



Evaluation of Multiparameter Water Meter for Environmental Toolkit for Expeditionary Operations

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PURPOSE: A new, commercially available, field-portable water sensor was evaluated for efficacy during operation and compatibility with current Environmental Toolkit for Expeditionary Operations (ETEO) software. The ETEO provides sensors to Soldiers to rapidly identify and quantify environmental contamination in soil, air, and water at potential new base sites during initial reconnaissance to ensure Soldier safety and minimize unnecessary remediation efforts by the Army. The primary objective of this study was to enhance ETEO performance by providing the capability to evaluate multiple water quality properties simultaneously.

BACKGROUND: The US Army currently faces several obstacles when accomplishing Environmental Baseline Survey (EBS) reporting. Soldiers often have minimal expertise collecting environmental samples/data and lack the appropriate tools to collect and process data at potential base sites. Therefore, collected environmental samples often cannot be analyzed in real time on-site, and delays to data analysis occur. These limitations restrict awareness of environmental contamination that could be harmful to the Soldiers' health and readiness. Also, lack of information about baseline environmental contamination leads to additional remediation efforts, as preexisting contamination cannot be effectively differentiated from new contamination when land is transferred back to a host nation. The ETEO has been developed as an intuitive solution to provide the capability to screen for multiple environmental contaminants and enable Soldiers to easily and comprehensively complete EBS reporting requirements. This ability to rapidly and accurately collect and report contamination information enables commanders to account for environmental considerations when basing field teams and ultimately prevent medical and environmental treatment costs.

The ETEO was initially funded by the Assistant Secretary of the Army (Acquisition, Logistics and Technology) (ASA[ALT]) as a four-year project led by the US Army Engineer Research and Development Center's (ERDC) Environmental Laboratory (EL). In that work, several sensors capable of detecting environmental contamination in various matrices were procured, modified, or developed. These devices were evaluated to determine their potential value to the intended application. The selection criteria included the function, toughness, and ease of use for each tool. The overarching principles used in selection of sensors for the ETEO were: (1) sensors must be rugged and easy to use and (2) the ETEO should analyze the highest number of environmental contaminants using the lowest possible number of sensors/tests.

The existing ETEO configuration consists of three sensors. A commercial off-the-shelf (COTS) Niton™ XL34t X-ray Fluorescence (XRF) Analyzer is included for heavy metal analysis in soil. This portable XRF provides rapid detection of 25 elements (sulfur [S] to uranium [U], including



many heavy metals) with quantitative accuracy. The COTS MultiRAE PGM-6228 is the second sensor included for its capability to monitor air quality and quantify potential harmful gases, such as hydrogen sulfide (H₂S), oxygen (O₂), carbon monoxide (CO), combustible gas (lower explosive limit [LEL]), and volatile organic compounds (VOC) quickly and efficiently. The last sensor is the Petroleum Hydrocarbon Field Screening Kit (PET kit) that analyzes for petroleum in water and soil. The PET kit uses a sample extraction technique and utilizes an ERDC-developed visual analyzer for rapid detection of hydrocarbons and COTS QuantiFluor®-P fluorometer (Promega) for expedient quantitation. These sensors (Figure 1) are all included in one COTS transit case for efficient transport and enhanced durability in use.



Figure 1. ETEO sensors, including A) XRF, B) gas monitor, and C) fluorometer.

The ETEO software streamlines the EBS reporting process via efficient data transfer from the sensors to the EBS template. Sensors evaluated for ETEO are compatible with this software, and data from these devices can easily be transferred to an EBS template via automatic population or manual entry of the data. The software also provides GPS mapping for documentation of each location when preparing an EBS. A rugged laptop, included in each ETEO set, operates this software for immediate access in the field.

Other sensors were considered for the ETEO, but ultimately eliminated from the recommended design. Particularly, the Water Diagnostics Operations Gear (WaterDOG), a prototype sensor developed by ERDC's Geospatial Research Laboratory (GRL), was developed for the ETEO. This device can measure multiple water quality properties, including turbidity and pH, to assess potability. It can also map the locations of water evaluations for efficient documentation. However, based on its size, this device is not sufficiently portable for the ETEO application (Figure 2) and was not included in the recommended design, thus eliminating water quality meter capabilities in this iteration of the ETEO.



Figure 2. WaterDOG in operation (Elder 2015).

The National Defense Center for Energy & Environment (NDCEE) funded the evaluation and demonstration of the ETEO to quickly add a new sensor for enhanced capability. Considering the absence of a water quality meter in the design at the conclusion of the ASA(ALT) project, the inclusion of a water quality tool in ETEO was chosen as the sensor to be added during this project. Adding this capability is crucial to accomplish the ETEO's intended application to protect the Warfighter and reduce costs and labor for extraneous remediation efforts.

OBJECTIVE: The objective for this study was to demonstrate the capability of the ETEO software to integrate an additional sensor quickly and with minimal programming. The primary capability to be attained for ETEO from the new sensor was water quality monitoring. This was achieved by completing the following five tasks:

1. Define success criteria for the selected sensor,
2. Survey and procure commercially available sensors,
3. Evaluate acquired sensors for functionality and accuracy,
4. Incorporate selected technology into the ETEO software procedures, and
5. Demonstrate the capability of the tool in a field scenario.

EVALUATION CRITERIA: The sensors included in this study were evaluated across the following eight criteria: (1) **commercial availability** to enable rapid demonstration, (2) **performance factors**, including capability and analytical accuracy using standard procedures per vendor recommendations, (3) **compatibility with existing software**, (4) **ease-of-use** to ensure minimal necessary training for operation, demonstration and potential transition, (5) **size**, (6) **weight**, (7) **ruggedness** to ensure adequate portability and durability, and lastly, (8) **cost** to support use of the ETEO for intended applications. The priority assigned to each attribute for selection is shown in Table 1.

Table 1. Selection criteria for water quality sensor.		
Priority	Technology Attribute	Success Criteria
1	Commercial availability	Rapid acquisition of COTS technology
2	Performance factors	Capable of providing accurate data for multiple parameters simultaneously
3	Compatibility with ETEO software	Efficient transfer of data to ETEO software
4	Ease of use	Minimal training required
5	Size of instrument	Sufficient portability
6	Weight of instrument	Sufficient portability
7	Ruggedness and durability of instrument	Suitable for field use
8	Cost of instrument	Minimal cost

INITIAL SURVEY AND EVALUATION OF AVAILABLE TECHNOLOGIES: An online market survey was conducted to identify technologies potentially suitable for this application. Leading vendors in water quality monitoring technologies were consulted regarding available instrumentation. Hanna Instruments, Hach Company, YSI, Fisher Scientific, Omega Engineering, and Horiba Group offered commercially available technologies consistent with ETEO objectives. One multi-parameter water quality meter was procured from each vendor for ETEO consideration.

Each instrument was evaluated per vendor recommendations using supplied solutions and standard solutions prepared by ERDC to ensure consistency among water meters. Among the units tested, the Hanna Instruments HI9829 was capable of testing for the most water quality parameters while providing sufficient portability and ease of use at a favorable cost. Based upon its ability to meet these success criteria, this commercially available instrument (Figure 3) was selected for further evaluation and potential adoption into the ETEO.



Figure 3. Hanna Instruments HI9829 multi-parameter meter and probe (Hanna Instruments 2018).

TECHNOLOGY DESCRIPTION: The HI9829 is a multi-parameter water meter capable of measuring up to 14 different water quality properties. Specifically, this device can measure dissolved oxygen (% or ppm DO), pH, oxidation reduction potential (ORP, mV), electroconductivity (EC, mS/cm), turbidity, temperature, atmospheric pressure, resistivity, seawater sigma, salinity (PSU), and total dissolved solids (ppm TDS) via the installation of three probes, as shown in Figure 4. Additional probes can be installed to measure ammonium, nitrate, and chloride in place of pH/ORP measurement.

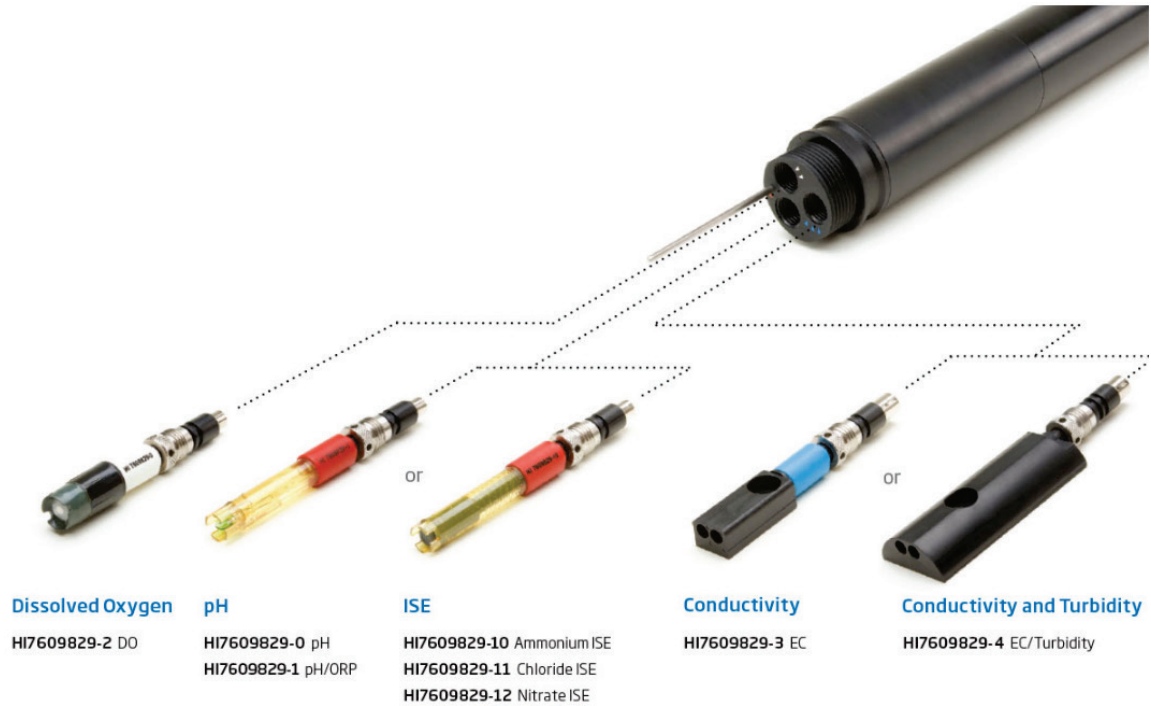


Figure 4. HI9829 analytical probes (Hanna Instruments 2018).

The water meter can record data from each measured property at time increments from one second to three hours. This data can be plotted to display real-time trends and averages during analysis; up to 44,000 individual data points can be stored on the device. Single-point data collection can also be performed. Data can be collected quickly and constantly with measurements for up to twelve properties displayed on one screen. The sample analysis data points are time-stamped during recording, and remarks can be added for further documentation within the meter's user interface.

Calibration can be performed using supplied or custom solutions and standard operating procedures for each water quality parameter. The meter signals to the user when certain properties require calibration by flashing the units of the parameter. Additionally, the measured data flashes when it is out of the defined calibration range. Both signals ensure quality control of data acquisition and analysis.

The handheld (8.7" x 4.5" x 2.2") meter is equipped with a hand-strap for ergonomics while in use. The HI9829 is also dust tight and waterproof up to depths of 1 m for approximately 30 min (IEC 60529). The touchpad on the meter provides access to all the device's functions and the brightness of the screen can be adjusted, as well. This meter has a mass of less than 2 lb, the detachable probe has a cord length of 13 ft, and the life of the rechargeable battery is 95 hr. The total cost for this unit is \$2,550.00 (Hanna Instruments 2019).

The HI9829 can also be connected to a Microsoft-based computer via USB. Software associated with HI9829 allows collected data to be imported by various spreadsheet programs for further analysis (Hanna Instruments 2018).

FURTHER ASSESSMENT OF SELECTED DEVICE: The HI9829 was procured by ERDC-EL for confirmation of preliminary results. Approximately 40 hr of effort were required to evaluate the HI9829's capability and accuracy using supplied calibration standards and ERDC-prepared standard solutions for pH and conductivity. These efforts successfully qualified the HI9829 in terms of performance. The portability and durability of the device was confirmed via brief inspections of the handheld, rugged unit. Additional tests verified its ease of use during data collection.

To assess the ease-of-use by non-experts, the HI9829 was distributed to ERDC employees unfamiliar with the technology. These researchers recorded the procedures necessary to operate the instrument and collect data. This effort resulted in a one-page standard operating procedure (SOP) comprising protocols for initiating, utilizing, and powering down the device. This SOP was successfully followed by other ERDC employees previously unfamiliar with the sensor, and water quality data was collected from various sources. Approximately 160 hr were required to prepare and test the SOP by the ERDC team.

SOFTWARE INTEGRATION OF SELECTED DEVICE: Once the HI9829 was selected for ETEO consideration, software integration efforts were executed. This instrument could successfully connect to ETEO laptops via USB for data analysis. The software allowed for code to be developed by ERDC to export data to a readable format for ETEO and import this data to the ETEO software application for EBS preparation. This inclusion allowed rapid and efficient data transport.

Although the HI9829 is not GPS-enabled, geographic location of analyzed samples can be added manually following data collection and export. This coordinate data would be included in the EBS.

Approximately 2,000 labor hours were dedicated to software integration. These efforts were led by ERDC experts in sensor and software development.

FIELD DEMONSTRATION: The HI9289 was included in a field demonstration at Ft. Leonard Wood, MO, in September 2018 in which the ETEO was displayed and discussed to visitors from various Department of Defense (DoD) organizations; including the National Guard, SOUTHCOM, and NDCEE. Water samples were collected from the field and compared to tap water onsite in terms of TDS. The HI9829 successfully measured a much higher TDS for the field sample compared to tap water throughout a 1-min duration. The recorded plot was displayed during analysis to confirm its pace and accuracy to the visitors. The SOP developed for the HI9829 was also discussed to demonstrate its ease of use. Following the demonstration of sample analysis, the HI9829 was connected to a compatible Microsoft laptop via USB. The data from the demonstration was imported to the ETEO software and included in an EBS. The coordinates of the site were included in addition to the date and time for documentation. This demonstration also included the MultiRAE, PET kit, and XRF at separate areas using field samples to further communicate the benefits of ETEO and the enhanced capability the HI9829 provides.

Additional demonstrations were conducted at the Forward Engineer Support Team – Advance and Environmental Support Team trainings under the direction of US Army Maneuver Support Center of Excellence (MSCOE) and USACE HQ Environmental Support Branch in Mobile, AL in April 2018 and USACE ERDC in Vicksburg, MS multiple times for various audiences.

DISCUSSION: The HI9829 adequately provides water quality analysis to meet the needs of the ETEO. Instantaneous measurement and logging of key properties allows for rapid assessment of water samples and efficient documentation of multiple sites. This data can easily be accessed and effectively analyzed using the ETEO software. The size and durability of the equipment allows for portability and use in the field under various wet and dry conditions. Additionally, the meter can be used in light and dark environments based upon the brightness of the screen. The small footprint of the meter, probes, and supporting equipment allows efficient inclusion and transport in the ETEO transit case.

A diverse team of researchers with expertise in chemistry, engineering, and software programming worked together to select, evaluate, and adapt the HI9829 to ETEO and its accompanying software. Evaluation efforts were executed by researchers with experience ranging from novice to expert levels regarding water sensors to confirm its accuracy and ease of use. And software integration efforts were conducted by researchers skilled in sensor development and utilization.

CONCLUSIONS AND RECOMMENDATIONS: The Hanna Instruments HI9829 successfully addressed a key capability gap for the ETEO by providing analysis of 14 water quality properties. This commercially available tool was selected after a market survey based upon its performance attributes, usability, and cost. Following performance evaluations, this technology was successfully adapted to the ETEO software package for efficient EBS reporting. The HI9829 and software integration capability was successfully demonstrated at Ft. Leonard Wood. Integrating the HI9829 into the existing toolkit demonstrated the capability of the ETEO to rapidly integrate new sensors with minimal programming.

The performance of the HI9829 could be further investigated through additional evaluations. Specifically, field samples from various locations could be analyzed to confirm the efficacy of the probes in different matrices. Additionally, wider ranges of laboratory-prepared solutions could be evaluated to further determine the accuracy of the probes. Evaluations of adjustments to multiple properties within standard solution sets would also be beneficial in terms of determining potential interference of one property on another. Repeatability and reproducibility studies could be performed by analyzing various sample solutions in sequence to evaluate and validate the precision of the equipment. Lastly, usability studies could be performed by non-technical individuals equipped with the HI9829, the SOP, and test samples during trial scenarios. Although these investigations could be performed to further confirm the capability of the HI9829, the technology has been selected for use in ETEO.

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