Recovering a Black Cemetery: Automated Mapping of Hidden Gravesites Using an sUAV and GIS in East End Cemetery, Richmond, VA

Stephanie A. Spera¹ · Matthew S. Franklin¹ · Elizabeth A. Zizzamia¹ · Ryan K. Smith²

Accepted: 8 December 2021 / Published online: 28 January 2022
© The Author(s) 2021, corrected publication 2022

Abstract

Estimates suggest that over 15,000 people are buried at East End Cemetery, a historic African American cemetery in Richmond, Virginia, that until recently received no public funding for upkeep. Here, we present a case study analysis and potentially replicable methodology for counting and locating unmarked burial depressions in non-forested areas using a low-cost sUAV (drone) and simple, hydrology-based geographic information systems analyses. Upon visual inspection of 12% of our final 8,000 burial site dataset, we find our dataset is a plausible representation (75% accuracy) of potential grave locations. We hope that the methods presented below can be implemented to assist in reclaiming historically underfunded Black cemeteries across the American South.

Keywords Black cemeteries · Drones · Virginia · Mapping

Introduction

East End Cemetery in Richmond, Virginia, is among the region's largest and most significant burial grounds (Fig. 1). Founded in 1897 by a private association of leading Black citizens, it would grow to span 16 ac (6.4 ha) and hold an estimated 15,000 burials, given observable burial patterns there. For decades, the cemetery provided one of the most prominent public arenas for memorializing Black lives within the constraints of the Jim Crow system. Families raised fashionable grave markers of all shapes and sizes throughout the site and enclosed their plots with

✉ Stephanie A. Spera
sspera@richmond.edu

¹ Department of Geography and the Environment, Carole Weinstein International Center, University of Richmond, 211 Richmond Way, VA 23173 Richmond, USA

² Department of History, Virginia Commonwealth University, Richmond, VA 23284, USA

Fig. 1 East End Cemetery occupies 16 ac (6.5 ha) in Henrico County and Richmond City and features thick underbrush, extensive tree cover, and uneven topography. Two additional African American cemeteries, the Colored Paupers Cemetery and Evergreen Cemetery, are directly adjacent. The inset map shows that the East End Cemetery (AOI, Area of Interest) is located on the eastern edge of the city and straddles the Richmond City/ Henrico County boundary.

personalized curbing and fencing. Burial activity within this collaborative memorial landscape peaked in the 1960s just as the city desegregated its cemeteries, with only 51 recorded interments in East End Cemetery after 1980 until a final burial in 2002 (Fig. 2). Since its peak, East End and its stewards have faced vandalism, dumping, extensive overgrowth, financial setbacks, and, most importantly, a lack of structural support in comparison with predominantly white cemeteries nearby. To date, only 3,340 grave markers have been found, as many remain lost or have been destroyed. Moreover, no formal interment records survive, and physically navigating the overgrown, uneven grounds is challenging.

In this predicament, East End Cemetery is not alone. On its southern boundary, East End adjoins the 60-ac (24.3 ha) Evergreen Cemetery (see Fig. 1), which was likewise founded in the 1890s by a private African American association that would face the same difficulties. The distressed condition of the two cemeteries' combined 76 ac (30.7 ha) and tens of thousands of burials presents one of the largest and most daunting preservation challenges involving Black graves in the United States. The problem extends in all directions. On the western boundary of East End Cemetery, the City of Richmond's "Colored Paupers Cemetery," founded in 1896, encompasses more than four acres of unmarked graves and lacks proper interment records (see Fig. 1). Three miles (4.8 km) to the northwest, Woodland Cemetery, founded in 1917, holds tens of thousands of African American graves in its 30 ac (12.1 ha), vast expanses of which remain obscured by overgrowth. And 30 mi (48.2 km) to the south, in Petersburg, Virginia, the surviving records are "inadequate to determine

Fig. 2 The number of burials at East End Cemetery in each decade since its inception based on recovered grave markers.

who is buried where” in the 8 ac (3.2 ha) of People’s Memorial Cemetery (Trinkley et al. 1999). The problem is so widespread that federal legislation was recently introduced to establish an “African American Burial Grounds Network” to locate and help preserve such cemeteries with the assistance of the National Park Service. Today, descendants and community members are looking for ways to connect a growing number of visitors with ancestors and the history represented across such grounds (Dunnivant et al. 2021; Mortice 2017; Rainville 2014; Smith 2020).

One non-invasive method in aiding the delicate work of restoring burial grounds and maintaining community outreach may be the use of small unmanned aircraft vehicles (sUAVs) to map grave depressions. Also known as “drones,” sUAVs are becoming a commonly used tool across a broad range of disciplines as they allow users to non-destructively survey landscapes at fine spatial resolutions over short periods of time at relatively low costs. As detailed in a recent review on the use of sUAV imagery for terrestrial applications, sUAVs are capable of carrying specialized payloads tailored to the exact data requirements for each application (Singh and Frazier 2018). Though these additional sensor packages can sometimes exceed the cost of the actual sUAV platform itself, they offer capabilities in a portable and affordable package that until recently have required a manned aircraft and costly equipment. This technology has allowed increasing numbers of researchers to obtain data they need to discover patterns and anomalies in highly localized contexts.

These advances have been an especially important boon to archaeologists and geographers. sUAV technology has allowed researchers to bridge the gap between coarse-spatial-resolution, high-temporal-frequency satellite imagery, airborne Light Detection

and Ranging (LiDAR) data, and costly fine spatial resolution optical satellite data (Luo et al. 2019). This ability to control the parameters of data collection — such as angle, timing, and scale — have led to new perspectives in recent years (see Adamopoulos and Rinaudo 2020 and Luo et al. 2019 for a review of spaceborne, airborne and sUAS technology in archaeology).

sUAV systems equipped with LiDAR and thermal sensors have been particularly useful, allowing centimeter-scale spatial resolution views of the earth's surface and providing data used in identifying and quantifying subsurface anomalies and structures (Adamopoulos and Rinaudo 2020; Caspari 2020; Sarasan et al. 2020). Although these systems and sensors generate excellent data, they are often either cost prohibitive (greater than \$5000 USD) or require expert technical knowledge to retrofit external sensors onto cheaper sUAVs. As we demonstrate and discuss below, recent advances in off-the-shelf sUAV hardware and software have provided possible workarounds to these budgetary constraints for those whose research questions require detailed orthomosaics and digital surface models (DSMs) (Evers and Masters 2018; Gutiérrez and Searcy 2016) but do not have an engineering or advanced image processing skillset.

Archaeologists and geographers often either manually interpret the aforementioned datasets—high-resolution optical satellite data, and sUAV-derived orthomosaics and DSMs (Caspari 2020; Lunga et al. 2020; Magnini and Bettineschi 2019; Sarasan et al. 2020), or rely on semi-automated mapping procedures like machine-learning algorithms or object-based image analyses (OBIA) with user-defined rulesets (Caspari et al. 2014; Caspari and Crespo 2019; Luo et al. 2019; Magnini and Bettineschi 2019; Orengo and Garcia-Molsosa 2019; Sarasan et al. 2020). Mapping cemeteries and burial mounds have been a particular focus of these studies: Evers and Masters (2018) demonstrated how sUAVs equipped with a near-infrared filter can be used detect both illegal and clandestine burials and assist in forensic work; Caspari (2020) manually mapped burial mounds in the Tuva Republic in southern Siberia using high-resolution (40 cm) panchromatic satellite data; Lunga et al. (2020) used high-resolution (30 and 40 cm) remotely sensed imagery and convolution neural networks to count grave sites in North and South Korea; and Sarasan et al. (2020) used sUAV data and OBIA to map burial mounds across the Plateau in Kyrgyzstan. And although OBIA and machine learning algorithms may decrease manual mapping and counting input time and efforts, these processes, again, often require specific software or expert computational knowledge to implement (Adamopoulos and Rinaudo 2020; Luo et al. 2019; Magnini and Bettineschi 2019).

Here, we focus on East End Cemetery, Richmond, VA, to demonstrate how one can couple an off-the-shelf unmodified sUAV system with straightforward hydrological geographic information systems (GIS) analyses to estimate the locations and number of the unmarked burials.

East End Cemetery, Richmond, VA

East End Cemetery straddles the border of Richmond and Henrico County (see Fig. 1). As highlighted above, it abuts both the larger Evergreen Cemetery, where famous Black Richmonders Maggie L. Walker and John Mitchell Jr. are

buried, and a smaller parcel designated by the City of Richmond for the burial of “colored paupers.” Following the opening of East End Cemetery in 1897, founders in the East End Memorial Burial Association promoted their site as “high, dry and rolling” and accessible to area streetcar lines. An advertisement from the time suggested that the association’s design and improvements for the grounds “will be an inducement to those desiring or contemplating purchasing resting places for their deceased relatives and friends” (*Richmond Planet* 1902). The layout of the cemetery featured several geometric pathways through the gridded grounds with lanes connecting it to the other cemeteries along its western and southern boundaries. The cemetery was occasionally colloquially known as Greenwood, after the name of an earlier initiative that had led to the creation of the East End Memorial Burial Association.

Thousands of African Americans found refuge and rest in East End, and its burials would include pioneering bankers, doctors, ministers, and educators, many of whom were born enslaved. Among the most prominent is Rosa Dixon Bowser, an educator and civil rights activist who graduated from the Richmond Colored Normal School following emancipation, passed the state teaching exam in 1872, and went on to lead the Virginia State Teachers Association among a wide range of other organizations until her death in 1931 (Davis 2021; Palmer 2021). Two grave markers survive for Bowser: a small, rectangular “plate” style marker celebrating her role as founder of the Baker Mothers’ Club and an upright granite headstone with an urn and flame motif.

Other individual stories there are less renowned yet just as powerful. One example is the janitor David Allen, who died at about 68 years old, also in 1931. Born in the midst of Civil War, Allen would make his home on Third Street in Richmond’s Jackson Ward by the time of his death. Allen’s small, “plate” style marker atop his grave notes his membership in the Elks fraternal order, allowing for what would have otherwise been a private life to be signified on the public landscape. The marker’s form, aligning with that of Bowser’s from the Baker Mothers’ Club and so many others like them at the cemetery, reinforced communal traditions.

The grounds of East End Cemetery offer more disturbing stories as well. In 2020 a rough box protruding from an eroded hillside on the border between East End and the Colored Paupers Cemetery revealed the commingled remains of at least nine individuals whose bones show signs of post-mortem anatomical study or dissection (Suarez 2000).

Throughout East End’s initial decades during the Jim Crow era, the cemetery’s founders and patrons did not have the same burial options as their white neighbors. Further, since 1902, the Commonwealth of Virginia has annually funded the maintenance of Confederate cemeteries while providing nothing for the cemeteries of the formerly enslaved and their descendants until 2017 (Palmer and Wessler 2018). With no public funding and perpetual care, East End relied on the families of those interred there for maintenance. And although those families struggled mightily amid a hostile city to keep grave sites and headstones clear, the cemetery was eventually engulfed by vegetative overgrowth and strewn with illegally dumped trash (Fig. 3a).

Management of the site suffered after 1959 when the East End Memorial Burial Association lost its charter for failure to file statements. As burials somehow continued (see Fig. 2), the property remained in legal limbo until 1970 when concerned citizens assembled a new, nonprofit “East End Burial Association” and successfully petitioned the county for rights to the cemetery. But then that association went quiet too, with the administrative burden falling onto the shoulders of a single trustee. By 2013, when a new group of volunteers began working to reclaim East End, most of the cemetery had become nearly impassable (Fig. 3a). In 2017 this core group of regular volunteers created a more formal structure, forming the Friends of East End Cemetery (FOEE), a nonprofit organization. By coordinating hundreds of workdays consisting of thousands of person-hours, FOEE cleared much of the cemetery and uncovered, mapped, and catalogued more than 3,300 grave markers (Palmer 2021). To assist with this important work, FOEE also partnered with the University of Richmond and Virginia Commonwealth University to form a community called the East End Cemetery Collaboratory (EECC). The EECC also now collaborates with and includes members from

Fig. 3 a. A view of Ben Green’s headstone in East End Cemetery in 2017; b. The same portion of East End in April 2021, after volunteer efforts to clear the overgrowth had taken place. Photo Credit: Brian Palmer.

a Descendants Council recently formed to give a structural voice to the descendant families.

To date, the EECC has produced a web map (<https://dsl.richmond.edu/eastend/>) that shows the precise location of each of the 3,300 grave markers that have been uncovered and cleared during these work days, and hyperlinks to any surviving historical records. The EECC is unique in that it provides an inter-sector, inter-collegiate, and inter-disciplinary space where members with expertise across fields including journalism, photography, archaeology, geography, history, library sciences, biology, religious studies, American studies, and civic engagement work together to document the history of East End and reconnect descendants of those buried at the cemetery with the resting places of their family members.

Despite this enormous, collaborative recovery effort, thousands of graves remain obscured by low-lying vegetation and overgrowth. The method presented below, then, serves many purposes, including helping identify grave sites, refining estimates of total burial numbers at a particular site, and assisting with rediscovering/uncovering cemetery histories. And, although we focus on the mapping results within East End Cemetery as a case study, we believe that similar methods could be applied at comparable sites to support new or ongoing reclamation efforts.

A Novel Methodology

sUAV Flight and Data Processing

The DroneDeploy software, which was previously freely available to non-commercial users, was used to create a flight plan over East End Cemetery. A DJI Mavic 2 Pro was flown at an altitude of 53.3 m with an image frontlap of 85%, and sidelap of 75%. Importantly, the sUAV flight was performed in early March 2020, when the deciduous trees within East End Cemetery bore no leaves to minimize leaf-cover interference. The flight took about 45 minutes, conservatively required three batteries, and 803 images were captured. We collected the latitude and longitude of six ground control points (GCPs) using an Arrow 100 GNSS receiver. These images were processed utilizing Pix4Dmapper software and georeferenced using the six aforementioned GCPs. We adjusted the calibration method of Pix4Dmapper's standard "Ag Multispectral" template to "Alternative" and set the "Internal Parameters Optimization" to "All Prior" to render and export a red-green-blue orthomosaic and a digital surface model (DSM) raster of the cemetery with a spatial resolution of 1.18 cm / pixel. It took six hours for Pix4Dmapper to create the orthomosaic and DSM on a standard Lenovo ThinkPad laptop.

GIS Analyses

All GIS analyses were performed in ESRI's ArcGIS Pro software. After an initial burial site classification attempt based on the orthomosaicked true-color image proved unsuccessful due to the lack of variance in color and texture between the grave depressions and the surrounding bare ground, we relied on the DSM and ArcPro's Hydrology Toolset. For a complete description of all of the specific parameters used when using the ArcPro tools, see the [Supplementary Material](#).

To provide a visual reference point for the analysis, the DSM was rendered as a hillshade image. Visual inspection confirmed that there were distinct, oblong depressions at the locations of known gravesites. Some of these burial depressions are evidenced both in the true-color orthomosaic and when walking the cemetery grounds. Some of these depressions, which measure 2 m in length and 1 m in width, are the result of the burial process: many of the formal graves at East End Cemetery were dug by hand and did not include vaults to protect caskets (Smith 2020). Burial vaults and elaborate "caskets" emerged only gradually from a funeral trade undergoing professionalization at the turn of the twentieth century, and mechanized tools for grave digging did not become available to all segments of American society until the latter part of the twentieth century (Mitford, 1963). As affluent cemeteries shifted toward underground vaults for graves and toward the use of mechanical devices to dig precise graves more quickly, East End Cemetery other comparable cemeteries for similarly distressed communities apparently continued traditional practices of hand-dug graves without adopting burial vaults in significant numbers. And although a rarer practice, some of the people interred at East End were apparently not buried in caskets at all but only in shrouds (Jackson 1981). Thus, because some burial sites have no underlying structure to support the topsoil, the excavated dirt that had been mounded atop the grave site settled and subsided, creating depressions of varying depth.

Low-lying grasses and plants that have grown over these sites do not confound the analysis. However, because East End Cemetery is home to many large, deciduous trees, even a low-altitude flight during leaf-off still obscured a portion of the grounds. To exclude noisy topographic areas or densely vegetated areas with many large trees in close proximity, a tree-mask was created using the RGB orthomosaic and applied to the DSM. Thus, we performed our analysis only on the 7.7 acres of cemetery area not obscured by canopy branches (Fig. 4).

Rather than creating user-defined image segmentation rules or implementing other intensive computational algorithms to quantify the gravesites, we instead relied on hydrographic analyses as we determined that the burial depressions acted as hydrologic sinks across the landscape. We performed a flow direction analysis on the masked DSM and then used the sink tool to highlight all of the cells in the flow-direction raster that were hydrologic sinks and had no outflow.

This sink tool was highly sensitive to minute topographic differences, initially producing sink point features that were located within any and all surface depressions, and the resulting sink point feature consisted of over 200,000 points which were often found in clumps of between 1 to 200 points in the bottom of each depression. Thus, we aggregated these points with the goal of reducing point clusters down

Fig. 4 **a.** Only the area (3.1 ha) not obscured by branches and overgrowth was included in the sink analysis. Note that the analysis area shown in the south west resides in the Colored Paupers Cemetery and has an area of 0.1 ha. The high-resolution orthomosaic image is shown as the background layer. Green shaded polygon shows the extent of the tree mask. Black inset highlights; **5b.** At 1:300 scale, the grave depressions – many of which are unmarked – are visible on the orthomosaic. These observations motivated our research to easily automate the mapping of each grave depression using a hydrologic sink process. Please note that the map frame has been rotated 18° to the northwest; **5c.** The sink analysis was run on the hillshade layer, clipped to the analysis area and aggregated several times to reduce point clusters until the final sink point layer, shown as yellow points, contained 8,136 features; **5d.** At 1:300 scale, the exaggerated (5x) hillshade layer with a demarcated typical grave depression (2 x 1 m), shown as a blue rectangle. The resulting sink points are shown as yellow points. Please note that the map frame has been rotated 18° to the northwest.

to a single point for each burial depression. In order to isolate one point per depression, we first aggregated all points within 15 cm of each other but the result was that some burial depressions still had two or three sink points. Therefore, the aggregate tool was run a second time, but a distance of 1 m was used instead. This 1-m distance was chosen because it is the approximate width of a grave site. The second aggradation process successfully merged any burial depressions with multiple sink points to result in one point per burial depression. Finally, to account for stray sink

points that often remained as a result of natural topography, using the buffer tool we created single point features which aggregated any points that were within 50 cm of one another. This resulted in a sink point layer with 8,136 features (i.e., graves). These features, then, reveal the presence of an enormous number of lives previously lost to visitors (see Fig. 4d). See Fig. 5 and the [Supplementary Material](#) for our complete workflow.

A Note on Cost

In Table 1, we tabulate the costs associated with this mapping effort, and also highlight areas where costs can be saved. In total, it cost \$1,700 USD for the sUAV hardware, \$3,000 USD for the sub-meter GPS unit, and \$1,900 for the image processing software, but costs can be saved for both the GPS unit and image processing software. The drone flight itself took less than an hour, and six hours of computational time were required to process the images.

Moreover, the costs and expertise associated with our proposed methodology are much lower than those associated with other commonly-used mapping methodologies. Ground penetrating radar (GPR) is a commonly used instrument in determining the location of unmarked graves (Beisaw et al. 2021; Fiedler et al. 2009). However, GPR systems are expensive – upwards of \$35,000 and range from \$15,000–\$50,000, and then there is the requirement of expertise for interpretation of results (Pruden 2021). GPR consultants can be hired, but those expenses can be prohibitive for smaller organizations. Based on estimates from a GPR survey on the University of Richmond campus, it cost ~\$3,500 for 0.5 ac (0.2 ha) and took a day for the field analysis plus the interpretation of GPR data (Miller, pers. comm.; Pruden 2021). Lastly, GPR instruments perform better in largely flat, cleared areas with dry, sandy soils. The waterlogged, clay soils on our own campus led to inconclusive GPR results (Miller, pers. comm.) and the uneven topography and often waterlogged

Fig. 5 Flow chart of sUAV and GIS mapping workflow.

Table 1 Total cost of sUAS drone-mapping set up, with notes/alternatives listed.

Item	Cost (\$USD)	Notes/Alternatives
DJI Mavic 2 Pro	1400	Currently can be purchased on sale for \$700 USD
Extra battery	150	
DroneDeploy	0	
		DroneDeploy was previously free; 14 day free trial: \$99/month
		Alternative mapping apps include:
		• PIX4D Capture – free
		• Litchi - \$25 USD
		• MapPilot – \$5–45 USD/month (iOS only)
ArcGIS	0	We have a university license; but analysis can be performed using the open-source QGIS and its Hydrology toolbox
Arrow 100 GNSS	3000	Many cheaper sub-meter GPS units exist (\$500–\$1000) or can be rented at a cheaper rate
Pix4D mapper	1990 for perpetual educator license	\$292/month subscription plan also available
Total	Drone + 2 batteries: \$1700	
	Sub-meter GPS: \$3000	
	Software: \$292-1990	

soil at East End Cemetery would not lend itself to a GPR survey even if that funding (\$7,000/ac for 16 ac would require \$122,000) could be secured.

An sUAV equipped with a LiDAR sensor may have allowed for more precise topographic mapping, particularly improving performance under the canopy, and resulting in a visibly tree-less digital elevation model allowing for the entire cemetery to be mapped. However, LiDAR systems cost upwards of \$20,000 USD and the customized sUAVs used to carry them cost, conservatively, upwards of \$10,000 (Van Tassel 2021). And estimates suggest LiDAR data processing software can range from \$8,000 to \$20,000. Thus, while our methodology is neither “free” nor without limitations, it can be performed for anywhere between \$2,000–\$5,000 USD, providing a “low-cost” alternative to do much of the heavy lifting in non-invasive mapping.

Validating the Unknown

Because we do not have recorded locations of these unmarked gravesites, traditional validation and accuracy assessment efforts cannot be performed. Even though over 3,300 grave markers have been mapped in the aforementioned outreach-related initiative by FOEE and the EECC, the location of a marker (often at the top of the plot) is not spatially coincident with the bottom of the corresponding grave depression, which in this analysis is represented by the sink point. Furthermore, many of those interred at East End were buried without identifiers, many grave markers remain lost, and, sometimes, a single grave marker or plot identifier is used to mark the location of a set of family graves. Thus, we cannot quantify and assess what we do not know exists.

To determine the accuracy of our methodology, then, we performed a visual validation on a randomly sampled subset of our final sink points dataset within the mapped areas. The use of random samples is traditionally considered “good practice” in remote-sensing accuracy assessments, especially in cases when validating the location of thousands of points is not practical (Olofsson et al. 2014). To perform this validation, we first separated our larger study area into seven different analysis areas (Fig. 6a, Table 2). We then created random, proportionally distributed 5-m buffers in each of the seven analysis areas (Fig. 6b, Figure 7a). Sink points that fell within these buffers were selected and used in a visual validation process. This process resulted in 982 features. The accuracy results associated with the 982 random selected points have margin of error $\pm 2\%$ with at a 95% confidence interval. These 982 points represent 12% of the total final sinks points across our entire study area; and within each analysis area, these selected sink points represented an average of 13% (range: 11% to 15%) of each analysis area’s sink points (Table 2).

We then visually validated the accuracy of the 982 randomly selected sink points. We compared the sink points to all available datasets for the cemetery to establish accuracy. The true color orthomosaic imagery, the exaggerated hillshade layer and the highly accurate field-mapped grave markers, if present, were used to determine if the sink point met simple spatial relationships. We define an errant sink point within our validation process as being either a point located within a ground

Fig. 6 **a.** The visual validation zones (5-m buffers, blue circle) were randomly and proportionally distributed across all analysis areas. Sink points that were located within these zones were selected to be validated; **6b.** The exaggerated hillshade (5x) clearly shows burial depressions and can be used to validate the hydrologic sink analysis. The selected validation points, shown as the orange symbol resided with the buffer but please note, the actual depression could fall outside that area.

surface depression but not associated with a burial depression, or a duplicate point within a burial depression. Although our analysis excluded areas dominated by trees and large shrubs, there were smaller areas within the analysis polygon features that had vegetation which compromised the sink analysis. With our visual validation, we sought to answer the following questions: (1) Is the selected sink point located within a reasonably interpreted burial depression according to the hillshade and orthomosaic?; (2) Is the sink point a duplicate or does it exist alone in the burial depression?; and (3) Is the sink point associated with a mapped grave marker? The results of these questions not only validate our methodology but they also help us define areas where cemetery caretakers may focus their reclamation efforts.

In answer to our questions above: (1) 75% of our sink points were located within a burial depression – demonstrating the potential utility of this method; (2) 97% of the sink points that were located in a burial depression were the only sink point, highlighting the effectiveness of our initial sink point aggregation; and (3) 36% of sink points were located with a mapped grave marker – illustrating the means by which this work can assist cemetery caretakers in locating unmarked burial depressions.

Focusing on question 1, Fig. 7 highlights the strengths and weaknesses of this methodology. Figure 7b, c shows many depressions occurring in a row like pattern and spacing consistent with a line of grave sites. There exist few mapped grave markers here, but we are confident that these sink points correspond to burial depressions. In this area, our mapped burial depressions, then, could confidently guide further investigation to either find hidden grave markers or increase confidence in burial count values. And, although we are extremely heartened that 75% of our sink points were located within a burial depression, this methodology is not without limitations. Figure 7d, e demonstrates where the sink analysis resulted in errant burial depression points caused by erroneous “sinks” in the DSM due to trees and shrubs. A quarter of sink points were found to be errant (Table 3). Sink points incorrectly

Table 2 The table shows the area of the analysis polygons, the proportionate number of sinks, and how many validation points were within each area.

Analysis Area ID	Name	Area (acres)	Area %	Random Points	Sink Points	Validation Area	PCT Validated Polygon	Selected Sink Points	PCT of sink in area
3	East End	2.42	31.3%	16	2573	0.12	12%	318	12%
1	East End	1.90	24.6%	12	2063	0.08	11%	243	12%
2	East End	1.56	20.4%	10	1587	0.08	12%	193	12%
11	East End	1.11	14.5%	7	1197	0.05	11%	126	11%
6	East End	0.44	5.6%	3	450	0.02	13%	65	14%
4	Colored Paupers	0.15	2.0%	1	143	0.01	12%	22	15%
7	Colored Paupers	0.12	1.5%	1	123	0.01	12%	15	12%
	Totals	7.70	100.0%	50	8136	0.37	12%	982	12%

Fig. 7 **a.** Validation was completed in 50 areas as shown as blue 5-m buffered circles. The black polygon shows the location of 6b and c and highlights a high-accuracy area. The red polygon shows 6d and e and highlights the low-accuracy area; **7b (orthomosaic)**, **7c(hillshade)**. Despite the presence of vegetation, the sink analysis method correctly found the bottom of each depression. Three duplicate points (pink) were also produced and dismissed as errors. Only five gravemarkers (blue squares) have been recovered in this area. This is an excellent example of an area that the results of this study could highlight for on-the-ground investigation. **Figure 7d (orthomosaic)**, **7e (hillshade)**. As obvious on the orthomosaic, several large trees created affected the results of the DSM. The sink points in this area were all found to be not plausible representation of burial depressions and marked as such. The exaggerated hillshade has a mottled appearance which would produce errant sink points.

Table 3 Validation rules were defined and examined in the randomly selected areas within the analysis mask. The validation method resulted in a clear understanding of the strengths and limitations of our sink analysis.

Validation Rule	Value	Method	Yes Count	No/Other Count	Total	PCT Yes	PCT No
The sink point is located within a burial depression.	Yes, Duplicate, No, Obscured by veg, Unclear	Visual inspection of hillshade and ortho-mosaic imagery	739	243	982	75%	25%
One sink point is located within one burial depression (not a duplicate).	Yes, No	Visual Inspection of hillshade	948	34	982	97%	3%
The sink point is associated with a mapped grave marker.	Yes, No	Proximity selection and visual inspection of imagery	354	628	982	36%	64%

created due to features within the DSM caused by taller cemetery features (obelisks, large headstones) or large vegetation (tall shrubs and trees) accounted for 21% of all validated points ($n=209$). Figure 7d, e demonstrates where the sink analysis resulted in errant burial depressions points caused by erroneous “sinks” in the DSM due to these trees and large shrubs. Importantly, as evidenced by our need to mask nearly half of the cemetery, this analysis should not be performed over heavily wooded areas with thick deciduous canopies.

Focusing on question 2: as evidenced in Fig. 7b, c, our point aggregation methods were highly effective with only one sink point located in each burial site. As we state earlier, of the 75% of points mapped in burial sites, 97% of the time, only one point was geolocated in each burial site, thus ensuring burial sites were not double counted.

Focusing on question 3: thousands of burial sites in East End Cemetery remain hidden by low-lying vegetated overgrowth. As highlighted above, of the estimated 15,000 + people buried at the site, only 3,300 headstones and grave markers have been discovered to date during the workdays of volunteer cemetery maintenance put in by the Friends of East End Cemetery. Not only do many burial sites remain hidden by low-lying vegetation, as shown in Fig. 7b, c, but also, not all of those interred at East End Cemetery received grave markers, and occasionally a single grave marker is used to mark the location of a set of family graves. Thus, having only 36% sink points located within proximity of its grave marker does not detract from this methodology. Instead, it emphasizes the means by which this work can assist cemetery caretakers in locating these unmarked burial depressions.

Lastly, we also invite readers to explore the complete results of our burial depression mapping work across East End Cemetery through an online map with the link provided in the [Supplementary Material](#).

Discussion

As highlighted above, a customized drone equipped with a LiDAR instrument would likely have collected data that would allow for mapping of the entire cemetery, but these systems are costly both in terms of money and, importantly, flight-time as the sensors add weight to the sUAV which decreases the amount of area one can cover on one battery. And although computationally intensive algorithms and methods like those of Caspari et al. 2014; Caspari and Crespo 2019; Luo et al. 2019; Magnini and Bettineschi 2019; Orengo and Garcia-Molsosa 2019; and Sarasan et al. 2020 may have produced similar or slightly better results, a hydrographic analysis using a GIS toolbox was both simple and effective.

At East End, the method put forward here is helping to re-populate a difficult site and return the focus of the cemetery efforts to the stories of those interred there. For example, the death dates on surviving grave markers near the previously unrecorded graves identified here point to the gradual development of East End Cemetery in chronological sections, and these new sink points help expand the likely scope of

those populations. As a result, we gain a better understanding of the cemetery's different stages of use.

Furthermore, our data confirmed the locations of numerous gravesites in the Colored Paupers Cemetery located southwestern portion of the field area (Fig. 8, also see Fig. 1). Visual inspection shows a similar burial depression pattern as seen in East End. A plausible interpretation, given that the terrain, soil, and burial practices were similar, is that it is likely these sink points indicate burial depressions in this area. Nearly all of the graves in this unbounded burial area lie unmarked, so this finding is significant, as little is known about the spread of pauper burials here. The grave depressions revealed at the Colored Paupers Cemetery could be used to represent generally the lives of those few paupers whose names do survive in city interment records. For example, the keeper of the city's nearby Oakwood Cemetery, who apparently had oversight of the Colored Paupers Cemetery, recorded roughly one dozen burials in those latter grounds for each month of 1913. We may not be able to locate the specific grave of William Smith, who died at 40 years old of tuberculosis in March 1913, or of James Keiter, who died at 49 years old of burns two months later, but we can see the graves of the larger community where those individuals are buried (Records of the City of Richmond). And we can see the important historical connections between those graves and the graves of other Black Richmonders up the hill at East End and Evergreen Cemeteries. Combined with oral history, our technique can help restore the places of such burials on the memorial landscape (Smith 2020).

Fig. 8 Close up of hillshade (with 5x vertical exaggeration) of analysis area (bounded in black) of the Colored Paupers Cemetery. Yellow dots represent sink points and thus estimated locations of burial depressions. Blue polygon is 1x2 m to show the typical burial depression dimension. To date, no mapped grave markers have been identified in this area as it remains covered by dense vegetation.

Concluding Remarks

Through our drone mapping efforts for an outreach component of the reclamation work, we discovered that we could use a low-cost, low-tech effort to map likely locations of many unmarked sites buried in overstory growth. This is a novel development as our EECC organization does not have access to a drone with a costly LiDAR instrument nor do we have money for a GPR survey; and neither do other volunteer/friends-of efforts working at these underfunded Black cemeteries. The purpose of this work, then, is to share, showcase, and essentially democratize the creation of knowledge and allow those without computational science expertise and/or massive funds and expensive equipment to see if this method can assist as part of their reclamation effort.

Currently, the optical sUAS imagery from our work is being used as a basemap for a public-facing website that includes the GPS locations of more than 3,300 grave markers recovered during FOEE workdays. The site allows visitors to search the spatial database by name or date of death and directs them to the location of the marker in the cemetery. Moreover, FOEE and the EECC are developing a public-facing digital archive that includes historical documents, family photographs, newspaper articles, and oral histories of East End descendants (<https://search.eastendcemeteryva.com/>). Ultimately, not only will mapping burial depressions assist in the recovery of grave markers, but pairing the digital archive with the online map will allow descendants and cemetery visitors to fully engage with this important burial ground. Since volunteer efforts remain subject to the same structural challenges long faced by these cemeteries, our mapping work may serve additional purposes in the future.

In 2017, the Commonwealth of Virginia passed a bill that annually allocates \$5 per grave, monument, or marker for those interred in certain African American cemeteries between 1800 to 1900 (VA HB 1547). However, to date, little money has been disbursed under VA HB 1547 (DHR 2021). Moreover, that law, written to fund “qualified charitable organizations...whose primary purpose is the preservation of historical cemeteries and graves,” was amended in 2018 by the General Assembly to expand eligibility to “any person or locality” that owns such an eligible cemetery. This cemetery ownership amendment has complicated matters at East End Cemetery, as the courts awarded ownership of East End to Parity LLC, a holding company linked to a local nonprofit, the Enrichmond Foundation. Enrichmond has not demonstrated the capacity to maintain even the bare minimum in terms of cemetery maintenance, and at the same time, the foundation has blocked the FOEE and EECC from continuing their work at East End since mid-2020 (Karns 2020; Suarez 2021). As the FOEE-cleared graves become engulfed by vegetation yet again, this burial depression work can help re-direct future on-the-ground clearing and maintenance efforts at East End.

On the federal level, the African American Burial Grounds Network bill has not been passed, though one version cleared the Senate in 2020 (S. 2827). Thus,

this important work is often left to volunteer groups working with limited budgets. Here, then, we present a relatively cheap, simple, and quick mapping method that may be used to analyze topography, assist in the recovery of obscured grave sites (which may, importantly, help provide evidence to secure funds under legislation like VA HB 1547), and ultimately contribute to the reclamation of historically underfunded Black cemeteries across the American South.

Conflicts of Interests

The authors declare that they have no conflict of interest.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s10761-021-00642-3>.

Author Contributions SAS and MAF contributed to study conception and initial methodology. Validation was performed by EAZ. The manuscript was written, reviewed, and edited by SAS, MAF, RKS, and EAZ.

Funding The authors received no financial support for the research, authorship, and/or publication of this article.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

References

- Adamopoulos, E. and Rinaudo, F. (2020). UAS-based archaeological remote sensing: review, meta-analysis and state-of-the-art. *Drones* **4**(3): 46. <https://doi.org/10.3390/drones4030046>.
- Beisaw, A., Tatum III, W. P., Buechele, V., and McAdoo, B. G. (2021). Mapping a poorhouse and pauper cemetery as community engaged memory work. *International Journal of Historical Archeology*. <https://doi.org/10.1007/s10761-021-00617-4>.
- Caspari, G. (2020). Mapping and damage assessment of “Royal” burial mounds in the Siberian Valley of the Kings. *Remote Sensing* **12**(5): 773. <https://doi.org/10.3390/rs12050773>.
- Caspari, G. and Crespo, P. (2019). Convolutional neural networks for archaeological site detection: finding “princely” tombs. *Journal of Archaeological Science* **110**: 10499.
- Caspari, G., Balz, T., Gang, L., Wang, X., and Mingsheng, L. (2014). Application of Hough Forests for the detection of grave mounds in high resolution satellite imagery. *2014 IEEE Geoscience and Remote Sensing Symposium*. 13–18 July, 2014. Quebec City, Canada. <https://doi.org/10.1109/IGARSS.2014.6946572>.
- Davis, V. (2021). Entry for Bowser, Rosa Dixon. In *Encyclopedia Virginia*. <https://encyclopedia.virginia.org/entries/bowser-rosa-l-dixon-1855-1931/>. Accessed 17 Nov 2021.
- DHR – Virginia Department of Historic Resources. (2021). African American Cemetery and Graves Funds Recipients. Updated July 23, 2021. <https://www.dhr.virginia.gov/cemetery-newsletter-content/african-american-cemetery-graves-fund-recipients/>. Accessed 17 Nov 2021.

- Dunnivant, J., Justinvil, D., and Colwell, C. (2021). Craft an African American Graves Protection and Repatriation Act. *Nature* **593**: 337–340.
- Evers, R. and Masters, P. (2018). The application of low-altitude near-infrared aerial photography for detecting clandestine burials using a UAV and low-cost unmodified digital camera. *Forensic Science International* **289**: 408–418. <https://doi.org/10.1016/j.forsciint.2018.06.020>.
- Fiedler, S., Illich, B., Berger, J., and Graw, M. (2009). The effectiveness of ground-penetrating radar surveys in the location of unmarked burial sites in modern cemeteries. *Journal of Applied Geophysics* **68**(3): 380–385.
- Gutierrez, G. and Searcy, M. T. (2016). Introduction to the UAV special edition. *SAA Archaeological Record* **16**(2): 6–9.
- HB30 385#9c. (2020). Restore Confederate Graves Funding-Department of Historic Resources. Budget Amendments HB30 - Conference Report. <https://budget.lis.virginia.gov/amendment/2020/1/HB30/Introduced/CR/385/9c/>. Accessed 17 Nov 2021.
- HB 1547. (2017). Historical African American cemeteries and graves bill. <https://trackbill.com/bill/virginia-house-bill-1547-historical-african-american-cemeteries-graves-disbursement-of-funds-appropriated-for-preservation/1319365/>. Accessed 17 Nov 2021.
- Jackson, E. (1981). “Cemeteries Fight Losing Battle.” *The Richmond Times Dispatch*. July 22.
- Karns, P. (2020). “In Need of Repair.” *Richmond Magazine*. October 14. <https://richmondmagazine.com/news/news/in-need-of-repair/>
- Lunga, D. et al. (2020). Learning to count grave sites for cemetery observation models with satellite imagery. *IEEE Geoscience and Remote Sensing Letters*: 1–5. <https://doi.org/10.1109/LGRS.2020.3022328>.
- Luo, L. et al. (2019). Airborne and spaceborne remote sensing for archaeological and cultural heritage applications: a review of the century (1907–2017). *Remote Sensing of Environment* **232**. <https://doi.org/10.1016/j.rse.2019.111280>.
- Magnini, L. and Bettineschi, C. (2019). Theory and practice for an object-based approach in archaeological remote sensing. *Journal of Archaeological Science* **107**: 10–22. <https://doi.org/10.1016/j.jas.2019.04.005>.
- Mitford, J. (1963). *The American Way of Death*. Simon and Schuster, New York.
- Mortice, Z. (2017). Perpetual neglect: the preservation crisis of African-American cemeteries. *Places*. <https://doi.org/10.22269/170530>.
- Notice!!! (1902). *Richmond Planet*.
- Olofsson, P., Foody, G. M., Herold, M., Sehman, S. V., Woodcock, C.E., and Wulder, M.A. (2014). Good practices for estimating area and assessing accuracy of land change. *Remote Sensing of Environment* **148**: 42–57. <https://doi.org/10.1016/j.rse.2014.02.015>.
- Orengo, H. A. and Garcia-Molsosa, A. (2019). A brave new world for archaeological survey: automated machine learning-based potsherd detection using high-resolution drone imagery. *Journal of Archaeological Science* **112**: 105013. <https://doi.org/10.1016/j.jas.2019.105013>.
- Palmer, B. and Wessler, S. F. (2018). The costs of the confederacy. *Smithsonian Magazine*, December. <https://www.smithsonianmag.com/history/costs-confederacy-special-report-180970731/>. Accessed 17 Nov 2021.
- Palmer, E. H. (2021). New East Cemetery archive documents Black lives. *Virginia Genealogical Society Newsletter* **47**(1): 4–6.
- Pruden, J. (2021). How the ground-penetrating technology used to locate unmarked graves is both amazing and complex. *Globe and Mail*. June 3. <https://www.theglobeandmail.com/canada/article-the-technology-used-to-search-for-lost-graves-is-amazing-and-murky/>. Accessed 17 Nov 2021.
- Rainville, L. (2014). *Hidden History: African American Cemeteries in Central Virginia*. University of Virginia Press, Charlottesville.
- Records of the City of Richmond. “Colored Interments in Oakwood Cemetery,” 1913–1943. Records of the City of Richmond, Library of Virginia. <https://ead.lib.virginia.edu/vivaxtf/view?docId=lva/vi02388.xml>. Accessed Nov 2021.
- S. 2827. (2020). African American Burial Grounds Study Act. <https://www.govinfo.gov/app/details/BILLS-116s2827es>. Accessed Nov 2021.
- Sărașan, A. et al. (2020). Mapping burial mounds based on UAV-derived data in the Suusamyry Plateau, Kyrgyzstan. *Journal of Archaeological Science* **123**: 105251. <https://doi.org/10.1016/j.jas.2020.105251>.

- Singh, K. K. and Frazier, A. E. (2018). A meta-analysis and review of unmanned aircraft system (UAS) imagery for terrestrial applications. *International Journal of Remote Sensing* **39**(15–16): 5078–5098. <https://doi.org/10.1080/01431161.2017.1420941>.
- Smith, R. K. (2020). *Death and Rebirth in a Southern City: Richmond's Historic Cemeteries*. Johns Hopkins University Press, Baltimore.
- Suarez, C. (2020). Human remains found at East End Cemetery this summer may have been used in medical experiments. *Richmond Times Dispatch*, October 27. https://richmond.com/news/local/human-remains-found-at-east-end-cemetery-this-summer-may-have-been-used-in-medical/article_89f27342-fbe4-516e-91f2-5cb3e4fc27f8.html. Accessed 17 Nov 2021.
- Suarez, C. (2021). Richmond withholding money for Enrichmond Foundation after concerns raised about management, oversight of historic Black cemeteries. *Richmond Times Dispatch*, May 16. https://richmond.com/news/local/govt-and-politics/richmond-withholding-money-for-enrichmond-foundation-after-concerns-raised-about-management-oversight-of-historic-black/article_bc8e54bc-7ffc-5282-a20c-04317313428a.html. Accessed Nov 2021.
- Trinkley, M., Hacker, D., and Fick, S. (1999). *The African American Cemeteries of Petersburg, Virginia: Continuity and Change*. Chicora Foundation, Columbia, SC.
- Van Tassel. (2021). Defining the true cost behind implementing Lidar systems into your business. CANDRONE. <https://candrone.com/blogs/news/the-real-cost-of-starting-a-lidar-drone-business>. Accessed 17 Nov 2021.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.