Evaluation of Non-regulated Portable Moisture Density Gauge

SP&R Part II, 775 Project # 19-SPR0-007

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16. Abstract

Standard portable nuclear moisture-density gauges are very accurate and easy to operate for determining density and moisture content of soils as well as other construction materials. Unfortunately, the size of the radioactive sources used in the standard nuclear gauges are such that they are regulated by the Nuclear Regulatory Commission and in Iowa, the Department of Public Health. Recently, a new portable gauge was developed by Troxler called the EGauge that measures wet density. The EGauge uses the technology of a nuclear gauge, but it has a low radioactive source and is exempt from licensing. The non-regulated EGauge is paired with the use of a moisture probe to measure moisture content. The Iowa DOT currently has ten portable nuclear gauges that are used for quality assurance (QA) testing on embankment construction with moisture and density control or moisture control only. If the new EGauge is sufficiently accurate, they could be made much more accessible to the construction and materials staff monitoring contractors' quality control (QC) testing. Based on the licensing exemption, there could be a quantifiable savings with the new gauges and more importantly a reduced risk of injury or death from radiation exposure. Additionally, if the new type of gauge is allowed, there would be a savings and reduced risk for contractors performing QC testing.

The study used comparative tests between the EGauge and the standard nuclear gauge on grading projects. Samples were collected to compare wet density, dry density, and moisture content using the different gauges.

A recommendation was made to allow the use of the non-regulated nuclear gauge for wet density only and Materials IM 204, Appendix A was revised to allow for low activity nuclear gauges, such as the Troxler EGauge, as an acceptable test method for wet density. Based on the inconsistency in differences (i.e. moisture offset) for the same material and the low R-square value comparing the EGauge moisture probe to oven-dried moisture content, it was not recommended to use the EGauge moisture probe.

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Background

Standard portable nuclear moisture-density gauges are very accurate and easy to operate for determining density and moisture content of soils as well as other construction materials. Unfortunately, the size of the radioactive sources used in the standard nuclear gauges are such that they are regulated by the Nuclear Regulatory Commission and in Iowa, the Department of Public Health. The regulations are intended to prevent accidental exposure of people to radiation from misuse of the gauge. However, with the regulations are added time and money for licensing, training, recordkeeping, and security measures.

Recently, a new portable gauge was developed by Troxler called the EGauge that measures wet density. The EGauge uses the technology of a nuclear gauge, but it has a low radioactive source and is exempt from licensing. The non-regulated EGauge is paired with the use of a moisture probe to measure moisture content.

The Iowa DOT currently has ten portable nuclear gauges that are used for quality assurance (QA) testing on embankment construction with moisture and density control or moisture control only. If the new EGauge is sufficiently accurate, they could be made much more accessible to the construction and materials staff monitoring contractors' quality control (QC) testing. Based on the licensing exemption, there could be a quantifiable savings with the new gauges and more importantly a reduced risk of injury or death from radiation exposure. Additionally, if the new type of gauge is allowed, there would be a savings and reduced risk for contractors performing QC testing.

Evaluation Procedure

Tasks completed were as follows:

1. Purchase two Troxler Model 4590 EGauges including the 6760 Moisture Probe (Figure 1).
2. Discuss and decide with the Technical Advisory Committee (TAC) members what locations and how many locations should be tested.
3. Run comparative tests between the EGauge and the standard nuclear gauge on grading projects.

Figure 1: Troxler Model 4590 EGauge (back) and 6760 Moisture Probe (front)

The TAC was comprised of the following individuals:

- Rod Graven, Construction & Materials Bureau
- Jeff DeVries, Construction & Materials Bureau
- Stephen Upchurch, Construction & Materials Bureau
- Melissa Serio, Construction & Materials Bureau
- Roger Boulet, District 6 Materials
- Mark Dutra, District 6 Materials
- Alex Crosgrove, District 3 Materials

Preliminary data was collected near the Ames DOT complex in August 2019 and in September and October 2019 at the Polk County – I-80 and IA 141 construction sites. At both locations, wet density, dry density, and moisture content were measured using at least one of the Troxler EGauges and a DOT

Humboldt nuclear gauge. Additionally, at the Polk County construction site, data was collected using a gauge operated by a consultant performing QC for the contractor.

The TAC met in 2021 to develop a formal testing plan to compare Troxler EGauge with standard nuclear gauges.

The testing plan included the following comparison testing:

- Use at least one EGauge and moisture probes at a testing location
- Use a standard nuclear gauge
- Collect wet density, dry density, and moisture content using the gauges
- Collect moisture samples to determine oven-dried moisture content

The first testing site was at the Ames DOT facility on April 22, 2021. Troxler sent representatives onsite to assist with this testing. Data was collected at three locations.

The remainder of comparison testing was completed during the 2021 construction season at the following locations in central Iowa:

- Boone County, IA 17, 7/2/21
- Polk County, US 69, 8/13/21
- Story County, 13th Street in Ames, 10/8/21

At these three construction sites, data was collected at eight locations per each site.

Results

Moisture content and wet density data collected from sites noted in the "Evaluation Procedure" section was compiled as follows:

- Wet Density: 35 locations of comparison testing (67 data points)
    - 2 non-regulated EGauges compared to 1 nuclear gauge (54 data points)
    - 1 non-regulated EGauge compared to 2 nuclear gauges (13 data points)
- Moisture Content: 27 locations (67 data points)

- 2 non-regulated EGauges compared to 1 nuclear gauge and 1 oven-dried sample (54 data points)
- 1 non-regulated EGauge compared to 2 nuclear gauges (13 data points)

Figure 2 shows a comparison of moisture data using the EGauge moisture probe versus corresponding oven-dried moisture contents. Additionally in this figure are shown a 1:1 line to illustrate if the EGauge provided the same readings as determined from oven-dried samples and 1:1 lines with the current tolerances (-1.5% to +1.5%) from Materials IM 216 for moisture content. Figure 3 shows EGauge moisture probe data versus both oven-dried and nuclear gauge moisture contents.

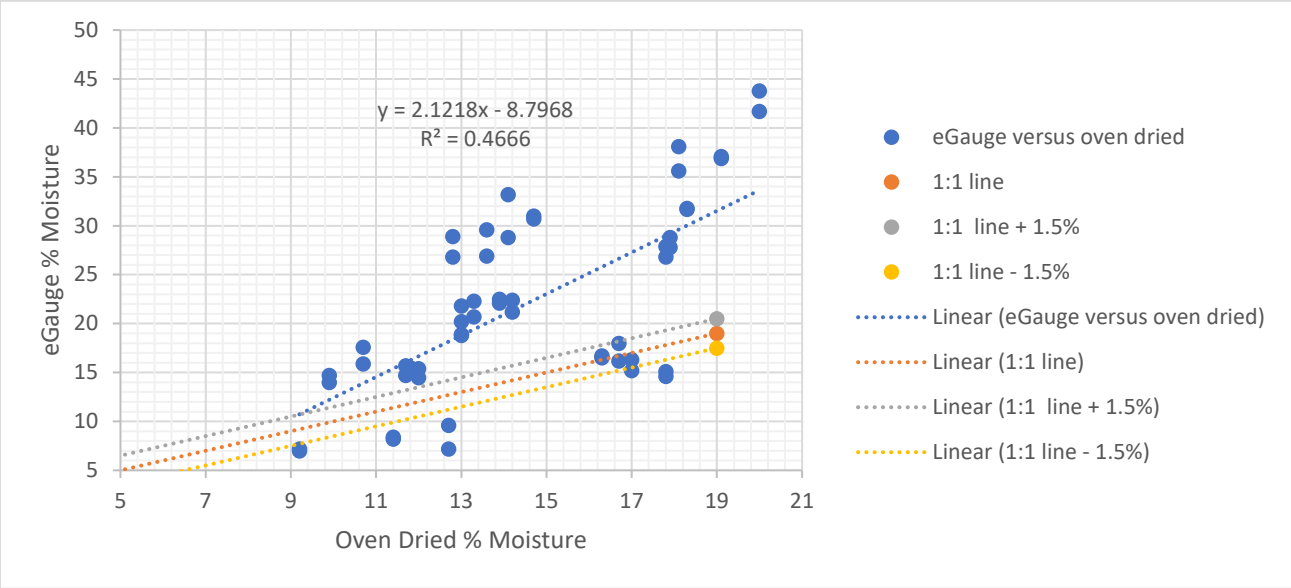

Figure 2: EGauge moisture probe data versus oven-dried moisture content (%)

Figures 2 and 3 show low R-squared values (0.4666 for oven-dried and 0.0074 for nuclear gauge), which indicate the data does not show a strong fit to the regression lines.

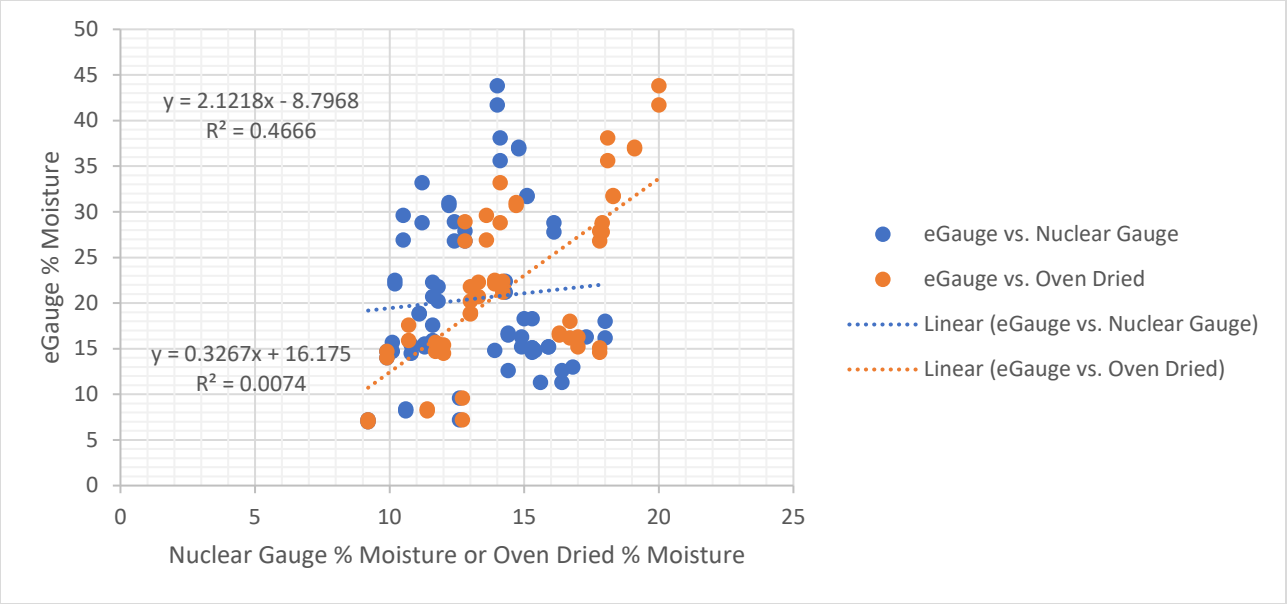

Figure 3: EGauge moisture probe data versus nuclear gauge and oven-dried moisture content (%)

To adjust the EGauge moisture probe values to match a specific soil more closely, Troxler recommends the use of a moisture offset. To determine a moisture offset, readings would be taken using the EGauge moisture probe at three to five locations and then compared to oven-dried samples. This process was performed at three of the construction sites for the different soil types observed. Differences between EGauge moisture probe values and oven-dried samples were as follows:

- Boone County:
  - Area 1: 7.6% to 9.6% higher
  - Area 2: 2.1% lower to 4.5% higher
- Polk County:
  - Area 1: 13.5 to 22.8% higher
  - Area 2: 0.3% higher to 4.3% lower
- Story County:
  - 5.9% to 16.9% higher

As shown, these differences (i.e. moisture offset) for the same soil type varied by 2% (comparing 7.6% to 9.6%) to 11% comparing (5.9% to 16.9%).

Figure 4 shows a comparison of EGauge wet densities versus the corresponding standard nuclear gauge wet densities. Additionally on this figure is shown a 1:1 line to illustrate if the EGauge provided the

same readings as the nuclear gauge. Along with the 1:1 line, the current tolerances (-2 pcf and +2 pcf) from Materials IM 216 for wet density are shown and proposed expanded tolerances (-5 pcf and +5 pcf).

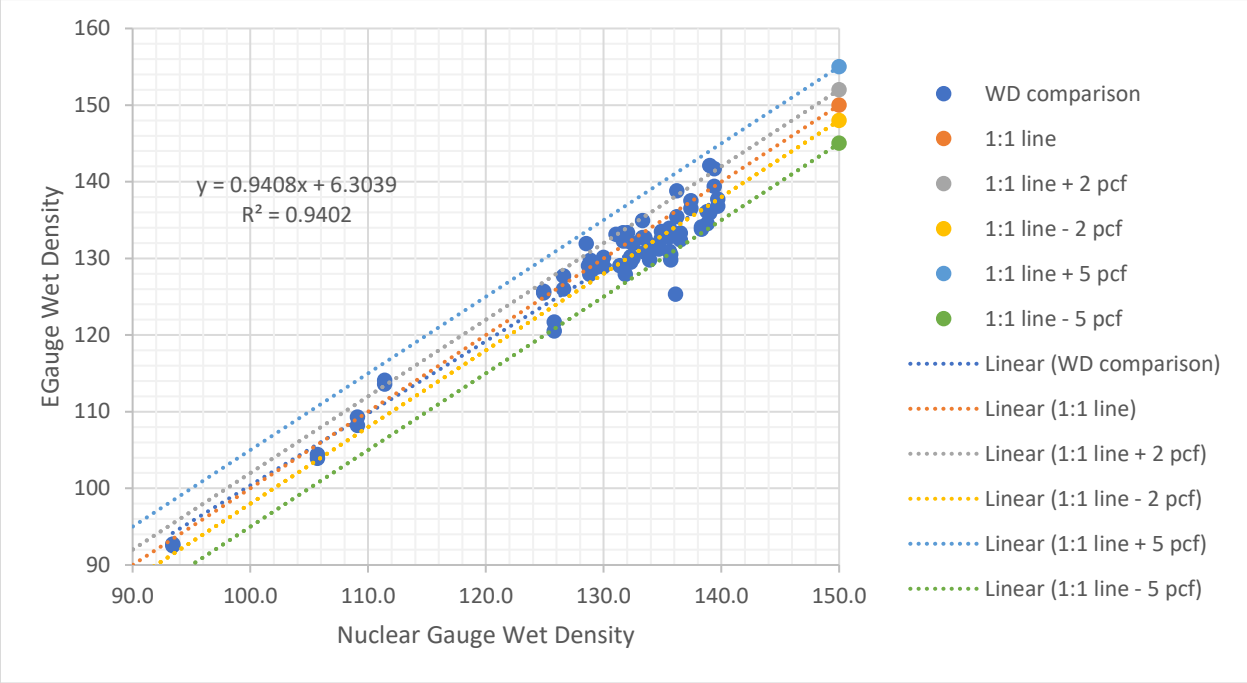

Figure 4: EGauge wet density versus nuclear gauge wet density (pcf)

The data comparing wet densities had a high R-squared value of 0.9402, which indicates a strong fit to the regression line.

Of the 67 data points, the following is a breakdown of tests (comparing EGauge wet density to nuclear gauge wet density) that would fall within the current tolerances from Materials IM 216 and proposed expanded tolerances:

- Current tolerance (+/- 2 pcf): 32 out of 67 = 48%
- Expanded tolerance (+/- 3 pcf): 49 out of 67 = 73%
- Expanded tolerance (+/- 4 pcf): 56 out of 67 = 84%
- Expanded tolerance (+/- 5 pcf): 63 out of 67 = 94%

Dry densities were not plotted because dry density is calculated using wet density and moisture content.

As part of our review of the EGauge, we considered additional data collected by the US Army Corps of Engineers. Figure 5 shows EGauge densities compared to densities collected using a nuclear gauge. On this figure, we added a 1:1 line to illustrate if the EGauge provided the same readings as the nuclear gauge, a 1:1 line with the current tolerances (-2 pcf and +2 pcf) from Materials IM 216 for wet density, and a 1:1 line with possible expanded tolerances (-5 pcf and +5 pcf). The Army Corps data for wet density showed a high R-squared value of 0.9367, which was very similar to our data.

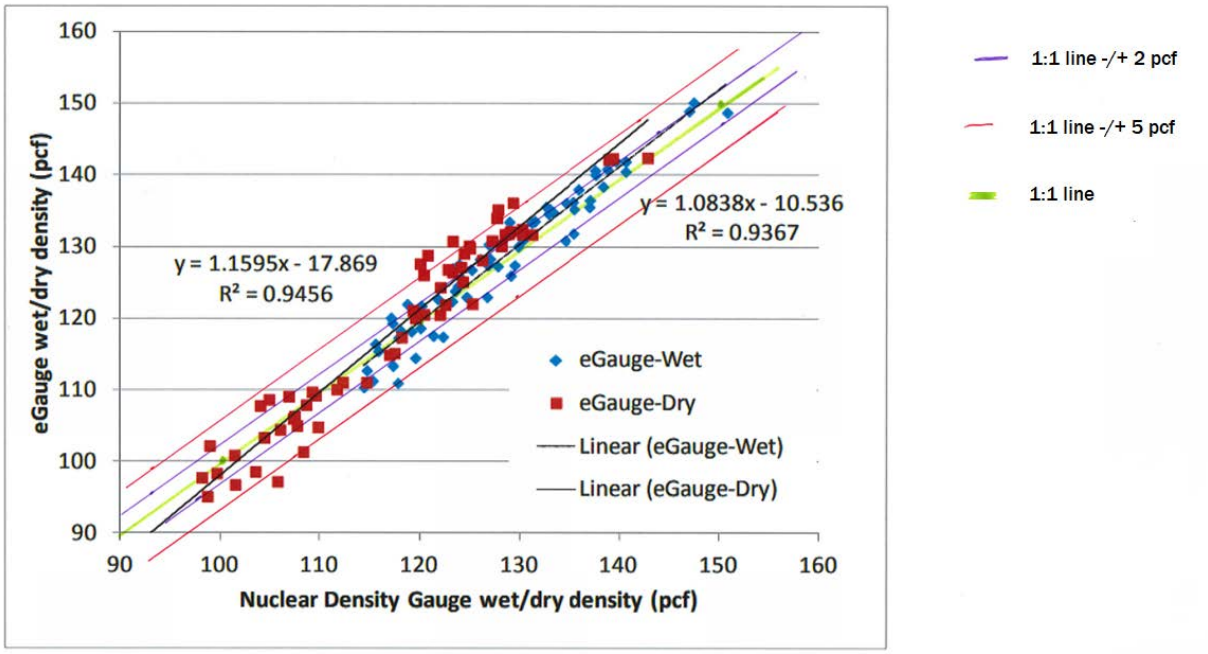

Figure 5: Army Corps of Engineers data comparing EGauge to nuclear gauge densities

Recommendations and Implementation

Information was presented to the District Materials Engineers (DMEs) at their November 17, 2021, meeting. A recommendation was made to the DMEs and accepted by the DMEs to allow the use of the non-regulated nuclear gauge for wet density only. As a result, Materials IM 204, Appendix A was revised (effective April 19, 2022) so ASTM D8167 for low activity nuclear gauges, such as the Troxler EGauge, is an acceptable test method for wet density. This revision is shown in Figure 6.

Additionally, it was recommended and accepted to keep the current tolerances in Material IM 216 for wet density as -2 pcf to +2 pcf. It was discussed that if this becomes an issue, then the tolerances will be re-evaluated.

Sampling & Testing Guide-Minimum Frequency

April 19, 2022 — **ROADWAY & BORROW EXCAVATION & EMBANKMENTS** — Matls. IM 204

Supersedes October 15, 2019 — Sections 2102, 2107, 2109 & 2432 — Appendix A (US) Units

MATERIAL OR CONSTRUCTION ITEM	TESTS	METHOD OF ACCEPTANCE & RELATED IMs	QUALITY CONTROL					INDEPENDENT ASSURANCE & VERIFICATION S&T						REMARKS
			SAMPLE BY	FREQ.	SAMPLE SIZE	TEST BY	REPORT	S&T TYPE	SAMPLE BY	FREQ.	SAMPLE SIZE	TEST BY	REPORT	
SOURCE INSPECTION														
Special Backfill, Crushed Stone (4132.02), Gravel (4132.03)		AS 209												
Crushed Concrete (4132.02), RAP (2303.02)		209,210												
Granular Backfill (4133, 4134)	Quality	AS 209												
Engr. Fabric (4196)	Quality	AS 496.01												
Contractor Furnished Borrow		545	CONTR	IM 545	IM 545	CONTR	IM 545 & Cert	V	RCE/ CONTR	1/10 QC tests	35 lb.	CTRL	Test Report	
GRADE INSPECTION														
Moisture Control, (QC by Contractor) Note 1	Proctor	309	CONTR	1/ soil class	25 lb	CONTR	Field Book & Test Report	V (7) IA (4)	CONTR/ RCE CONTR/ DME	1/ 10 req'd QC tests (min. 1)(5) 1/proj.	25 lb. 25 lb.	RCE/ DME CTRL/ DME	Field Book Test Report	Note 8
	Moisture	335, 334	CONTR	1/lift/1500 ft (for max of 1300 cy) (6)	3 lb	CONTR	Field Book & Test Report	V (7) IA (4)	RCE (2) DME	1/ 10 req'd QC tests (min. 1)(5) Witness 1/proj.	3 lb.	RCE	Field Book	Note 8
Moisture & Density Control, including Special Compaction of Subgrade (2109.03C), (QC by Contractor) Note 1	Proctor	309	CONTR	1/ soil class	25 lb	CONTR	Field Book & Test Report	V (7) IA (4)	CONTR/ RCE CONTR/ DME	1/ 10 req'd QC tests (min. 1)(5) 1/proj.	25 lb. 25 lb.	RCE/ DME CTRL/ DME	Field Book Test Report	Note 8
	Moisture	335, 334	CONTR	1/lift/1500 ft.(for max of 1300 cy) (6)	3 lb	CONTR	Field Book & Test Report	V (7) IA (4)	RCE (2) DME	1/ 10 req'd QC tests (min. 1)(5) Witness 1/proj.	3 lb.	RCE	Field Book	Note 8
	In-place Density	326 & 334, ASTM D2937, D2167, D1556, D8167 (3) AASHTO T191 & T233	CONTR	1/lift/1500 ft (for max of 1300 cy) (6)	As req'd by test	CONTR	Field Book & Test Report	V (7) IA (4)	RCE/ DME DME	1/10 req'd QC tests (min. 1)(5) Witness 1/proj.		RCE/ DME	Field Book	Note 8

AS-Approved Source
ASD-Approved Shop Drawing
S&T-Sampling & Testing

Cert- Certification Statement

RCE-Resident Construction Engineer/Project Engineer
DME-District Materials Engineer
CTRL-Central Laboratory
CONTR-Contractor

IA-Independent Assurance
V-Verification

Note 1: When Contractor QC testing is not required in the contact documents. The RCE will perform verification testing at the frequency listed for QC.
Note 2: RCE will direct the Contractor to take a moisture sample beside the RCE verification sample location.
Note 3: Low activity nuclear gauge, such as Troxler EGauge, is approved for use for wet density only. Location for testing shall be as described in IM 334, and moisture content determined per IM 335.
Note 4: For earthwork quantities of less than 50,000 Yd^3, no IA will be required.
Note 5: If no QC tests are required, then no verification or independent assurance tests are required.
Note 6: If source of excavation and moisture have been consistent and within moisture control limits and density has been greater than or equal to minimum density (if required), testing of each lift will be waived. Minimum frequency will be 1 per 1300 Yd^3.
Note 7: For earthwork quantities of less than 1300 Yd^3, no verification tests will be required.
Note 8: For Local agency projects not receiving Federal funding, Independent Assurance, IA, tests are not required.

Figure 6: Materials IM 204, Appendix A (Effective April 19, 2022)

Allowing the use of a non-regulated gauge, such as the EGauge, for determining wet density of soil provides an additional way for the Iowa DOT, testing company, contractor, or local public agency to test soils. As noted in the Background section, this type of equipment may be used as an alternative to the standard nuclear gauge.

Based on the inconsistency in differences (i.e. moisture offset) for the same material and the low R-square value comparing the EGauge moisture probe to oven-dried moisture content, we did not recommend allowing the use of the EGauge moisture probe. As shown in Materials IM 204, Appendix A (Figure 6), moisture contents shall be determined by Materials IM 335, which allows for use of direct heat (e.g. hot plate, etc.), microwave, or drying oven.

References

Berney, E.S., IV, Mejias-Santiago, M, and Norris, M.D. November 2016. *Validation Testing of Non-Nuclear Alternatives to Measuring Soil Density*. ERDC/GSL TR-16-28. US Army Corps of Engineers, Engineer Research and Development Center. Retrieved from: https://erdc-library.erdc.dren.mil/jspui/bitstream/11681/20381/1/ERDC-GSL%20TR-16-28.pdf