on the accuracy, precision, and susceptibility to fouling and calibration drift. Sensor performance evaluations based on data analysis are discussed in Section 5.0, and the Data Quality Objectives (DQOs) for this study are outlined in Appendix B of this QAPP.

3.6 Special Training Requirements

Per SESD's Field Branches Quality System, the Project Leader and all scientists assigned to this project have been deemed competent by SESD management, under ISO 17025 accreditation, to conduct ecological surveys and assessments required to fulfill the prescribed goals within this QAPP. Additionally, these project members are trained and competent to conduct the described field activities. The SESD Field Quality Manager maintains all training records and competency evaluations.

3.7 Documents and Records

Field logbooks will be maintained according to the SESD Operating Procedure for Logbooks (USEPA, 2017e) during the field study. Following completion of the study, logbooks and the project file will be

maintained by the project leader according to the SEDS Operating Procedure for Control of Records (USEPA, 2017a). At the completion of the project a copy of the final report will be transmitted to WPD, and a copy of the final report along with the project file will be maintained in the SEDS Records Center. Final report distribution and storage will be conducted following the SEDS Report Preparation and Distribution Operating Procedure (USEPA, 2014d). The most current records schedules are available at <http://epa.gov/records/policy/schedule>.

4.0 Data Generation and Acquisition

4.1 Study Design

During this study, four continuous water quality monitoring sites will be established at the locations outlined in Table 3. Each of the monitoring stations will house a low-cost sensor containing open-source temperature, pH, dissolved oxygen, and conductivity probes. The low-cost sensors will be co-located with multi-parameter sondes for field comparisons of in-situ water quality measurements collected at 15 minute intervals. An additional low-cost water quality sensor will be deployed in tap water at the SEDS laboratory for controlled comparisons to a multi-parameter sonde under well mixed, steady-state conditions. All measurements of in-situ water quality, GPS coordinates, and water depth will be conducted in accordance with the standard operating procedures listed in Section 4.2 of this QAPP. Detailed maps of the study areas are in Appendix A.

Table 3: Station Location & ID

Stream	Site ID	Description	Approximate Coordinates		County
			Lat. (DD)	Long. (DD)	
North Oconee River	EPANO	North Oconee River, Adjacent to SEDS Laboratory	33.922854	-83.362379	Clarke
Middle Oconee River	EPAMU	Whitehall Forest, Upstream of White Dam	33.877240	-83.353070	
	EPAMD	Whitehall Forest, Downstream of White Dam	33.877710	-83.350210	
Vickery Creek	EPAVC	Chattahoochee River National Recreation Area, Upstream of Riverside Road	34.006412	-84.350658	Forsythe

4.2 Sampling Methods

Table 4 summarizes all measurements, methods of collection, and data formats for this study. Table 5 summarizes all parameters, units, technology, and measurement uncertainties for all field measurements

of *in-situ* water quality that will be collected in this study in accordance with SESD Operating Procedure for Field Measurement Uncertainty (USEPA, 2016a) and SESD Table of Field Measurement Uncertainties (Type B) (USEPA, 2016g).

Table 4: Sampling Methods and Data Formats

Measurement	Methodology	Data Format
Surface Water Stage	Operating Procedure for Hydrological Studies (USEPA, 2016d)	Data recorded electronically (file name recorded in field logbook).
<i>In-Situ</i> Water Quality	Operating Procedures for <i>In-situ</i> Water Quality Monitoring (USEPA, 2013), Field pH Measurement (USEPA, 2016b), Field Temperature Measurement (USEPA, 2014a), Field Measurement of Dissolved Oxygen (USEPA, 2017c), Field Specific Conductance Measurement (USEPA, 2016c)	Data recorded electronically (file name recorded in field logbook).
GPS Location Data	Operating Procedure for Global Positioning System (USEPA, 2015)	Data recorded in field logbook.

Table 5: *In-Situ* Water Quality Parameters and Measurement Uncertainties

Parameter	Units	Technology	Measurement Sensitivity
pH	S.U.	Glass Electrode	± 0.2 SU
Dissolved Oxygen	mg/L	Luminescent DO Probe	± 0.2 mg/l $\pm 2\%$ of reading (whichever is greater)
Temperature	°C	LDO Thermistor	± 0.2 °C
Specific Conductance	$\mu\text{S}/\text{cm}$	Nickel Electrode Cell	$\pm 0.5\%$ of reading

4.3 Quality Control

Each sampling, analysis, or measurement technique to be performed for this project has associated Quality Control (QC) requirements. Multi-parameter sondes used for *in-situ* measurements will be verified for operation within established acceptance criteria following the procedures discussed in Section 4.4 of this QAPP. All documents and forms generated from this study will be completed following measurement

guidance described by SESD Operating Procedures and/or other referenced manuals listed in Table 4 of this QAPP, as well as by peer review from SESD scientists.

4.4 Equipment Maintenance and Calibration

All equipment used during this study will be maintained and calibrated according to the requirements of the SESD Operating Procedure for Equipment Inventory and Management (USEPA, 2017b). Calibration procedures for the *in-situ* multi-parameter water quality sondes and low-cost sensor alternatives will be performed in accordance with the SESD Operating Procedure for *In-Situ* Water Quality Monitoring (USEPA, 2013). Each multi-parameter sonde and low-cost sensor used in the study will be calibrated prior to sampling activity or before sonde/sensor deployment. A post operational verification will be performed after retrieval of deployed sondes/sensors. Additional operational verifications may be performed to determine if site conditions have adversely affected the performance of the multi-parameter sondes/sensors, if the field team leader deems it necessary.

4.5 Inspection/Acceptance for Supplies and Consumables

All calibration standards, field equipment, field supplies and field consumables will be inspected and maintained in accordance with the SESD Operating Procedures for Equipment Inventory and Management (USEPA, 2017b), Purchasing of Services and Supplies (USEPA, 2017f), and Field Sampling Quality Control (USEPA, 2017d). The SESD Field Quality Manager and the Branch Quality Assurance Officers (QAOs) are responsible for ensuring that these requirements are met.

4.6 Data Acquisition Requirements for Non-Direct Measurements

Non-direct measurement data include information from site reconnaissance, literature searches, online resources, and interviews. Any measurement data included in information obtained from the above referenced sources will determine further action at the site only to the extent that those data can be verified. If any deficiencies are observed by the QAO, the field project leader and the project requestor will be contacted to aid in the resolution of the problem.

4.7 Data Management

All field data generated during this study will be recorded, stored, and managed in accordance with SESD Operating Procedures for Logbooks (USEPA, 2013d), Control of Records (USEPA, 2017a), and Sample and Evidence Management (USEPA, 2016f). All *in-situ* water quality data will be electronically saved to a file on the multi-parameter sonde recorder or an SD card onboard the low-cost sensor data logger and the file names will be recorded into a bound logbook, along with the dates and times associated with sonde/sensor deployment, maintenance and retrieval. Electronic data files will be downloaded from the sonde/sensor onto a laptop computer. The project co-leaders are responsible for ensuring that all requirements for data management are met.

5.0 Data Analysis and Decision Criteria

5.1 Low-Cost Sensor Accuracy

Low-cost sensor data will be compared to concurrent data collected via multi-parameter sondes in order to evaluate the performance of the open-source/low-cost water quality sensors. In order to assess the accuracy of the low-cost water quality sensors the relative error (RE) between low-cost sensor and sonde data with matching timestamps will be computed for each parameter. Hypothesis tests will be performed on computed REs using a one-sample, one-tailed, t-test on the mean RE. A non-parametric alternative such as the Wilcoxon Sign Rank test will be used if the data violates distribution assumptions of normality. A threshold of < 20% RE is being used as the criteria to determine the low-cost sensors as an appropriate screening tool. A threshold of < 10% RE is being used as the criteria to determine if the low-cost sensors are an appropriate alternative tool for in-situ water quality measurements of temperature, pH, dissolved oxygen, and specific conductance at SESD.

Relative Error (RE):

$$RE_i = \left| \frac{x_i - y_i}{y_i} \right|$$

Where:

x_i = low cost sensor measurement at (time = i)

y_i = sonde measurement at (time = i)

Hypothesis Testing Decision Criteria:

Null Hypothesis (H_0): $\mu \geq \mu_0$ ($\mu_0 = 0.02$ or 0.01)

Alternative Hypothesis (H_a): $\mu < \mu_0$ ($\mu_0 = 0.02$ or 0.01)

Rejection Region: $t \leq -t_{\alpha, n-1}$ ($\alpha = 0.05$, n = sample size)

Test Statistic:

$$t = \frac{\bar{X} - \mu_0}{S / \sqrt{n}}$$

Where:

$$\bar{X} = \text{sample mean} = \frac{\sum_{i=1}^n RE_i}{n}$$

$$S = \text{sample standard deviation} = \sqrt{\frac{\sum_{i=1}^n (RE_i - \bar{RE})^2}{n-1}}$$

5.2 Low-Cost Sensor Precision

The precision of the continuous data collected via the low-cost sensors and multi-parameter sondes will be assessed by computing the root mean square (RMS) of the scaled relative differences of data collected under lab controlled steady-state conditions (Hyslop & White, 2009).

$$RMS \text{ Precision} = \sqrt{\frac{1}{n} \sum_{i=1}^n D_i^2} \times 100\%$$

Where:

$$D_i = \frac{\frac{1}{\sqrt{2}}(x_i - x_{i+1})}{\bar{x}_i}$$

x_i = low cost sensor measurement at (time = i)

x_{i+1} = low cost sensor measurement at (time = $i + 1$)

5.3 Sensor Fouling and Calibration Drift Errors

Cumulative errors due to sensor fouling and calibration drift will be assessed according to the U.S. Geological Survey's Guidelines and Standard Procedures for Continuous Water-Quality Monitors: Station Operation, Record Computation, and Data Reporting (Wagner et al., 2006).

$$E_T = |E_f| + |E_d| \quad (\text{Total Error})$$

Where:

$$E_f = M_a - M_b \quad (\text{Sensor Fouling Error})$$

$$E_d = V_s - V_c \quad (\text{Calibration Drift Error})$$

M_a = sensor reading before cleaning

M_b = *sensor reading after cleaning*

V_s = *known value of calibration standard*

V_c = *sensor reading in calibration standard*

6.0 Assessment and Oversight

6.1 Assessments and Response Actions

All field activities specified in this QAPP will be managed through the Ecology Section of the Field Services Branch (FSB). The project co-leaders for FSB are responsible for conducting assessments during the field investigation in accordance with SEDS Operating Procedure for Project Planning (USEPA, 2016e) to ensure the QAPP is being implemented as approved. The project co-leaders are responsible for all corrective actions while in the field. Any corrective actions or issues that arise during the study will be recorded in the logbook. This documentation and any corrective actions taken will be used to determine the overall quality and usability of the data.

6.2 Reports to Management

The project co-leaders will be responsible for notifying the appropriate SEDS management if any circumstances arise during the field investigation that may adversely impact the quality of the data collected. Any issues documented during field activities that may impact the usability of the data will be addressed in the final report.

7.0 Data Validation and Usability

7.1 Data Review, Validation and Verification

All data derived from SEDS field measurements and sampling will be reviewed, verified, validated and deemed usable in accordance with the SEDS Operating Procedure for Report Preparation and Distribution (USEPA, 2014a).

7.2 Reconciliation with User Requirements

The usability of all data generated from SEDS field activities conducted during this study will be evaluated in accordance with the SEDS Operating Procedure for Report Preparation and Distribution (USEPA, 2014a). All data to be generated in this study were requested to meet the needs of U.S. EPA SEDS and

ORD scientists with associated data quality objectives and criteria outlined in Section 3.5 and Appendix B of this QAPP.

7.3 Applicable Regulatory Information

This is an exploratory study in which *in-situ* water quality data resulting from this project will be collected for the sole purpose of evaluating the low-cost water quality sensors with respect to industry standard equipment.

8.0 References

- Hyslop, N.P. & White, W.H., (2009). *Estimating Precision Using Duplicate Measurements*. Journal of the Air & Waste Management Association, 59:9, pp. 1032-1039, DOI: 10.3155/1047-3289.59.9.1032. <https://doi.org/10.3155/1047-3289.59.9.1032>
- USEPA. (2013). *Operating Procedure for In Situ Water Quality Monitoring*, SESDPROC-111-R3. Region 4, SESD, Athens, GA.
- USEPA. (2014a). *Operating Procedure for Field Temperature Measurement*, SESDPROC-102-R4. Region 4, SESD, Athens, GA.
- USEPA. (2014b). *Operating Procedure for Report Preparation and Distribution*, SESDPROC-003-R5. Region 4, SESD, Athens, GA.
- USEPA. (2015). *Operating Procedure for Global Positioning System*, SESDPROC-110-R4. Region 4, SESD, Athens, GA.
- USEPA. (2016a). *Operating Procedure for Field Measurement Uncertainty*, SESDPROC-014-R2. Region 4, SESD, Athens, GA.
- USEPA. (2016b). *Operating Procedure for Field pH Measurement*, SESDPROC-100-R4. Region 4, SESD, Athens, GA.
- USEPA. (2016c). *Operating Procedure for Field Specific Conductance Measurement*, SESDPROC-101-R6. Region 4, SESD, Athens, GA.
- USEPA. (2016d). *Operating Procedure for Hydrological Studies*, SESDPROC-501-R4. Region 4, SESD, Athens, GA.
- USEPA. (2016e). *Operating Procedure for Project Planning*, SESDPROC-016-R5. Region 4, SESD, Athens, GA.
- USEPA. (2016f). *Operating Procedure for Sample and Evidence Management*, SESDPROC-005-R3. Region 4, SESD, Athens, GA.

- USEPA. (2016g). *Table of Field Measurement Uncertainties (Type B)*, SESDFORM-034-R3. Region 4, SEDS, Athens, GA.
- USEPA. (2017a). *Operating Procedure for Control of Records*, SESDPROC-1001-R0. Region 4, SEDS, Athens, GA.
- USEPA. (2017b). *Operating Procedure for Equipment Inventory and Management*, SESDPROC-1009-R0. Region 4, SEDS, Athens, GA.
- USEPA. (2017c). *Operating Procedure for Field Measurement of Dissolved Oxygen*, SESDPROC-106-R4. Region 4, SEDS, Athens, GA.
- USEPA. (2017d). *Operating Procedure for Field Sampling Quality Control*, SESDPROC-011-R5. Region 4, SEDS, Athens, GA.
- USEPA. (2017e). *Operating Procedure for Logbooks*, SESDPROC-1002-R0. Region 4, SEDS, Athens, GA.
- USEPA. (2017f). *Operating Procedure for Purchasing of Services and Supplies*. SESDPROC-1008-R0. Region 4, SEDS, Athens, GA.
- Wagner, R.J., Boulger, R.W., Jr., Oblinger, C.J., & Smith, B.A., (2006). *Guidelines and standard procedures for continuous water-quality monitors—Station operation, record computation, and data reporting*: U.S. Geological Survey Techniques and Methods 1–D3.
<http://pubs.water.usgs.gov/tm1d3>

Appendix A: Site Maps

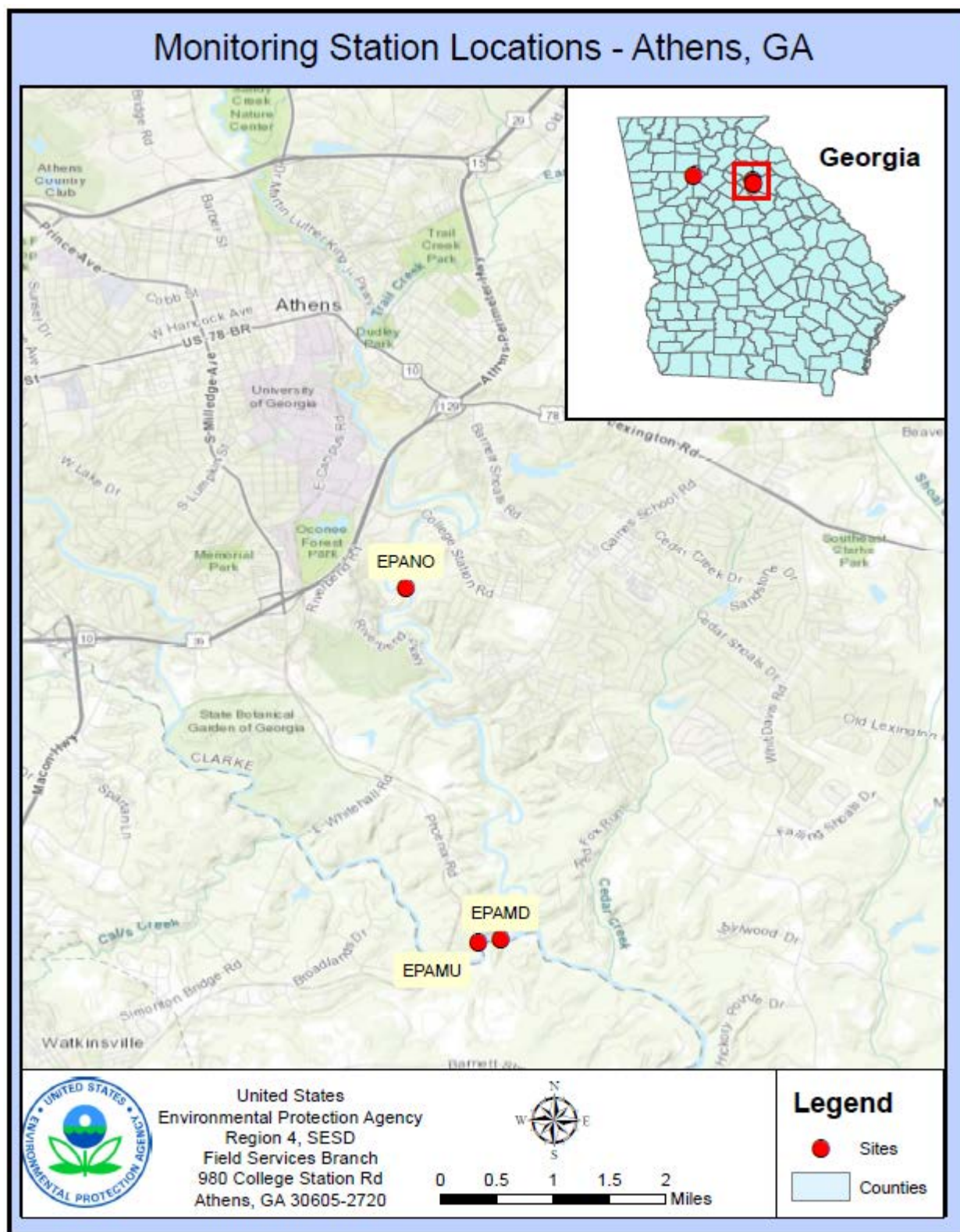


Figure 1: Map of Athens Monitoring Sites



Figure 2: North Oconee River Site Map

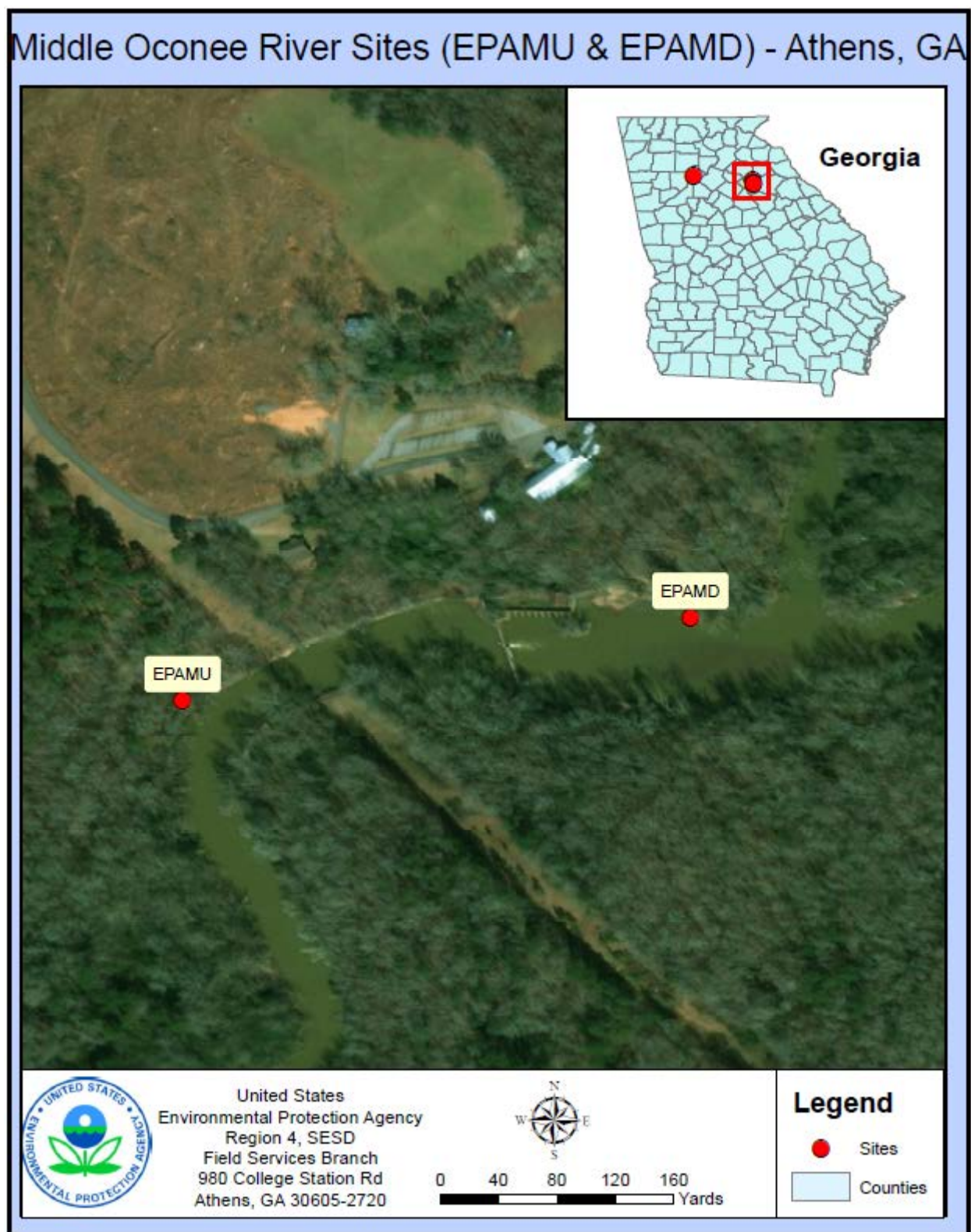


Figure 3: Middle Oconee River Sites Map

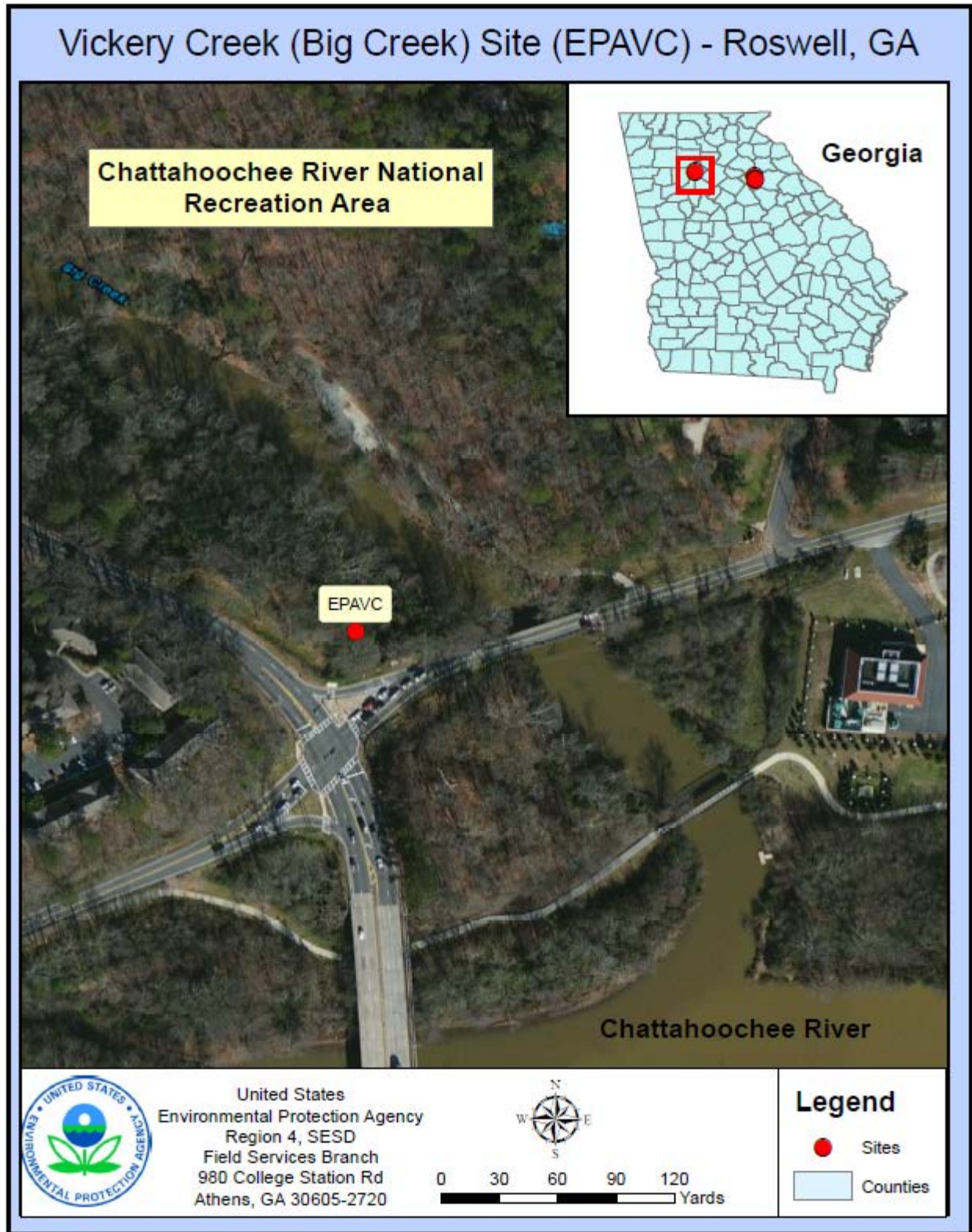


Figure 4: Vickery Creek Site Map

Appendix B: Data Quality Objectives

Evaluation of Low-Cost Sensors for Continuous Water Quality Monitoring

Step	Data Quality Objectives	Description
1	State the problem: - Identify planning team members - Define the problem - Identify primary decision maker - Specify available resources and relevant deadlines for the study	<u>Planning Team:</u> Nathan Barlet, EPA, Region 4, SEDS Derek Little, EPA, Region 4, SEDS <u>Problem Statement:</u> The primary objective of this study is to evaluate the performance of low-cost water quality sensors with respect to industry standard equipment. All decisions based on data will be discussed in the final report by the project co-leaders and peer reviewed by SEDS scientists. Low-cost sensors will be deployed for 3 months between March – June, 2018 and collocated with multi-parameter sondes. The final report is to be completed by July 16 th .
2	Identify the decision: - Identify principal study question - Define action that could result from resolution of principal study question	<u>Principal Study Question:</u> How does the performance of low-cost water quality sensors compare to industry standard equipment with respect to accuracy, precision, and susceptibility to fouling and calibration drift? This is an exploratory study with no associated regulatory or management actions.
3	Identify decision inputs: - Identify required information to resolve decision statement - Identify information needed to establish action level - Confirm methods exist to provide data	Decisions regarding low-cost sensor performance will be based on comparative analysis of data collected from low-cost sensors and industry standard equipment deployed in this study. There are no action levels associated with this study.
4	Define study boundaries: - Specify characteristics of population of interest - Define spatial boundary - Define temporal boundary - Define scale of decision making - Identify practical constraints on the data collection	Parameters of interest include pH, temperature, dissolved oxygen, and specific conductance. Streams are dynamic systems which can display significant variation for above parameters both spatially and temporally. Continuous water quality monitoring stations will be deployed on the North Oconee River and Middle Oconee River in Athens, GA, as well as on Vickery Creek in Roswell, GA, for a period of 3-months. All sites were selected based on reasonable site access and security. Decisions from this study will focus solely on the performance of the low-cost sensors. Data collection constraints include inclement weather, funding and personnel availability.

Evaluation of Low-Cost Sensors for Continuous Water Quality Monitoring

Step	Data Quality Objectives	Description
5	Develop a decision rule: - Specify the statistical parameter of interest - Specify the action level for the study - Develop a decision rule	Decisions of low-cost sensor performance will be based on comparing the relative error (RE) of <i>in-situ</i> measurements of sondes to low-cost sensor alternatives. Computed REs will be compared to thresholds of 20% and 10% using one-sample, one-tailed t-tests. There are no regulatory or management action levels for this study.
6	Specify decision error limits: - Determine possible parameter ranges - Identify the decision errors and null hypothesis - Specify a range of possible parameter values where the consequence of decision errors is relatively minor - Assign probability limits that reflect tolerable probability for the occurrence of decision errors	The null hypothesis is that the mean RE between sondes and low-cost sensors will be greater than or equal to the thresholds of 10% and 20%. A type-1 error probability of 5% ($\alpha = 0.05$) will be used in this study.
7	Optimize the design for obtaining data: - Review DQO outputs and existing environmental data - Develop general data collection design alternatives - Formulate the mathematical expressions needed to solve the design problems for each data collection design alternative - Select the optimal sample size that satisfies the DQOs for each data collection design alternative - Select the most resource effective data collection design that satisfies all of the DQOs - Document the operational details and theoretical assumptions of the selected design in the sampling and analysis plan	Limited data exists on emerging technologies such as low-cost sensors for continuous water quality monitoring. This exploratory study was designed to utilize existing EPA resources and low-cost sensors built as part of an ORD Regional/State Innovations project initiative.

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