

# **Verification Statement**



## Stony Brook Nitrogen Sensor Registration number: (V-2021-09-01) Date of issue: 2021-September-23

Technology type	Nitrogen Sensor			
Application	Sensor for real-time nitrate plus nitrite and ammonium measurement in wastewater treatment system effluent			
Company	The Research Foundation for the State University of New York			
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## Verified Performance Claim

Operating at a temperature not lower than 4°C under low sample turbidity, a single Stony Brook Nitrogen Sensor unit provides simultaneous detection and measurement of nitrate plus nitrite and ammonium concentrations with no interferences from cations, anions, and dissolved organic matter in domestic wastewater matrices, with varying frequency of readings (hourly, daily, weekly, monthly).

Verified performance of the sensor, based on third-party testing over a six-month period, includes the following:

**Measured Parameters**: Nitrate (NO<sub>3</sub><sup>-</sup>) plus nitrite (NO<sub>2</sub><sup>-</sup>) and ammonium (NH<sub>4</sub><sup>+</sup>) in a single sample stream

**Accuracy**: Bias  $\leq 20$  % using wastewater (as defined in the Test/Quality Assurance Plan<sup>1</sup>) with selfcalibration, self-cleaning and self-sensor recovering after power outage

**Precision**: RSD  $\leq$  20 % using wastewater (as defined in the T/QAP)

Selectivity: No interferences from cations, anions, and dissolved organic matter in wastewater

Response range: 2 to 70 N-mg/L for NO3<sup>-</sup> , NO2<sup>-</sup> , NH4<sup>+</sup>

Limit of detection: 2 N-mg/L

Measurement frequency: Variable frequency of readings (hourly, daily, weekly, monthly)

**Data management**: Record and automatically transmit data to designated server on the cloud, including remote capability of programming variable sampling frequencies.

<sup>&</sup>lt;sup>1</sup> Test Quality Assurance Plan (T/QAP) Phase II of the Advanced Septic System Nitrogen Sensor Challenge, Revision 3.0, June 2019, Battelle and EPA, 2019



## **Technology Application**

The Stony Brook Nitrogen Sensor<sup>2</sup> can be directly deployed with advanced septic systems or Innovative/Alternate Onsite Wastewater Treatment Systems (I/A OWTSs) for real-time nitrate plus nitrite and ammonium measurement in the system effluent with a range of 2 to 70 N-mg/L nitrogen, with a frequency of every hour, day, week or anytime scheduled. It could also be used for in-situ nitrogen monitoring in surface water when nitrogen concentration is < 2 N-mg/L if a more sensitive probe is used.

The Stony Brook Nitrogen Sensor could also measure nitrate plus nitrite and ammonium for real-time process control at municipal wastewater treatment plants (WWTPs). Because the sensor is self-cleaning and self-calibrating, it can measure these nitrogen species accurately and reliably in real time for months at a time without taxing instrumentation maintenance staff. Because the sensor is relatively inexpensive, multiple units could be deployed at multiple key points in a WWTP process such as in screened primary effluent, aeration basin influent, aeration basin effluent and final effluent.

## **Technology Description**

The Stony Brook Nitrogen Sensor is designed for in-situ, long-term deployment in domestic wastewater treatment systems, and for low maintenance (i.e., no more than quarterly), self-calibration, self-cleaning, self-sensor recovering after power outage and remote data transmission. The sensor can continuously and simultaneously measure real-time nitrate plus nitrite and ammonium concentrations.

Operation of the Stony Brook Nitrogen Sensor requires 12-volt DC power (or suitable battery/charging system), Internet access over Wi-Fi, and temperature of 4 to 35°C.

A picture of the sensor box (measuring 1 cubic foot), similar to the one used during testing, is shown in Figure 1. Constant data readings are automatically transmitted to designated server/cloud.



Figure 1. Stony Brook Nitrogen Sensor Housing

Stony Brook University describes the Stony Brook Nitrogen Sensor as Technology Readiness Level (TRL) 7 based on the sensor system being at, or near, the scale of the operational system, with most functions available for demonstration and use. The Research Foundation for the State University of New York has a patent pending on the Stony Brook Nitrogen Sensor.

<sup>&</sup>lt;sup>2</sup> Stony Brook Nitrogen Sensor as set forth in the State University of New York (SUNY) Research Foundation New Technology Disclosure 050-9145 and as further developed by Dr. Qingzhi Zhu and colleagues at Stony Brook University



## **Description of Test Procedure**

Field performance testing of the Stony Brook Nitrogen Sensor took place over a six-month period, from November 2020, through May 2021, at the Massachusetts Alternative Septic System Testing Center (MASSTC) located at 4 Kittridge Road, Buzzards Bay, MA. The U.S. Environmental Protection Agency (EPA) designed the test to evaluate the dynamic range, precision, accuracy, and stability of nitrogen sensors under controlled performance conditions following a Test Quality Assurance Plan (T/QAP)<sup>3</sup> prepared by Battelle. The T/QAP specified test procedures and a schedule to test the performance of the Stony Brook Nitrogen Sensor using effluent from advanced septic systems by evaluating the accuracy, precision, and range of nitrate (NO3-) and ammonium (NH4+) measurements in different wastewater mixtures. Table 1 provides a list of all test fluid solutions used in the six-month field performance test. Standards and spikes were prepared by mixing the indicated salts with deionized water immediately before being added to the test cell.

1. Low Standard Tap Water spiked with:	- Nitrate solution (KNO3)): 1-15 mg N/L
	- Ammonium solution (NH4CI): 10-15 mg/L
	- Nitrite solution (KNO2): 0.25-1 mg N/L
2. Medium Standard Tap Water spiked with:	- Nitrate solution (KNO3): 10-40 mg N/L
	- Ammonium solution (NH4CI): 10-40 mg/L
	- Nitrite solution (KNO2): 1-4 mg N/L
3. High Standard Tap Water spiked with:	- Nitrate solution (KNO3): 30-60 mg N/L
	- Ammonium solution (NH4CI): 30-60 mg/L
	- Nitrite solution (KNO2): 4-8 mg N/L
4. Treated Sewage Effluent	Secondary treated effluent that has passed through a traditional septic
-	system and then through additional innovative/advanced nitrogen removal
	treatment.
5. Matrix Spike – Treated Sewage Effluent	- Nitrate solution (KNO3): 1-15 mg N/L
spiked with Low Standard:	- Ammonium solution (NH4CI): 10-15 mg/L
	- Nitrite solution (KNO2): 0.25-1 mg N/L
6. Primary Sewage Effluent	Raw primary treated effluent direct from a traditional septic system without
	additional treatment for nitrogen removal.

#### Table 1 - Test Fluid Solutions for 6-month Field Performance Test

Testing was conducted inside a temperature-controlled trailer on the MASSTC property to facilitate sensor testing using effluent from different advanced septic treatment technologies installed and in use at the Center. The trailer provided heat and air conditioning to protect the contents of the sensor test cell from freezing and overheating. The sensor was immersed in fluids with a temperature range between 5.9 and 20.8°C, measured by MASSTC's Yellow Springs Instrument (YSI) probe. The sensor recorded air temperatures in the range of 3 to 25°C.

The intake tubing for the Stony Brook Nitrogen Sensor was placed or immersed in a sensor test cell, a circular enclosed tub made of plastic, approximately 2 feet in diameter and 1 foot in depth. The thickness of the outside wall of the test cell was approximately ¼ inch. The septic system treatment unit discharge effluent entered the sensor test cell via flow-through plumbing, which was situated at the top of the test cell and exited at the center bottom of the test cell, with the sensor being tested just outside of the tub. A positive displacement mixing pump was used inside the tub to ensure uniform sensor exposure to the challenge and field performance test solutions. Figure 2 shows the nitrogen sensor test cell.



#### Figure 2. The Nitrogen Sensor Test Cell at MASSTC

<sup>&</sup>lt;sup>3</sup> Test Quality Assurance Plan (T/QAP) Phase II of the Advanced Septic System Nitrogen Sensor Challenge, Revision 3.0, June 2019, Battelle and EPA, 2019



120-volt alternating current (AC) power was available inside the trailer for use by the sensor system. The sensor's power adapter converts the 120-volt AC to the sensor's required 12-volt DC. The sensor had to maintain electrical isolation between the fluid, 120-volt AC power, and earth ground to prevent galvanic issues or ground looping. The sensor system (sensor and associated connections and tubing) could not discharge or release any substance into the test cell that would alter the test fluid. The sensor itself was located outside the test cell but was connected to two intake tubes inside the test vessel, which fed sample fluid to the sensor at predetermined sampling times to take measurements during the performance test.

Stony Brook set up and calibrated the sensor prior to initiating the six-month field performance test. The Barnstable County Department of Health and Environment (BCDHE) laboratory located in Barnstable, Massachusetts, independently analyzed discrete septic test fluid and wastewater samples using standard EPA test methods.

The field performance test had two components: off-line testing and on-line effluent testing. During the off-line testing (intake valves of the test cell closed), sampling for laboratory testing and sensor readings were conducted simultaneously. The sensor test cell was sequentially filled with tap water, low standard test fluid, medium standard test fluid, and high standard test fluid. Nitrogen salts to prepare the standards were supplied by U.S. EPA Region 1 personnel. The sensor test cell was mixed for one hour, and a time stamped laboratory sample was collected no less than 50 minutes after the introduction of each test fluid. During the off-line part of the test, the flow-through septic fluid plumbing was turned off so the test fluid was "off-line" or static.

During the on-line effluent monitoring phase, the flow-through valves were opened and used to deliver the live advanced septic system effluent to the sensor. Testing was done using the advanced OWTS treated effluent and raw untreated wastewater effluent (to simulate OWTS failure).

During off-line testing (valves of the test cell closed), the sensor was supplied with tap water alone, or with tap water spiked with a test fluid solution. Measured standard spikes were added manually with test cell water rinse. Other test fluids were supplied to the sensor through a gravity-fed calibration inlet with test cell valves open (on-line). Sensor probes or inlet tubing immersed in each test fluid solution were supplied for no less than 50 minutes prior to sampling.

During on-line testing, twenty-four hours prior to sampling, MASSTC staff introduced live advanced septic system on-line effluents to ensure that the test vessel was flushed and uniform before taking a test sample. MASSTC staff collected samples throughout the performance test period following procedures described in the T/QAP. MASSTC used a polyethylene bottle to collect grab samples of the test vessel fluid, which were then aliquoted to the appropriate sample containers, preserved if necessary, and submitted to the BCDHE laboratory for analysis. The sensor provided results for nitrate plus nitrite and ammonium as nitrogen. BCDHE analyzed samples for nitrate, nitrite, and ammonium as nitrogen. Each grab sample was documented, and date and time stamped. Samples were transported to the BCDHE laboratory for analysis using appropriate chain-of-custody procedures to ensure analysis holding times were met.

Test vessel measurements of pH, dissolved oxygen (DO), conductivity, and temperature were performed after each test fluid was stabilized and during each sampling period. The measurement of these test vessel solution parameters was performed with a YSI ProDSS Multi Probe Sensor (MPS) by MASSTC personnel. All calibrations, field observations, and data were recorded in the sampling logbook. An electronic download of these data was provided to Battelle for review.

The Stony Brook Nitrogen Sensor recorded sensor readings remotely and then transferred the data to an Excel spreadsheet, which was provided to Battelle for review.

## Performance Test Results

The Stony Brook Nitrogen Sensor was tested for accuracy, precision, range, and completeness of data return as the sensor was exposed to a range of test fluids over the duration of the six-month field performance test. Data from the sensor were compared to laboratory analytical data from samples taken at specific time intervals.



**Accuracy** was estimated by comparisons between reference and measured values. A percent recovery was determined for each sensor reading against each laboratory value. Mean recoveries were determined for each similar test material by parameter tested. Data accuracy results are summarized in Table 2 for each test fluid (i.e., all test fluids, standard solutions only, and wastewater).

Stony Brook Nitrogen Sensor recoveries for nitrate plus nitrite range from 46.8% to 115.36%. Of the 123 calculable recoveries, 119 or 96.75% are within the performance criteria of 80 to 120%. Stony Brook Nitrogen Sensor recoveries for ammonium ranged from 81.96% to 136.39%. Of the 79 calculable recoveries, 77 or 97.47% are within the performance criteria of 80 to 120%.

	% Recovery 80-120%					
	All Test Fluids		Standard Solutions		Wastewater	
	Nitrate + Nitrite-N	Ammonium-N	Nitrate + Nitrite-N	Ammonium-N	Nitrate + Nitrite-N	Ammonium-N
Minimum	46.80%	81.96%	46.80%	82.12%	79.16%	81.96%
Maximum	115.36%	136.39%	115.36%	113.14%	108.27%	136.39%
Average	93.46%	98.79%	94.36%	97.93%	93.12%	99.40%
Available						
Points	123	79	34	33	89	46
# In Control	119	77	31	33	88	44
% In Control	96.75%	97.47%	91.18%	100%	98.88%	95.65%

#### Table 2. Stony Brook Nitrogen Sensor 6-Month Performance Test – Accuracy Summary in Different Test Fluids

**Precision** is closeness of agreement between independent test results obtained under stipulated controlled conditions. Relative standard deviation (RSD) was used to provide precision measurements where repeated measurements (n=3) during testing were done with sensors placed in, or exposed to, known stable test fluid conditions. Data precision results are summarized in Table 3 for each test fluid (i.e., all test fluids, standard solutions only, and wastewater).

RSD results were calculated for all sensor results where replicate measurements were collected. All RSD results (37 for nitrate plus nitrite and 25 for ammonium) met the performance criteria of  $\leq$ 20% RSD for both nitrate plus nitrite and ammonium in all test fluids.

	% RSD ≤20%					
	All Test Fluids		Standard Solutions		Wastewater	
	Nitrate + Nitrite-N	Ammonium-N	Nitrate + Nitrite-N	Ammonium-N	Nitrate + Nitrite-N	Ammonium-N
Minimum	0.30%	0.73%	1.22%	0.76%	0.30%	0.73%
Maximum	14.55%	6.61%	14.55%	6.61%	5.20%	6.59%
Average	2.35%	3.27%	4.06%	2.64%	1.72%	3.69%
Available						
Points	37	25	10	10	27	15
# In Control	37	25	10	10	27	15
% In Control	100%	100%	100%	100%	100%	100%

#### Table 3. Stony Brook Nitrogen Sensor 6-Month Performance Test – Precision in Different Test Fluids

**Range** is the upper and lower-level limits of detection and quantification, determined by an analysis of the variance within repeated sensor readings on a known test solution of the measurement parameter. Table 4 provides a summary of the concentration ranges and the counts of samples collected for each parameter for the BCDHE laboratory and the Stony Brook Nitrogen Sensor.

The exposed (lab) and measured (sensor) ranges of the nitrate plus nitrite data were 2.24 mg/L to 79.6 mg/L and 2.34 mg/L to 70.83 mg/L, respectively. The exposed and measured ranges of the ammonium data were 0.32 mg/L to 48 mg/L and 2.14 mg/L to 47.67 mg/L, respectively.



The performance claim range is <2 to 70 mg/L. For nitrate plus nitrite that range was achieved. For ammonium, spiked levels to 70 mg/L were not provided during the six-month field performance test, even though the ammonium spike concentrations used in the six-month field performance test were within the planned concentrations of the T/QAP design. However, linearity for ammonium as nitrogen was shown to be  $r^2$ =0.997, indicating linearity from 2 to 70 mg/L is likely.

	BCDHE Laboratory		Stony Brook Nitro	gen Sensor
	Nitrate + Nitrite-N	Ammonia-N	Nitrate + Nitrite-N	Ammonium-N
Minimum	2.24	0.32	2.34	2.14
Maximum	79.6	48	70.83	47.67
Average	26.09	11.12	25.02	11.81
Non-detect or <2	8	48	9	50
Total Detected	129	89	124	83
Missed Samples <sup>1</sup>	1	1	5	5
Total Samples	138	138	138	138

Note - Minimum, maximum, and average concentrations are in mg/L.

1 - Sensor missed samples are from power outage. Laboratory missed sample from MASSTC failed collection.

## Table 4. Stony Brook Nitrogen Sensor 6-Month Field Performance Test – Concentration Ranges and Counts of Samples Collected

**Completeness** is the amount of time the sensor operates in a submerged deployment setting without needing maintenance or recalibration. Sensor data were recorded hourly when samples were being collected for the laboratory and daily when no samples were being collected. Comparisons were also made of the percent data recovered as a proportion of the planned data collected during its deployment period.

Table 5 shows the number of hourly and daily (depending on the sampling activity) sensor readings planned and completed each month and a completeness summary. The T/QAP called for a total of 465 sensor readings to be taken for nitrate plus nitrite and ammonium over the full six-month period. One reading was a planned failure, so 464 readings were planned. 15 readings were missed due to power outages or Wi-Fi loss. Considering power and Wi-Fi loss are outside the sensor control, function of the sensor showed completeness as 100%.

Month	# Hourly Readings	# Daily Readings	Total Planned Readings	Adjusted Total	Total Completed Readings	% Complete (based on Total Planned)	% Complete (based on Adjusted Total)	Missed Readings	Reason
1	121	20	141	140	140	99%	100%	1	Planned power off
2	33	28	61	56	56	92%	100%	5	Power outage
3	44	27	71	63	63	89%	100%	8	No Wi- Fi
4	33	28	61	59	59	97%	100%	2	No Wi- Fi
5	33	28	61	61	61	100%	100%	0	
6	44	26	70	70	70	100%	100%	0	
Total	308	157	465	449	449	97%	100%	16	

Note - Adjusted Total =Total Planned Readings minus readings omitted due to conditions outside the control of the sensor (i.e., power outage and loss of Wi-Fi).

#### Table 5. Stony Brook Nitrogen Sensor 6-Month Field Performance Test – Completeness Summary

Two maintenance visits were performed during the six-month period, which included adding additional reagents, dumping the sensor waste containers, recalibrating the sensors, changing pump tubing, checking for leaking, and other preventive maintenance.



At the conclusion of the test, on May 10, 2021, the Stony Brook Nitrogen Sensor team, the U.S. EPA Coordinator, and the Battelle Quality Assurance Officer inspected the condition of the sensor. The sensor was in a condition good enough that with some minor preventive maintenance the sensor team left the sensor at MASSTC for another six-month testing period to continue to evaluate the performance of the sensor.

## Verified Performance

Verification of the Stony Brook Nitrogen Sensor was conducted by Battelle Memorial Institute (505 King Avenue, Columbus, OH 43201 USA) in accordance with the International Organization for Standardization (ISO) standard for environmental technology verification (ETV), ISO 14034:2016, and the VerifiGlobal Performance Verification Protocol. A Verification Plan was prepared by VerifiGlobal to guide the verification process<sup>4</sup>.

The performance claim verification is based on data and information provided by Stony Brook University and test results obtained through third-party testing at the Massachusetts Alternative Septic System Testing Center (MASSTC) and the Barnstable County Department of Health and Environment (BCDHE) laboratory.

BCDHE provided 49 data reports for the full six-month field performance test to the Battelle for compliance review to laboratory SOP requirements and the T/QAP. Battelle verified 100 percent of the reported results with the laboratory data reports and recalculated 10 percent of the sample results from the raw data. All laboratory method blanks, laboratory fortified blanks (LFBs), laboratory duplicates, and laboratory fortified matrix samples (LFMs) were within method control limits. All calibration criteria were met.

Figures 3 and 4 provide the plots of the sensor data and laboratory data for nitrate plus nitrite and ammonium, respectively, for the six-month field performance test. As shown in the figures, the sensor and laboratory data overlap, indicating significant agreement. The blue sensor data lines tracked throughout the time period, whereas the orange laboratory data lines only tracked periodically when samples were collected. When both laboratory and sensor data are displayed, the overlap is such that only one line is visible, showing complete agreement.

To illustrate the accuracy of the Stony Brook Nitrogen Sensor, the sensor data were plotted against the laboratory data, showing correlation coefficients of 0.986 for nitrate plus nitrite and 0.997 for ammonium, where non-detects were reported as zero. The linear regression of laboratory results versus sensor results is shown in Figure 5.

The performance claim for the Stony Brook Nitrogen Sensor specified that the accuracy is based on "using wastewater". The six-month field performance test utilized both standard solutions and wastewater test fluids. Table 2 shows a summary of all test fluid accuracy results, just standard solutions, and the wastewater accuracy results. Based on the wastewater results only, one nitrate plus nitrite result exceeded the performance claim goal of  $\leq 20\%$  bias out of 89 possible readings (99% of the data were in control), with an average of 93.12% recovery. Ammonium had two exceeded wastewater results out of 46 possible readings (96% of data were in control), with an average of 99.4% recovery.

<sup>&</sup>lt;sup>4</sup> VerifiGlobal. 2021. Verification Plan for The Research Foundation for the State University of New York Stony Brook University New York State Center for Clean Water Technology, Stony Brook Nitrogen Sensor. June 2021





Figure 3. Stony Brook Nitrogen Sensor – Comparison of Nitrate and Nitrite Nitrogen as Measured by the Sensor and in Lab Samples



Figure 4. Stony Brook Nitrogen Sensor – Comparison of Ammonium Nitrogen as Measured by the Sensor and in Lab Samples

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Figure 5. Stony Brook Nitrogen Sensor – Linear Regression of Laboratory Results versus Sensor Results

Table 6 below provides a summary of the verified Stony Brook Nitrogen Sensor performance claim in relation to the sensor test results.

Attribute	Performance Claim Met	Stony Brook Nitrogen Sensor Performance Summary Comments
Parameter	Yes. Measures Nitrate and Nitrite (NO₃'/NO₂') and Ammonium (NH₄+)	Measures NO <sub>3</sub> <sup>-</sup> plus NO <sub>2</sub> <sup>-</sup> , not NO <sub>3</sub> <sup>-</sup> only. However, NO <sub>3</sub> <sup>-</sup> plus NO <sub>2</sub> <sup>-</sup> provides additional data towards TN. Also measures NH <sub>4</sub> <sup>+</sup>
Data Management	Yes. Records and automatically transmits data to designated server on the cloud.	Internal computer tracks data. Data accessible to sensor developer over the internet. Sensor reading frequencies are programmable remotely. Daily and hourly reading options demonstrated during the six-month field performance test. Also, had a situation which required change in sampling schedule during the field performance test due to a holiday necessitating the sensor developer to revise the sampling schedule of the sensor remotely after deployment, which was done without an issue.
Applicability & Accessibility	Yes. Can be directly deployed with advanced septic systems or I/A OWTS for real-time NO <sub>3</sub> /NO <sub>2</sub> <sup>-</sup> and NH <sub>4</sub> <sup>+</sup> measurement and in WWTPs.	During the six-month period, the sensor was subject to six different treated sewage effluent fluids and ranges in concentrations from 2 to 70 mg N/L for nitrate plus nitrite and 2 to 50 mg N/L for ammonium, showing diversity in conditions and concentrations.
Frequency of Sensor System Maintenance	Yes. Sensor designed for in- situ, long-term deployment in wastewater systems with low maintenance (i.e., no more than quarterly), self- calibration, self-cleaning.	Two maintenance visits were included in the Verification Plan and were completed on December 4, 2020 and March 4, 2021. The maintenance that was done was only preventative and not for repairs. The chemical reagents, waste solution, nitrogen reactors, pump tubing and flow cell were checked. Reagents were topped off and waste emptied. No repairs were necessary.
Accuracy: Bias ≤ 20 % using wastewater	Yes. 97% of data met criteria	<ul> <li>119 of 123 recoveries (97% of data) for nitrate plus nitrite are within ±20% recovery range with total average recovery of 93.46% in all test fluids. The low recoveries for nitrate plus nitrite may be due to the test vessel recirculation being left on Feb. 3, 2021 (a deviation from the test design).</li> <li>77 of 79 recoveries (97% of data) for ammonium are within ± 20% recovery range with total average recovery of 98.79% in all test fluids.</li> <li>The performance claim specifies accuracy in "wastewater". Evaluating only the wastewater samples (not the standard solutions), 88 of 89 recoveries (99% of data) for</li> </ul>



		nitrate plus nitrite are within ±20% recovery range and 44 of 46 (96% of data) for ammonium are within ±20% recovery range.
Precision: RSD ≤ 20 % using wastewater	Yes. All data met criteria	All %RSD results met the ideal criteria of ≤20% RSD for both parameters (nitrate plus nitrite and ammonium). The highest %RSD for nitrate plus nitrite was 14.55% and the highest for ammonium was 6.61% in all test fluids. The performance claim specifies precision in "wastewater". Evaluating only the wastewater samples (not the standard solutions), all %RSD results met the ≤20% RSD for both parameters.
Range	Yes. Response range is 2 - 70 N-mg/L for NO3- , NO2- , NH4+	Range measured for nitrate plus nitrite-N was <2 to 70.83 mg/L. Note: lowest reported value was 2.34 mg/L. Range measured for ammonium-N was <2 to 47.67 mg/L. Note: lowest reported value was 2.24 mg/L. For ammonium, spiked levels to 60 mg/L were not provided during the six-month field performance test, however, linearity was shown to be r <sup>2</sup> = 0.997.
Frequency of Sensor Readings <sup>1</sup>	Yes. frequency: Variable frequency of measurement readings (hourly, daily, weekly, monthly)	The sensor provided daily and hourly readings throughout the six-month field performance test, varying depending on when laboratory sampling was performed. The schedule adjustment was also available remotely. 449 readings recorded out of 449 obtainable readings (with power and Wi-Fi) for nitrate plus nitrite and ammonium. 100% completion.
Sensor Operating Temperature Range	Yes. Operates at a temperature not lower than 4 <sup>o</sup> C	The water temperature of the test cell was recorded during the performance test, but the air temperature was not independently recorded. The test cell water temperature range was 5.9°C to 20.8°C. The sensor recorded air temperature range from 3°C to 25°C; therefore, this attribute was achieved.
Deployment	Yes. Sensor designed for in- situ, long-term deployment in wastewater systems	The sensor operated the entire six-month period as documented from the hourly or daily readings received. The only times the system was not working was when there was a power outage. The sensor automatically recovered after power outage.
Selectivity	Yes. There are no interferences from cations, anions, and dissolved organic matter in wastewater	Accuracy recoveries of nitrate plus nitrite and ammonium within 80 to 120% demonstrate selectivity of sensor within complex matrices, which likely contain multiple cations, anions, and dissolved organic matter.
Limit of Detection	Yes. Limit of detection is 2 N- mg/L	The lowest value reported when not detected was 2 N-mg/L.

Table 6. – Summary of verified Stony Brook Nitrogen Sensor performance claim in relation to sensor test results.

## Variance

Only three deviations from the test schedule in the T/QAP were noted. These were: - One laboratory sample (1110-APD-MS-1) was not collected for analysis on November 10, 2020, which resulted in loss of data to determine accuracy of the sensor based on that sample.

- A power outage on December 7, 2020 resulted in the loss of 5 sensor data readings.

- Test vessel recirculation was left on when it was supposed to be turned off during off-line testing on February 3, 2021.

The verifier determined that these deviations did not alter the performance of the technology (i.e., the sensor continued to operate and/or restart after power was restored). There may have been some low recoveries due to the test vessel recirculation being left on but the overall performance of the sensor was not affected.

#### **Quality assurance**

Performance testing and verification of the Stony Brook Nitrogen Sensor were conducted in accordance with the requirements of ISO 14034:2016 and the VerifiGlobal Performance Verification Protocol. The verifier, Battelle, has confirmed that quality assurance requirements were addressed throughout the performance testing process and in the generation of performance test results. This includes reviewing all data sheets and data downloads, as well as overall management of the test system, quality control and data integrity.

In November 2020, the Battelle Quality Assurance Officer visited the MASSTC site to observe the project setup, sampling procedures, and chain-of-custody process in the field. Project conditions, sampling procedures, and chain-of-custody process were compliant with the T/QAP. Field documentation and calibration documentation were complete. The Battelle QAO also visited the BCDHE Laboratory to review the project sampling scope and T/QAP requirements with the Laboratory Director and analysts to ensure readiness for the upcoming performance sample analysis. No issues were found. In December 2020, Battelle completed and submitted an ISO 17025 audit checklist review of BCDHE as a more in-depth review of the laboratory's QA processes.



## **Verification Summary**

In summary, the Stony Brook Nitrogen Sensor<sup>5</sup> can be directly deployed with advanced septic systems or Innovative/Alternate Onsite Wastewater Treatment Systems (I/A OWTSs) for real-time nitrate plus nitrite and ammonium measurement in the system effluent with a range of 2 to 70 N-mg/L nitrogen, with a frequency of every hour, day, week or anytime scheduled. It could also be used for in-situ nitrogen monitoring in surface water when nitrogen concentration is < 2 N-mg/L if a more sensitive probe is used.

The verified performance claim is as follows:

Operating at a temperature not lower than 4°C under low sample turbidity, a single Stony Brook Nitrogen Sensor unit provides simultaneous detection and measurement of nitrate plus nitrite and ammonium concentrations with no interferences from cations, anions, and dissolved organic matter in domestic wastewater matrices, with varying frequency of readings (hourly, daily, weekly, monthly).

Based on the results of a six-month field performance test conducted at MASSTC during the period of November 2020 to May 2021, this verification of the Stony Brook Nitrogen Sensor confirms the following:

**Measured Parameters**: nitrate (NO<sub>3</sub><sup>-</sup>) plus nitrite (NO<sub>2</sub><sup>-</sup>) and ammonium (NH<sub>4</sub><sup>+</sup>) in a single sample stream

**Accuracy**: bias  $\leq$  20 % using wastewater (as defined in the Test/Quality Assurance Plan<sup>6</sup>) with selfcalibration, self-cleaning and self-sensor recovering after power outage

**Precision**:  $RSD \le 20$  % using wastewater (as defined in the T/QAP)

Selectivity: no interferences from cations, anions, and dissolved organic matter in wastewater

Response range: 2 to 70 N-mg/L for NO3<sup>-</sup>, NO2<sup>-</sup>, NH4<sup>+</sup>

Limit of detection: 2 N-mg/L

Measurement frequency: variable frequency of readings (hourly, daily, weekly, monthly)

**Data management**: record and automatically transmit data to designated server on the cloud, including remote capability of programming variable sampling frequencies.

The verified performance test results also confirm that:

- The Stony Brook Nitrogen Sensor operated continuously during the 6-month period with 449 readings out of 449 achievable readings (100% completion).

- The concentration ranges of the sensor were: <2 to 70.83 milligrams per liter (mg/L) for nitrate plus nitrite as nitrogen and <2 to 47.67 mg/L for ammonium

- 119 of 123 recoveries in all test fluids for nitrate plus nitrite were within the ±20% recovery range with average recovery of 93.46%

- 77 of 79 recoveries in all test fluids for ammonium were within the ±20% recovery range with average recovery of 98.79%.

- The sensor operated within an air temperature range of 3°C to 25°C and a water temperature range of 5.9°C to 20.8°C.

- Two maintenance visits were conducted during the six-month field performance test as preventive maintenance, not repair visits.

- All sensor components were contained in a 1 cubic foot box.

<sup>&</sup>lt;sup>5</sup> Stony Brook Nitrogen Sensor as set forth in the State University of New York (SUNY) Research Foundation New Technology Disclosure 050-9145 and as further developed by Dr. Qingzhi Zhu and colleagues at Stony Brook University

<sup>&</sup>lt;sup>6</sup> Test Quality Assurance Plan (T/QAP) Phase II of the Advanced Septic System Nitrogen Sensor Challenge,

Revision 3.0, June 2019, Battelle and EPA, 2019. Note: Some of the qualitative attributes included in the original EPA challenge performance goals, such as installation price and system lifetime, were not verified.



## What is ISO 14034?

The purpose of environmental technology verification is to provide a credible and impartial account of the performance of environmental technologies. Environmental technology verification is based on a number of principles to ensure that verifications are performed and reported accurately, clearly, unambiguously and objectively. The International Organization for Standardization (ISO) standard for environmental technology verification (ETV) is ISO 14034, which was published in November 2016.

## Benefits of ETV

ETV contributes to protection and conservation of the environment by promoting and facilitating market uptake of innovative environmental technologies, especially those that perform better than relevant alternatives. ETV is particularly applicable to those environmental technologies whose innovative features or performance cannot be fully assessed using existing standards. Through the provision of objective evidence, ETV provides an independent and impartial confirmation of the performance of an environmental technologies by supporting informed decision-making among interested parties.

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